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Casting Self-Reflection: Three-Dimensional Mirrors within Kiln-Cast Glass Sculpture

Joanna Manousis

A thesis submitted in partial fulfilment of the requirements of the University of Sunderland for the degree of Doctor of Philosophy

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Joanna Manousis. The University of Sunderland 2026

Abstract

This practice-based research positions cast glass mirrors as expressive, conceptual forms that contribute uniquely to the fields of visual art and mirror-making, both technically and symbolically. The study offers new practical and material insights for artists to control the quality of investment cast glass surfaces, presenting a unique and diverse range of reflective and non-reflective mirror effects when silver nitrate is applied.

A desire to produce fully reflective, three-dimensional surfaces using investment core-cast glass fired at 790–825 °C (1454–1517 °F) initiated this project. Molten glass interacts and sticks to investment ingredients at high temperatures, producing satin, semi-opaque glass surface finishes. Rather than achieving a reflective mirror using chemical silvering, the cast surface is dull in tone, like brushed aluminium.

This led to a central research question: Can kiln-fired glass cast in an investment mould achieve a reflective mirror in which a viewer can identify themselves? With limited published guidance on controlling the surface clarity of cast glass or the application of silvering on cast surfaces, this research helps identify factors that inhibit and enhance the translucency and reflectivity of investment-moulded glass.

Over 200 samples were created across three phases of studio testing to examine how base models, investment materials, firing schedules, and acid polishing affect mirroring coatings applied to Cristalica, Bullseye, Gaffer, and Reichenbach glasses. Cast mirror effects were then selected to create artworks informed by the history and symbology of mirrored surfaces used in domesticity and contemporary art practice. These artworks act as case studies that extend the testing phase due to the insights gleaned from changing scale and form.

Historically, mirroring has been limited to blown and sheet glass applications. Although a reflective finish equal to commercial mirrors was not attained, a wide spectrum of effects was made that challenge the conventions of how mirrors can look and function. Original contributions are made in the advancement of cast glass mirror-making, technical insights giving practitioners greater control with cast-glass surface duplication, and a new body of artworks inspired by contextual analysis disseminated through international exhibitions, documentary photography, lectures, journals, and a written thesis.

Author Declaration

According to the regulations, I declare that during my registration, I was not registered for any other degree. I have not used material in this thesis for any other academic award.

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would not have been possible without access to these material-specific resources.

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1 Chapter 1: Introduction

This chapter details my artistic journey using blown and cast glass mirrors in visual art practice before undertaking practice-based PhD research. The practical possibilities and limitations that have shaped the direction of this study are explored, along with the themes that inspire the works I create. The research questions, aims, and methodological approaches underpinning this study are given, along with a summary of studio testing, idea development, and the artworks I produced. Finally, the introduction concludes with an overview of the thesis structure.

1.1 Reflecting on the Reflective

As an artist, my practice centres on casting processes that use moulds to translate texture and form into glass. For over a decade, my ambition has been to create fully reflective, three-dimensional mirrored surfaces within the negative hollows of core-cast glass sculpture. This technical pursuit allows the work's conceptual themes to unfold, activating an interior space as a site of encounter and contemplation.

The mirrored interior of core-cast glass destabilises perception, skewing and fragmenting the reflected image while extending the sculptural space beyond its physical boundaries. I explore how interior spaces can operate as both a container and a threshold, inviting optical and philosophical shifts in perspective.

I use mirrored surfaces to position the viewer within sculptural objects that often embody everyday forms. Through reflection, the observer is bound to the work, thus becoming integral to its dialogue. My work engages with themes such as transience and the cyclical nature of time. I use polished, transparent glass as a lens to distort, give clarity, and embody both fragility and strength. I am drawn to the paradoxical nature of glass, where these opposing qualities coexist.

The process of core-casting involves installing cores made of heat-resistant investment materials within a mould. Molten glass flows around the core but cannot penetrate it. A residual impression within the casting is left as a result, which is visible when the mould is divested (broken apart) from the glass after the firing process.

Through silvering, a process in which a series of chemicals, including tin and silver nitrate, are applied to the interior surface of the glass, I want to transform interior cast glass surfaces into dimensional, reflective mirrors that invite viewers to engage and perceive themselves. Such effects were successful in earlier sculptures using mould-blown glass, whereby the interior surface retains a pristine, transparent surface. This was most notable in a mirrored glass pomegranate featured in *Inverted Vanitas*, 2010 (Figure 1),

and a grouping of mylar balloons in *Reaching an Ulterior Realm*, 2010 (Figure 2).



Figure 1. Joanna Manousis, *Inverted Vanitas* (Detail), 2010, Glass, Mirror, Mixed Media. Dimensions Vary.

The fruit in *Inverted Vanitas* is a physical metaphor for vanity and desire, prompting self-reflection while playfully mimicking the colour and texture of real skin and seeds. This interplay of illusion and introspection draws from the founding principles of trompe-l'œil still-life painting, a genre that flourished in the 17th century, and one that strived to remind us of our fleeting mortality.



Figure 2. Joanna Manousis, *Reaching an Ulterior Realm*, 2010, Blown Glass / Cast Bronze. Dimensions Vary. Image Credit: Mike Flemming.

The blown glass Mylar balloons, which comprise *Reaching an Ulterior Realm* (Figure 2), look to perspire in anticipation of being shot by a flight of bronze arrows. They are playful, while serving as a metaphor for dispirited experiences and the fragility of life. The mirrored balloons reflect, allowing a viewer to perceive themselves clearly. However, this visual clarity was

obtained by polishing areas of the exterior glass surface with abrasive machinery. By doing so, light can pass through the translucent glass and reflect from the silver coating with ease, producing a crisper reflection that is uninhibited by the satin surface inherent to investment-moulded glass.

Unlike the balloons in *Reaching an Ulterior Realm*, the intimate detail and delicacy of the glass pomegranate made for *Inverted Vanitas* would not withstand abrasive polishing. Yet, reflective areas in the pomegranate flesh are evident where the blown glass did not touch the investment mould during fabrication, leaving a glossy surface.

Hollow glass forms made using investment core moulding methods pose further challenges for mirror-making and are rare in visual art practice. The semi-translucent surfaces cast as a hollow relief within the glass body cannot be polished with abrasives. Stubborn investment debris, left from the heat-resistant mould material used to cast the glass objects, can get lodged into crevices, leading to black/beige contamination marks or a brushed silver aesthetic that negates reflection.

The creation of *Distilled Portrait I* (2012, Figure 3) sparked a decade-long pursuit to produce reflective cast mirrors, a line of inquiry that ultimately led to this PhD research. I intended to capture the audience's reflection within the mirrored surface of a magpie suspended inside a cast crystal jar. For me, the

magpie embodies the collector. Known for gathering reflective fragments within its nest, I wanted the bird's presence distilled as a mirror within a jar, a vessel used for accumulation and preservation.



Figure 3. Joanna Manousis, *Distilled Portrait I*, 2012, Core-Cast Crystal / Mirror / Stainless Steel / Taxidermy, 16" x 6" x 6" / 40.5 cm x 15 cm x 15 cm

Naively, I thought that mirroring the internal surface of a core casting would create a reflective mirror. Yet, the bird was transformed into what looked to be a solid, brushed-silver statuette that denied reflection completely. The technical struggles I faced in attempting to achieve reflectivity within this piece and other core-cast works revealed why mirrors have historically been reserved for blown and sheet glass, where smooth, transparent surfaces provide a more suitable base. Moreover, the technical challenges of producing core-cast glass integrating translucent, uncontaminated surfaces for mirroring explain why this union of processes would not be an obvious choice for most practitioners. Finding a solution to achieve the transparency needed to create a reflective mirror on cast glass was, therefore, required. In doing so, I would be able to bring the artworks in my mind's eye to reality.

Along with an overarching goal to create reflective cast mirrors, a plethora of mirroring effects was anticipated during the testing phases of this research project. Surveying combined behaviours of glass bodies, investment materials, firings, durations and post-firing treatments was likely to cause differentials, a hypothesis supported by years of previous trial and error. Diverse qualities have been incorporated into finished artworks within this thesis, allowing both pristine and contaminated mirrors to stand side by side.

Although artists may not have commonly considered cast glass mirrors within visual art practice, many practitioners strive to achieve optimal surface detail, transparency, and shine when casting glass, thus reducing the need for labour-intensive hand-polishing processes (Platt and Morales, 1989; Thwaites, Angela, 2002). This research gives insights in controlling the surface quality of investment-cast glass. It also fills a gap in understanding how cast glass mirrors can be integrated for their visual and thematic impact within contemporary glass sculpture.

1.1.1 Cast Mirror Artworks Made Before PhD Research

Several attempts had been made to create artworks incorporating reflective, cast-glass mirrors before this study, which ultimately provided a foundation of knowledge and experience to support this line of enquiry. These works were of considerable scale (up to 165cm / 65” in height and width), taking up to 9 months to create. Progress was slow as a result. A limited variety of glass bodies and investment materials were used, with little to no time/finances for experimentation with other products, processes and firing cycles to achieve superior results. Figures 4-7 illustrate a succession of works within the *Oculus* and *Indra* series made between 2013 and 2017.

Dominant Sophia is a jewel-like manifestation of a rose window commonly found in Gothic churches and cathedrals. Rather than infiltrating ‘God’s’ light into a sacred space, I wanted light to be reflected towards the viewer, who

would in turn see themselves reflected in wheat husks, seed pods, urns and figs, motifs symbolic of life, death, fertility and sustenance.



Figure 4. Joanna Manousis, *Dominant Sophia*, 2014. Core-Cast Crystal / 24-Carat Gold Mirror / Steel / Aluminium. 40” H x 40” W x 3.5” D / 101.5 cm x 101.5 cm / 9 cm

Dominant Sophia (2014, Figure 4) was the first wall-mounted installation within this series. Each segment contains the residual impressions of wheat husks, emblems of labour and sustenance, gilded with 24-carat gold mirror, a material/colour linked to wealth and divinity. The work was intended to capture the viewer’s reflection. Through this encounter, the individual is

situated within a collective system, suggesting that, like grains within a harvest, we exist as part of a larger, interconnected whole.

Dominant Sophia was cast in lead crystal to achieve surface clarity through acid polishing. This finishing process, commonly used in the glass-cutting trade, transforms the dull, opaque appearance of cut and engraved marks to a brilliant translucency. In this method, lead-bearing glass is immersed in a heated bath of hydrofluoric and sulfuric acids. The acids react with the lead within the glass, gently dissolving and smoothing surface irregularities, producing a clear, sparkling sheen.

However, the silver nitrate and gold coatings applied to the glass after chemical polishing failed to produce a true mirror-like quality (Figure 5). This limitation resulted from the stippled texture and intimate scale of the wheat impressions: the roughened convex surfaces fragmented and refracted light rather than reflecting it coherently. Even with perfectly smooth forms, the compact scale of the wheat would have inhibited clear self-reflection.



Figure 5. Joanna Manousis, *Dominant Sophia* (Detail), 2014. Core-Cast Crystal / 24-Carat Gold Mirror / Steel / Aluminium. 40” H x 40” W x 3.5” D / 101.5 cm x 101.5 cm / 9 cm

Demeter’s Rose (2015) (Figure 6) constitutes the most complex composition within the *Oculus* series. The wheat elements, scaled to approximately the size of quail eggs, are arranged across a structure measuring nearly six feet in diameter. I was residing in the United States during the fabrication of this piece, and I was unable to transport a piece of this scale for acid polishing in Brierley Hill, UK. Consequently, the glass segments were not acid-polished and remain unmirrored. Rather than reflecting light, *Demeter’s Rose* foregrounds the frosted, satin-like surface produced through the interaction between molten glass and the investment mould during firing.

These surfaces offer a more subdued, diffuse luminosity that contrast the assertive visual presence of mirrored glass.



Figure 6. Joanna Manousis, *Demeter's Rose*, 2015, Cast Crystal, Steel, Aluminium, 65" H x 65" W x 4" D / 165cm x 165cm x 10cm

After completing *Demeter's Rose* in 2015, I fabricated a wall-based installation that replaced curved forms with faceted interior details. This shift was intended to test whether flat surfaces taken from hand-polished base

models would produce better reflective qualities when cast in chemically brightened, lead-bearing glass.

Indra's Web, 2015 (Figure 7) consists of a cluster of investment-cast glass prisms with mirrored, prismatic interiors that collectively form the appearance of a globular starburst. The work draws inspiration from the Hindu proverb of *Indra's Net*, which describes a vast and systematic configuration of reflective jewels used as a metaphor for individuals within the complex structure of society. In the proverb, each jewel reflects all the others, suggesting a network of mutual visibility and interdependence.

Interconnectedness underpins the conceptual framework of *Indra's Web*. The proverb proposes that regardless of our individual roles in life, each person contributes to the functioning of society. For this reason, it was important that viewers could see themselves reflected within the glass prisms. In doing so, the reflective surfaces simultaneously reference both the jewels of *Indra's Net* and the stars of the cosmos, positioning the viewer within a larger network of relationships and reflections.



Figure 7. Joanna Manousis, *Indra's Web*, 2015. Core-Cast Crystal, Mirror, Stainless Steel, Aluminium. 65" H × 51" W × 4" D / 165.1 cm × 129.5 cm × 10.2 cm

Faceted glass prisms were used as base models for mould making to give superior, pristine surfaces within the glass casting for mirroring. Yet, although the prisms were cast in crystal, mechanically and chemically polished before mirroring, a full reflective quality was not achieved. The large prism seen in

the lower left corner of Figure 8 presents cracked surface details on the faceted mirror. This was likely a result of surface degradation on the investment core resulting from its angular shape and exposure to high temperatures and firing durations in the kiln, which may have left impressions on the glass.



Figure 8. Joanna Manousis, *Indra's Web (Detail),* 2015. Core-Cast Crystal, Mirror, Stainless Steel, Aluminium. 65" H × 51" W × 4" D / 165.1 cm × 129.5 cm × 10.2 cm

Figs and Urns, 2016 (Figure 9) demonstrates the most successful cast glass sculpture made before commencing doctoral research. Several forms within the piece contain a mirror finish in which a viewer can distinguish themselves. Comprising forty-eight cast-crystal elements arranged in concentric rings, the wall sculpture features spear and teardrop-shaped forms that evoke rays of sunlight. Residual impressions of figs and urns were replicated using hand-polished glass models that served as prototypes for the cast components.

The final crystal pieces were acid-polished internally, hand-polished externally, and subsequently mirrored. Reflections are discernible within several interior cavities, offering a rare instance of successful optical clarity and depth within the series.



Figure 9. Joanna Manousis. *Figs and Urns,* 2016. Core-Cast Crystal, Mirror, Stainless Steel, Aluminium. 54” H × 54” W × 3” D / 137 cm × 137 cm × 7.5 cm

Acid polishing is difficult to access in many countries, while being hazardous and toxic to the environment. It was therefore important to ascertain if reflective mirror coatings could be achieved on un-chemically treated glasses cast using materials that are largely accessible to the greater glass-art community. Although progress was made in understanding some of the

variables that affect the translucency and reflectivity of investment-cast glass when a mirror coating is applied, a full investigation was needed to determine cause-and-effect relationships using a range of glass bodies, investment materials, firing temperatures and post-firing treatments to obtain reflective and non-reflective cast mirrors for visual art and jewellery practices.

1.2 Research Questions

From the outset, there was uncertainty about the possibility of creating a reflective mirror that accurately reflects its environment within a cast glass object. I understood that the glass surfaces needed to be clear, smooth, and pristine to enable reflection. However, a review of current cast glass practices revealed that the relationship between moulds, commercial glasses, investment mixes, firing schedules, and their effect on the level of reflectivity when a mirror coating is applied had not been systematically examined. With these factors in mind, this research was launched with the following questions in mind.

1. What factors inhibit and enhance the reflective qualities of a mirror coating on a cast glass surface?
2. Can cast glass surfaces made with an investment mould fired in a kiln be reflective once mirrored?
3. What are the potential practical and creative parameters of using three-dimensional mirrored cast glass at varying scales and

complexities?

4. How might the use of mirrors throughout history and within contemporary art practice inform this research?

1.3 Research Aims

This research investigates the factors influencing a studio practice centred on cast glass mirror-making, while developing artwork themes informed by the use and ideology of reflective mirrors in past histories. In doing so, the research seeks to provide new, practical and material insights that other artists can apply to enhance the quality of their cast glass surfaces or to incorporate cast mirrors into their artistic practices, whether in the sculptural, architectural, jewellery or design fields. The research also enriches and extends my studio practice. The artworks produced in this study aim to push the boundaries of how cast glass mirrors can be manipulated in terms of form, function and thematic expression within contemporary art.

The aims of this research are:

1. To establish a range of visual effects in creative cast glass mirror-making.
2. To provide practical guidance for creative practitioners seeking to enhance the surface quality of their cast glass objects and/or those aiming to incorporate cast glass mirrors into their work.

3. To create cast glass mirror artworks that identify and develop themes and interpretations, drawing on the historical associations of reflective glass.
4. To establish how the methods used in this research are translated by others through teaching placements and workshops.

The objectives of this research are:

1. To carry out a contextual review investigating how mirrors were made, used and symbolised throughout history, and within contemporary art practice.
2. To investigate through studio testing how base models, glass bodies, investment materials, firing temperatures, firing durations, and chemical polishing affect the surface quality and reflectivity of cast glass.
3. To produce artworks and jewellery using a range of base models that extend the material testing phases to demonstrate the varied potential of cast mirrors within contemporary art.
4. To explore how cast mirror practices can be integrated into jewellery designs.
5. To disseminate the results of studio testing and finished artworks to establish research.

1.4 Methodological Approaches to This Research

This section examines the methodological approaches used within this creative practice-based research, which are rooted in the hands-on experience of making, along with careful contemplation (reflection) before, during and after each artistic pursuit. The methods of creative practice-based research are outlined, along with their historical ties, highlighting key texts that define their applications and use. Specific approaches to this research, and how they are similar or different to other researchers, are discussed, along with the inherent strengths and weaknesses of practice-based research in the arts and how these limitations have been mitigated.

For the aid of reference, the methodologies used within this PhD research are outlined in the following bullet points:

- Creative practice-based research exploring research questions through hands-on experience, experimentation, observation, teaching and reflection that culminate in creative artefacts that support a written thesis.
- Embraces Haseman's 'Performative' research paradigm, whereby findings are expressed in creative outputs (material tests and artworks).
- Employs a multi – method approach, in which glass artefacts and the subsidiary materials and equipment used to form them are carefully

considered, catalogued (through photographs and note-taking), manipulated and reflected on to inform further creative works.

- Integrates Frayling's research 'into', 'through, and 'for' art through investigating the history of mirror-making and mirrors in visual art practice within a contextual review, through studio experimentation and the creation of finished artworks.
- Uses 'reflective practice' and 'reflection in action' in which the practitioner sets and solves problems cognitively by reflecting on them before, during, and after a particular action takes place. These acts are influenced heavily by the researcher's previous experience as a glass artist and educator.

1.4.1 Creative Practice-Based Research

This art project could not have come to fruition without creating physical objects. Creative practice-based research is, therefore, central to its approach. This mode of research explores research questions tackled through hands-on experience, experimentation, observation, teaching and reflection that culminate in creative artefacts. It is an 'original investigation undertaken to gain new knowledge partly using practice and the outcomes of that practice' (Candy, 2006; Candy and Edmonds, 2018), and this knowledge can only be fully understood when referencing practical outcomes (Candy, 2006), for example, the nuances of glass colour attributed to raw ingredients

(Brachlow, 2012), or thin-shell and higher aspect ratio forms within studio glass kiln casting (Pollock, 2012).

The nature of this kind of practice-based research, in which tactile experiences with materials and processes seek new working methods that are not derived from pre-determined routes, often leads to unpredictable outcomes. For example, before embarking on this research, Bullseye glass often stuck to investment moulds, producing white, contaminated mirrors. This study revealed that molochite is a superior mould ingredient in preventing surface fusion, while certain Boron Nitride (Hbn) pastes can create raised, painterly effects in cast glass mirrors.

Creative practice-based research has historical roots in the Polytechnic establishments set up by the British Government in the late 1960s and beyond (Candy, 2006). Practice was encouraged to develop new ways of ‘doing’ to improve one’s ability to ‘act in the world.’ This led to a critical clause by the Council for National Academic Awards (CNAA) that a thesis could integrate written text and physical artefact(s) / record of an artefact(s) when such institutions were granted the ability to award higher degrees (Candy, 2006). Therefore, the methodological approaches adopted within practice-based research are less established than those of other Doctorates in Philosophy, which date back to the early 19th Century (Bogle, 2018). This can make them more difficult to quantify in some instances.

Art-making's subjective, intuitive and ambiguous nature (Gray and Malins, 2004; Marley and Combrink, 2012) leads to re-definitions of appropriate methodology that go beyond qualitative and quantitative research paradigms, such as ‘Performative’, whereby ‘findings are expressed not in numeric data or words, but in symbolic form (such as visual or other creative outputs) (Haseman, 2006). This PhD encompasses Haseman’s ‘performative’ paradigm through hands-on making, along with the three models of art and design research expressed by British educationist and writer, Sir Christopher Frayling.

1. Research into art and design
2. Research through art and design
3. Research for art and design

This research project integrates research into art within Chapter 2: Contextual Review by investigating historical fabrication methods, cultural associations and the use of reflective mirrors within a domestic sphere and art practice. A broad number of contemporary artworks integrating reflective materials highlights how mirrors are used to heighten the visual and metaphorical dialogue of the artwork, while also emphasising a gap in the integration of cast glass mirrors as a method of artistic expression.

Research ‘through’ art practice is underscored as ‘material research’. This can be seen in Chapter 3 when accessing the factors that inhibit and enhance reflectivity on cast glass surfaces; ‘development work’ by customising methods to create a range of samples and finished artworks using cast mirrors that have not been considered before; and ‘action research’ whereby a research diary catalogued the step-by-step approaches and outcomes of practical experiments using investment cast glass mirrors (Figure 4). These notes were then further contextualised and expanded within Chapter 3.

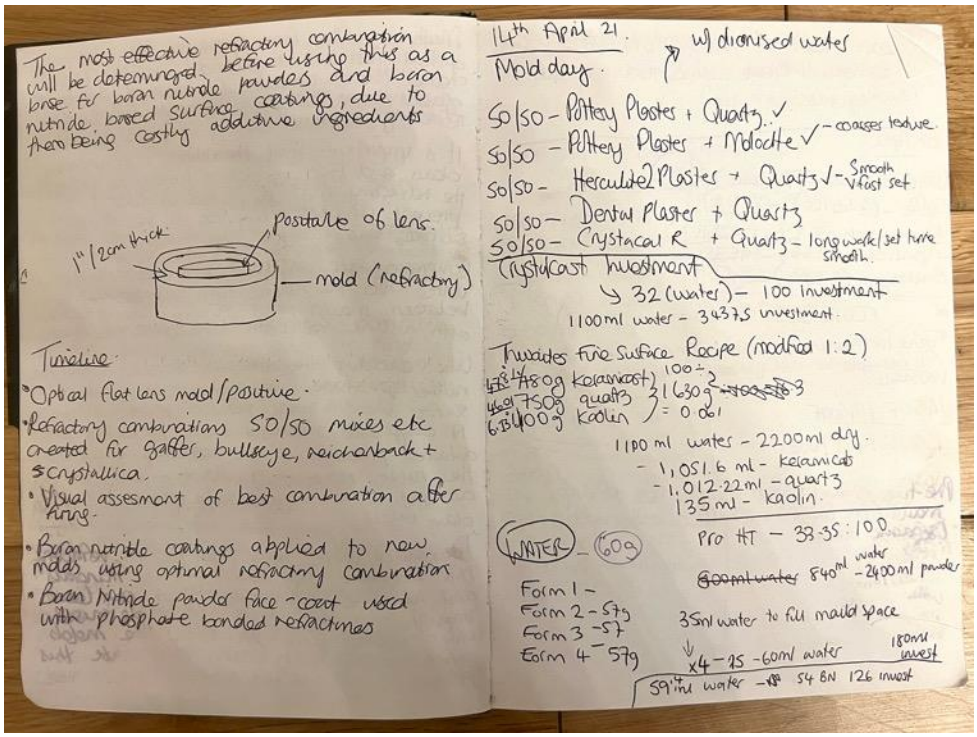


Figure 10. Joanna Manousis. Research diary highlighting firing schedules, investment recipes and outcome notes as a tool to review and refer to at a later

Finally, research ‘for’ art and design is evidenced through the act of making new artworks informed through practical material testing and historical links found within the contextual review. Picasso likens this to the gathering of

reference material embodied in an artefact that communicates visually rather than verbally (Frayling, 1993).

Varied approaches are often used in practice-based research. These might include, but are not limited to, evaluating case studies and literature to inform research questions, using analogue and digital processes for experimentation to produce artefacts, performance and sound, keeping logs and records, and image capture through photography. Most practice-based research is conducted qualitatively, where non-numerical data is analysed to ‘draw attention to processes, meaning patterns and structural features’ (Flick, 2010) that contribute knowledge to the field. This research project employed multiple approaches to practice-based research, whereby glass artefacts and the subsidiary materials and equipment used to form them were carefully considered, manipulated and reflected on to inform further creative works.

Key texts that speak towards the capricious and often enigmatic nature of artistic practice, how creatives think and bring solidity to their ideas within creative, practice-based research include Gray and Malins (2004); Bolt (2010); Bell (2019), Candy (2006) and Frayling (1993). Some of these writers consider researchers from a broad range of disciplines and how they synthesise ideas to create works that offer impact beyond the individual practitioner.

Candy (2006) and Gray and Malins (2004) reference the work of Donald Schön, a pioneer in recognising the role of reflection within learning to create new understandings of experience and change (Candy, 2006; Gray and Malins, 2004; Schon, 1984). Practice-based researchers in glass art, Thwaites, 2018 and McManus, 2024, discuss the use of ‘reflective practice’ and ‘reflection in action’ as a methodology for creative research, whereby the practitioner sets and solves problems cognitively by reflecting on them before, during, and after a particular action takes place.

Reflection becomes a feedback mechanism; Through the act of making and reflecting upon making, the project synthesises and evolves, leading to new thoughts, ideas and knowledge (Gray and Malins, 2004; Schon, 1984). Schön remarks that reflective practice is ‘intuitive’ and that this ‘knowing-in-action’ is informed by previous experience.

Twenty years of practice as a glass artist/maker have influenced the directions taken within this research project. The careful planning, decision making and practical actions made within the studio have been continually reflected upon before making further choices and actions. Reflective practice has, therefore, played an instrumental methodological role in this research project.

Many practice-based researchers working in glass, such as Heike Brachlow (2012), Anthony Pollock (2012) and Angela Thwaites (2018), dedicate much of their projects to experimentation, honing methods of studio practice for their work that others can adapt and expand. Sometimes, the ‘test’ is re-appropriated and treated as finished artwork rather than a stepping stone to a final piece(s).

For example, when investigating the colour density of kiln-cast glass, Brachlow used a cubic form with an internal recess as a base model for testing. These modules are then stacked in multiples to create the ‘Theme and Variations’ series, completing the ‘transformation from test to work’ (Brachlow, 2012). This approach is comparable to the test pieces exhibited as artworks within this thesis. Rather than discarding tests that did not conform to a certain set of expectations, in this case, a perfect reflection on a cast glass surface, tests displaying varied nuances that do not have reflective properties have been embraced.

McManus (2024) likens her methodological approach to ‘bricoleur’. The term was coined by Levi Strauss (1966) to differentiate the bricoleur ‘tinkerer’ who makes do with the materials and tools around them to make something new. This is in opposition to the ‘engineer’, who creates new systems from scratch (Gray and Malins, 2004; Honeychurch, 2023; McManus, 2024).

The multi-method approach used within this research does integrate a set of interpretive practices (Gray and Malins, 2004); yet, a diverse range of materials were not integrated into the practice due to being readily available (Honeychurch, 2023). Rather, experimentation was carried out in a similar way to an engineer in a lab-like condition. Materials, methods and variables were carefully selected, monitored and quantified to minimise room for error. This reduced inconsistencies to provide processing routes that others can emulate.

While creative practice-based research establishes new knowledge through physical acts of doing, it can often be seen as a catalyst for change, with wide-ranging impacts, such as new practical approaches in art-making or outputs that can influence and expand perspectives (Coombs, 2023). However, some artists' practices can be enigmatic, and the broad methods used in their development can sometimes be seen as weak compared to other sectors of scholarly research, as noted previously when discussing the routes of practice-based research (p.28).

A recurring critique is that the knowledge generated through such approaches is neither systematic nor repeatable, and that a lack of rigour makes it difficult to distinguish between experience and verifiable truth (Schrag, 2023). For instance, the benefits of medical research, such as advances in stem cell studies, can be clearly measured and replicated. By contrast, assessing the

public impact of gestural oil painting, or striving to reproduce creative acts more generally, can be difficult.

The challenges that other artists might encounter in attempting to replicate this research were addressed by documenting a clear, step-by-step studio process. This included details of how original models for mould fabrication were produced, the materials and firing cycles selected to achieve specific results, and the precise methods of construction.

Potential variables were systematically controlled throughout the project's development. For instance, a readily available optical flat lens was used as a base model for testing open-face moulds, and only materials widely accessible within the field were employed. All castings were carried out using the same kiln and firing schedule, while deionised water, rather than tap water, was used to create investment moulds, reducing inconsistencies caused by geographically varying mineral content. These processes and outcomes are carefully catalogued and visually organised within the thesis, enabling readers to follow the methods, achieve comparable results, and build upon them in future work.

1.5 Specific Research Stages and Summary of Thesis Structure

The methodological approaches outlined in the previous section, particularly the use of reflective practice informed by earlier and ongoing experience, have shaped the literary, documentary and 'performative' physical act of making within this study. These approaches, in turn, have guided the specific stages of inquiry undertaken, which address the research questions, aims and objectives that Frayling describes as being 'in', 'through', and 'for' art and design.

The history of mirror-making is vast and diverse. While it is easy to become immersed in the many fascinating avenues of this field, Chapter 2 gives a succinct overview of its fabrication and use in domestic and artistic spheres. This includes an examination of mirrors made from metal and glass, including various glass-making techniques and the silvering methods used to transform glass into reflective devices.

Chapter 2 also addresses some of the dual connotations that exist in the symbolism and meaning of mirrors across various cultures and traditions. Mirrors were, and still are, artefacts that hold dual values. They hold good and evil attributes, some of which serve as thematic bases for the artworks made in this thesis, such as *Iris Obscura, Celeste*, and *Distilled Portrait I: Series II.*

The discussion of mirrors in contemporary art (Section 2.4) is organised into two categories: glass and non-glass mirrors. These groupings reveal how artists negotiate issues of scale, complexity, durability, accessibility, and cost when working with reflective materials. They also draw attention to the conceptual implications of reflectivity, particularly its role in shaping viewer participation and interaction. Moreover, the categories illustrate the growing prominence of mirrored surfaces in contemporary practice, valued both for their visual impact and their metaphorical resonance. This focused consideration of related artworks underscores the significance and timeliness of this research, while offering points of inspiration through parallel and contrasting approaches.

The research objective to carry out a contextual review investigating how mirrors were made, used and symbolised throughout history, and within contemporary art practice directly addresses the question: How might the use of mirrors throughout history and within contemporary art practice inform this research? As mentioned, Chapter 2 serves as both a technical and thematic base from which artworks are envisioned and conceived.

A discussion on the factors influencing the transparency and smoothness of cast glass surfaces, with an emphasis on refractory (investment) formulas, firing temperatures, and the variables inherent in process and working

environments, concludes Chapter 2. This sets the stage for Chapters 3 and 4, which provide a more in-depth exploration of the making processes at large.

Rigorous practice-based studio testing, outlined in Chapter 3, was conducted to understand how base models, glass bodies, investment materials, firing temperatures, firing durations, and chemical polishing affect the surface quality and reflectivity of cast glass. Meeting this objective enabled the question, ‘what factors inhibit and enhance the reflective qualities of a mirror coating on a cast glass surface’, and ‘can cast glass surfaces made with an investment mould fired in a kiln be reflective once mirrored?’ The aim to create a range of visual effects in creative cast glass mirror-making was established, and practical guidance is provided for creative practitioners seeking to enhance the surface quality of their cast glass objects and/or those aiming to incorporate cast glass mirrors into their work.

Chapter 2 is segmented into phases 1, 2 and 3 of testing, along with a ‘roughness comparator’ test, in which a piece of metal with varying textures that is used to categorise surface abrasions in industry is transformed into a core-cast glass mirror. Preliminary experiments were made using multiple refractory compositions for the mould-making process and readily available glasses (Gaffer, Reichenbach, Bullseye and Crystalica). This resulted in a standardised series of over one hundred tests as bas-relief surfaces for

mirroring made from silicone ‘positives’ taken from an optical flat lens for a flawless, flat finish in ‘open face’ investment moulds.

Samples made in ‘Phase 1’ of testing show how the reflectivity of cast glass could be inhibited or enhanced by surface irregularities and opacity caused by the model, glass, refractory, firing and methods used. This was determined visually by eye. Each stage of making was catalogued through photographs and note-taking. Finished results before and after mirroring were also photographed, allowing for direct observation and comparison throughout the research journey that practitioners can follow.

A reduced number of the most diverse visual effects seen in Phase 1 of testing were applied to three-dimensional ‘enclosed’ dome forms containing the recess of a bullet-shaped piece of polished glass (Phase 2 testing). Casting glass into enclosed moulds necessitated a more complex mould-making strategy and, in many cases, a higher firing temperature that allows the glass to flow greater distances from a reservoir to the mould cavities.

Differing mirroring effects were anticipated between phases 1 and 2 of testing when using an altered mould set-up and firing. However, the visual effects remained relatively constant overall, with a slightly higher degree of reflectivity on the curved recesses of the enclosed core-formed tests. This was evident when using applications of hBN BN-Lubricate (ZYP Coating Inc) and

hydrofluoric/sulphuric acid polishing treatments to reduce surface opacity on lead crystal castings, such as Gaffer G20 and Reichenbach 1500.

Tests were scaled up further within phase 3 of testing to verify the consistency of six silvered surface finishes using tension-set moulds. A more complex recess of a hand-sculpted magpie housed within a glass dome was used for these tests. Several deviations were found, including more noticeable striations across the mirrored surfaces caused by glass flow and devitrification, along with severe sticking when using Boron Nitride 'Lubricoat'. Further open-face tests using fresh hBN coatings were reproduced for these reasons to evaluate if contrasting results would continue when using different batches of the product. The results from phases 2 and 3 informed the development of a final palette of mirrored surfaces for creative use, while also identifying further factors that affect the reflectivity of cast glass mirrors.

The new artworks presented in Chapter 4: Case Studies were shaped by prior testing as well as historical and contemporary insights gleaned from the contextual review. Four case studies serve as improved continuations of previous works made prior to this research project to improve cast mirror qualities and meet artistic intentions. These revelations, in tandem with the use of mixed effects in singular artworks, directly engage with all four research questions posed on page 24.

Chapter 4 also examines how the methods developed in this research were transferred and appropriated by ten jewellery students at the Birmingham School of Jewellery. The teaching placement revealed both consistencies and variations in cast-mirror surface finishes produced by practitioners with no prior glassmaking experience. It further demonstrated the adaptability of core-cast mirroring processes to objects of an intimate scale.

This opportunity directly addressed question 3, ‘what are the potential practical and creative parameters of using three-dimensional mirrored cast glass at varying scales and complexities ‘, along with the aims, ‘to provide practical guidance for creative practitioners seeking to enhance the surface quality of their cast glass objects and/or those aiming to incorporate cast glass mirrors into their work’, and, ‘to establish how the methods used in this research are translated by others through teaching placements and workshops. Finally, the objective ‘to explore how cast mirror practices can be integrated into jewellery design’ was achieved.

Each case study begins with a visual analysis of the work, describing its physical characteristics and the conceptual narratives it suggests. This is followed by an examination of the technical processes used in its production, concluding with a summary of key findings. Together, these sections provide a clearer understanding of both the motivations behind the work and the methods used to realise it, while addressing the research objectives.

The case studies serve as further tests, as varying scales, complexities, and methods reveal new characteristics in cast mirrors that were not observed in previous, smaller-scale tests. This directly addresses objective 3, ‘to produce artworks using a range of base models that extend the material testing phases, while contributing bodies of work that have never been seen before, demonstrating the varied potential of cast mirrors within contemporary art to the wider public’.

Practical tests and artworks were disseminated to the public through various channels, including social media platforms such as Instagram and Facebook, updates on www.joannamanousis.com, and through teaching workshops. Several invitations to present ‘lec-mo’ (lecture/demonstrations) and seminars at leading venues such as Bullseye Glass Company, Pilchuck Glass School, and The Glass Arts Society underscored the timeliness and heightened community interest in this research. Additionally, artworks have been showcased through national and international exhibitions. Such ventures have broadened the study's reach as a model for others to follow.

Original tests and artworks serve as the foundation of this research, illustrating how mirrored cast glass can emulate other materials, enhance reflectivity and optical properties, and convey creative themes. This work extends and enriches the field of glass art by contributing new knowledge on how to control the surfaces of cast glass, as well as on the creative use of

varied mirroring effects on cast glass. It also contributes new methods of production within the history of mirror-making at large.

Chapter 5 concludes the thesis, detailing the research's original contributions to knowledge. The chapter draws together findings that answer the initial research questions and presents how the aims and objectives were met. A review of the PhD learning outcome is shared, along with further avenues to expand this research topic.

Following these chapters are the References and Appendices. The Appendices are divided into four sections. Appendix A presents detailed images of tests made in Chapter 2. Samples are captured before and after mirroring to provide a better sense of surface textures, hues and reflective qualities. Appendix B provides firing and annealing schedules for the works made within the thesis, materials and tool resources. Appendix C provides a health and safety disclaimer for individuals considering using the methods in this research, while Appendix D outlines the dissemination of the research through exhibitions, journal articles, and magazines. Exhibition photographs show details of works, their scale, relation to other artworks and viewer participation during opening receptions. The featured publications are written by the researcher and by other researchers who describe the research.

2 Contextual Review

This chapter introduces the mirror as a pivotal tool for self-awareness, tracing its evolution from an artefact once associated with power, wealth, and superstition to a passive screen encountered in contemporary society. It examined both the historical struggle and the practical innovations involved in producing reflective surfaces, as well as the mirror's symbolism and dualistic resonance across cultures. This chapter also reviews the use of mirrors in contemporary art, highlighting how artists employ reflective surfaces, including non-glass, glass, and gold-leaf mirrors, to attract viewers, embellish details, and/or generate meaning. Finally, it addresses the goal of achieving translucency and shine with investment-moulded glass among artists. Attention is paid to existing products and resources designed to reduce surface adhesion and enhance brightness, qualities essential for creating reflective cast-glass mirrors.

2.1 Introduction

A direct correlation exists between industrial developments in glass manufacturing and the widespread availability of reflective mirrors. This chapter traces the transformation of the mirror from a rare and luxurious object, once emblematic of wealth, power, and superstition, into a ubiquitous domestic tool. This has led to shifts in perceptions and cultural attitudes toward self-awareness. It has been argued that the rise of mirrors in private homes during the 19th century coincided with individualism and introspection in Western societies, where personal identity and appearance became closely linked to moral character and social status (Gregory, 1998; Maxwell, 2020; Melchoir-Bonnet, 2001).

The mirror has a rich and multifaceted history that has been extensively examined by scholars across a range of disciplines. This chapter does not aim to catalogue historical accounts in full. Instead, it seeks to unravel selected aspects of mirror fabrication and symbology from the 3rd century CE to the present that are particularly relevant to the technical, visual, and thematic elements of this research project and related artworks using sculptural cast glass.

Although, mirrors serve a wide range of optical and scientific functions, enabling technologies such as cameras, telescopes, lasers, and other industrial instruments, the scope of this chapter is limited to their most immediate and culturally resonant applications: the visual presentation of the self and surrounding environment in both domestic and public contexts, as well as their conceptual use within visual art.

This chapter explores how mirrors, once imbued with symbolic power due to their rarity and visual allure, have become increasingly integrated into contemporary art practice. This shift coincides with technical advancements in sheet-glass manufacture and the growing availability of chemical silvering products. Access to materials and techniques has empowered artists to challenge and expand the aesthetic and conceptual potential of mirrors, positioning them as mediums that embody both function and metaphor. A survey of reflective mirrors used within contemporary art, including but not

limited to glass, is detailed. This gives an understanding of how artists have overcome scale, durability, detail, cost and toxicity in their practices.

In evaluating relevant literature and practice on investment casting for glass, the chapter establishes a methodological foundation for material experimentation using core-casting methods to create residual spaces for silvering. Publications on surface duplication and shine in investment cast glass are highlighted, as these are the two critical factors in creating reflective mirrors. An overview of refractory casting processes, including key investment ingredients, processing variables, and post-firing treatments used to optimise surfaces for mirroring, is examined. Finally, the chapter situates this research project within broader practice-based research models in the glass-art field.

2.2 A Brief History of the Mirror

Arguably, humans have been compelled to observe their reflection since the evolution of the species. Before the implementation of tools, water was nature's first mirror. As depicted in Caravaggio's painting *Narcissus* (Figure 11), the Greek myth is emblematic of humanity's desire to behold the self, while cautioning self-obsession. Cursed by Nemesis, the goddess of divine retribution, Narcissus falls in love with his reflection in a still pool of water. Unable to look away, he ultimately perishes in the prolonged act of consuming his own image.



Figure 11. *Narcissus* (1591) Michelangelo Merisi de Caravaggio, Oil on Canvas, 92 x 110 cm. Collection of Galleria Nazionale d'Arte Antica, Rome, Italy.

With advances in material manipulation and industry, reflective surfaces evolved: hand-polished stone, obsidian, and later polished metals were used as mirrors for the elite. The production of mirrors, especially glass ones, remained costly and labour-intensive due to the high level of craftsmanship required and the frequent failure rate during manufacture. As a result, mirrors remained items of luxury and status well into the mid-twentieth century (Gregory, 1998; Melchoir-Bonnet, 2001; Schechner, 2005).

The use of glass as a reflective surface dates back no earlier than the 3rd century CE (Melchior-Bonnet, 2001). Before the invention of glassblowing in

Syria in the 1st century CE, glass mirrors were produced by casting and grinding the material (Figure 12). These early mirrors were typically small, hand-polished objects used more as amulets or decorative items than as tools for self-contemplation. Due to the uneven thickness of the glass and its intimate scale, the reflections they produced were often distorted and imprecise (Melchoir-Bonnet, 2001; Schechner, 2005).



Figure 12. *Circular Mirror*, 200-699 (possibly), Roman Empire or Eastern Mediterranean, Overall Dimension: 9.3cm. Thickness: 1 cm. CMoG 70.1.55 D, gift of Toufic Arakji. Image licensed by the Corning Museum of Glass, Corning, NY (www.cmog.org)

For these reasons, highly polished cast alloys of tin, lead, and copper were the preferred materials for creating reflective surfaces for centuries. The durability of these metals has allowed many early mirrors to survive into the present day. A notable example is the ancient Greek mirror seen in Figure 7.

Its elaborate design includes a handle representing Aphrodite, the goddess of love, vanity, and desire (Werness, 1999). Above her, Eros is depicted in flight, accompanied by animals that symbolically evoke the cycle of life. These metal mirrors were typically ground and polished to a high sheen using abrasives such as sand, a laborious process that contributed both to their value and to the clarity of reflection (Evans, 1977; Melchoir-Bonnet, 2001).



Figure 13. *Bronze Mirror with a Support in the Form of a Draped Woman*, (mid-5th Century BCE). Greek (Argos), Bronze, 40.41cm H. The Metropolitan Museum of Art, NY, USA.

As seen in Figures 13 and 14, the ornate embellishments encircling the two Greek and Roman hand mirrors were cast in metal. These served not only to reinforce and protect the fragile, highly polished reflective surfaces but also to

elevate the mirrors with grandeur and/or symbolic meaning. Functioning as both sculptural art objects and practical tools, these mirrors embodied utility and aesthetic significance.



Figure 14. *Mirror in Lead Frame*, 400-699, Roman Empire, Syro-Palestinian Coast, Overall Dimensions: W: 5.7 cm, L: 8.6 cm. CMoG 82.1.2, gift of Viktor Barakat.Image licensed by the Corning Museum of Glass, Corning, NY (www.cmog.org)

The Romans perfected and expanded glassblowing techniques, producing utilitarian objects for trade, such as containers for goods. Alongside these glass vessels, they also developed methods for creating mirrors. Glass orbs

were blown and coated internally with hot metal, such as lead, to create a reflective surface. However, due to the risks of thermal shock during the metal application, many pieces broke in the process. As a result, mirrors remained small, convex or concave discs, and were expensive to acquire.

No known examples of ancient mirrors feature intentional decoration applied directly to the reflective surface, whether through casting or hand tooling. This absence is likely due to practical constraints, available production methods, and the desire to perceive one's reflection as clearly and realistically as possible. Physical embellishments on glass surfaces appear much later in history, with the advent of brilliant cutting techniques using lathe wheels to incise ornate patterns.

Reflective distortions in glass mirrors persisted well into the Renaissance. As Schechner, 2005 described, even by the early 1400s, glass mirrors remained crude and unreliable. She uses this evidence to challenge David Hockney's claim that the heightened naturalism seen in Flemish painting during the late 1420s and early 1430s (particularly in the works of Robert Campin and Jan van Eyck) was achieved by using concave mirrors to project accurate reflections of the subject onto canvas (Hockney, 2006). Schechner eloquently disputes this, pointing out the technical limitations of the time; she argues that such mirrors were still incapable of producing the level of clarity Hockney suggests.

Glass quality and mirror-making techniques remained relatively crude until the 15th century, when Venetian glassmakers developed a refined glass batch capable of producing translucent, high-quality glass (Melchoir-Bonnet, 2001). Flat plates were made using the cylinder process, also known as broad or muff glass, where tubes of molten glass were blown, cut lengthwise, and unfurled while hot to form flat panels.

Pinpointing the exact origins, dates, and quality of glass produced using the broad process is challenging. Some sources indicate that this hand-blown sheet glass technique was used in Sussex, England, as early as 1226, although the glass produced was of poor quality (Winbolt, 1933). The process gained prominence in the glassmaking industry and was gradually refined in Italy, Germany, France, and England, yielding markedly improved results in glass production and mirror reflectivity from the 16th century onward (Melchoir-Bonnet, 2001).

Alongside the cylinder method of sheet glass production, the crown process was also employed to create rondelles**,** flat glass discs formed by spinning molten glass spheres into plates using centrifugal force. This technique produced a characteristic rippled texture and a central punty or pontil mark, where the glass was detached from the rod. While aesthetically distinctive, these features rendered crown glass unsuitable for accurate mirror reflection due to optical distortions resulting from uneven surface textures.

In the 17th century, glass plates were cast onto large copper tables and rolled into sheets. The process, developed by French artisan Bernard Perrot in the late 1680s and driven by Louis XIV's appetite for large-scale architectural mirrors, did not produce the textured surfaces typically associated with cast glass. Instead, the rolled sheets were laid into plaster beds and laboriously ground and polished by hand to produce the thin, transparent sheet glass we now take for granted (Melchior-Bonnet, 2001; Wills, 1965). This painstaking method is illustrated in Figure 15 of Denis Diderot's Manufacture des Glaces (Glassmaking)



Figure 15. Polishing 'broad' plate glass. Diderot, Denis. Manufacture des Glaces (Glassmaking) Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers. Plates vol. 4 Paris (1765)

A more modernised process of sheet glass production developed by James Hartley in 1847, in which molten glass was passed through rollers, along with mechanised methods for removing surface irregularities from cast plate glass, significantly reduced reliance on manual polishing. However, it was not until 1952 that British manufacturer Sir Alistair Pilkington revolutionised the industry with the invention of float glass, a method in which molten glass is floated over a bath of tin. This innovation enabled the fast, low-cost production of clear, smooth sheet glass, a process still in use today (Nippon Sheet Glass Company, 2025).

Pilkington's method revolutionised sheet glass manufacture and, by extension, mirror production, making them more widely accessible. No longer exclusive possessions of the elite, mirrors became global commodities integrated into everyday life. Today, looking at one's reflection is like taking a breath. We seldom give it thought. Yet a review of mirror production throughout history reveals that this casual familiarity is a relatively recent development.

The use of a tin-mercury amalgam to produce a reflective metallic coating on plate glass became widespread in the 16th century and continued until the early 20th century (Hadsund, 1993). This hazardous technique involved applying liquid mercury to a thin sheet of tin using a rabbit's foot (Schechner,

2005). A meticulously polished glass sheet that would have taken many workers' days, if not weeks, to grind and polish, was then pressed over the top of the mercury and tin to reveal the mirror. This process is illustrated in Denis Diderot's *Manufacture des Glaces* (Figure 16), a rare and valuable text that meticulously documents 18th-century industrial practices through detailed, hand-rendered etchings.

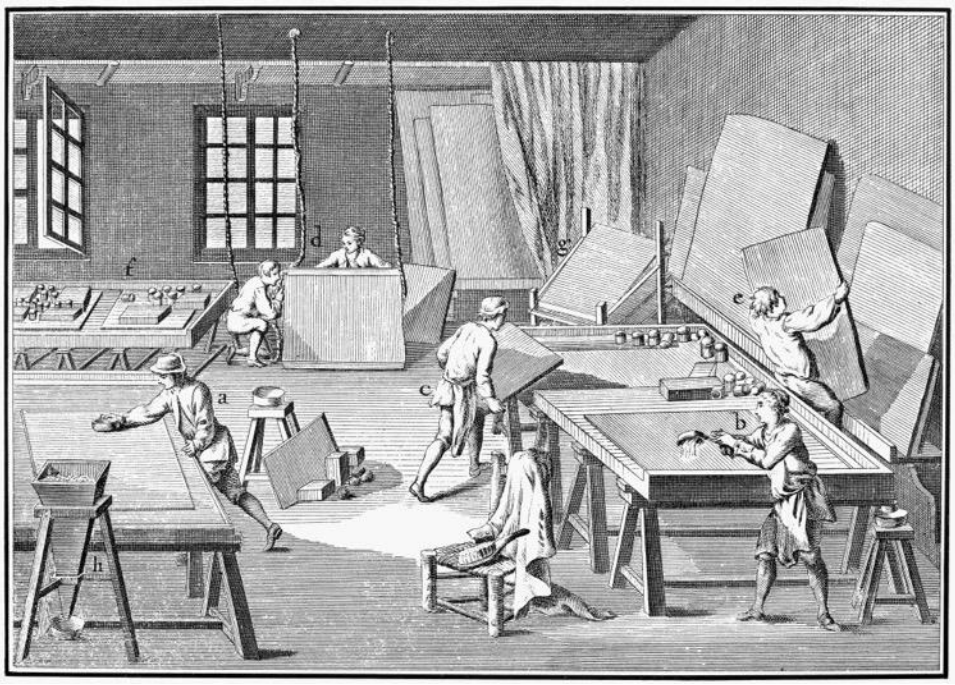


Figure 16. The tin-mercury amalgam process. Diderot, Denis. Manufacture des Glaces (Glassmaking) Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers. Plates vol. 4 Paris (1765)

While effective, the method was labour-intensive and extremely toxic. The resulting mirrors were characterised by a distinctive deep grey-silver hue, which contrasts with the brighter silver finishes of modern mirrors. Over time, the crystallisation of the tin-mercury amalgam and the gradual evaporation of

mercury led to the formation of voids between the glass and the reflective layer, often accompanied by dark staining due to oxidation and tarnish.

Figure 17 highlights an example of an aged tin mercury amalgam mirror. The staining is most prominent around the seams and outer edges of the glass. Several plates were set side by side to create larger panels, as the production of large mirrors were limited by process and more susceptible to breakage.



Figure 17. Example of a tin mercury amalgam mirror seen at the Rodin Museum, France, 2013. Image taken by Joanna Manousis

The invention of the chemical silver deposition process by German chemist Justus von Liebig in 1835 was a pivotal development in the modernisation of mirrored glass (Schweig, 1973). This technique involves chemically reducing silver nitrate to deposit a thin, uniform layer of metallic silver onto a glass surface. Compared to the darker, grey-toned finish of tin-mercury amalgam mirrors, silvered glass offers significantly improved brightness and reflectivity, which is less toxic. Today, chemical silver deposition remains the primary method for both industrial-scale and studio-based mirror production, and it is the process used in this research to achieve mirrored cast glass surfaces.

The marketing of companies such as Angel Gilding (USA), which distribute chemicals, instructions, and equipment for silver deposition with minimal setup, has enabled studio artists to create mirrors with ease in their working environments. Previously, mirror-making was considered an industrial process, and artists seeking mirrored glass had to purchase manufactured sheet glass or commission commercial mirror-makers, such as Dutton Glass & Mirrors Ltd, established in Birmingham, England, in 1967.

This new accessibility may explain an increase in experimentation with mirrored glass in studio art practice. This was observed in the increasing inclusion of mirrored artworks in New Glass Review, published by The Corning Museum of Glass in NY, USA. The annual publication features 100 innovative glass projects selected by a rotating panel of jurors.

Mirror coatings achieve full reflectivity on blemish-free, pristinely smooth surfaces and are best viewed optically through transparent, clear glass (Gregory, 1998; Melchior-Bonnet, 2001; Pendergrast, 2003). For these reasons, mirror-making has traditionally been limited to blown and sheet glass, where surfaces have these inherent qualities or can be finely polished to produce a true reflective finish. This may explain why refractory cast glass has not been considered a viable surface for mirror coatings. Attaining a pristine, clear surface directly from an investment mould is a significant technical challenge.

The historical overview of glass and mirror production presented in this chapter highlights the labour-intensive processes required to achieve optical clarity. Throughout history, great effort was devoted to producing reflective surfaces to meet the growing societal demand for mirrors. With the advent of technological innovations, new systems and materials for glass production, along with the refinement of mirror-coating techniques, have made the mirrors we now take for granted in daily life widely accessible.

2.3 Mirrors in Culture

A review of historical and cultural sources reveals a recurring tension in the symbolism of mirrors, which are positioned not only as vehicles of enlightenment but as instruments of deception and vanity. These functions, however, are not merely two sides of the same coin but highlight clear

differences in meaning: mirrors can illuminate truth and divine perception, or they can distort appearances and mislead (Gregory, 1998; Melchoir-Bonnet, 2001; Werness, 1999).

The mirror's capacity to reflect everything within its surroundings was likened to the all-seeing eye of God, a metaphor for spiritual awareness and a means through which humanity could contemplate its likeness to the divine (Gregory, 1998; Melchoir-Bonnet, 2001; Werness, 1999). In contrast, the infamous "magical mirror" owned by Elizabethan alchemist John Dee (1527–1609) was used as an occult tool for communicating with angels. Produced between the 14th and 16th centuries, the round plate of polished grey obsidian was used as a reflective wall embellishment to amplify the light and splendour of an Aztec temple of worship. This illustrates how mirrors could be seen with ambiguity and suspicion. The use and interpretation of mirrors differed across cultures.

Medieval texts tempered mirrors with caution, warning of self-absorption. This is explicitly evidenced in de Latour Landry, 1519. A graphic etching (Figure 18) depicts a young woman gazing into a convex mirror, only to see the devil's reflection. The image cautioned women against the sin of vanity, and that if they looked at themselves for too long, the devil would emerge.

Schechner (2005) argues that such examples not only highlight the moral anxieties of the time but also the crude, distorted nature of early mirrors, which rendered ambiguous and often unsettling reflections that were open to interpretation (Schechner, 2005).



Figure 18. Etching of a young maiden and the devil from *Der Ritter vom Turm (The Knight of the Tower*), 1495. Photograph taken by Joanna Manousis at The British Museum, London.

Traces of mirror-related superstitions persist today. One of the most enduring beliefs is that breaking a mirror brings seven years of bad luck. This belief can be traced back to ancient Roman thought, where it was said that the body and soul underwent a cycle of renewal every seven years. Breaking a mirror, an object that reflects the self, symbolically damaged the soul and disrupted this regenerative cycle, thereby ushering in a prolonged period of misfortune

(Gregory, 1998; Markovsky, 2021; Melchoir-Bonnet, 2001; Pendergrast, 2003; Werness, 1999).

Just as the creation of mirrors is complex, so too are their symbolic meanings and uses across different cultures, periods, religions, and traditions. Werness (1999, p.1) argues that in our 'pragmatic Western, technological society', humans have 'sacrificed an understanding of the numerousness of experience'. She suggests that the intangibility of mirror reflections serves as a reminder that the material world is merely a dim reflection of an unseen, ineffable spiritual reality, offering us a 'glimmer of this other reality' (Werness, 1999).

This perspective highlights the mirror's capacity to symbolise the mysterious and the unexplained, elements that speak to power, beauty, and truth, which are inherently subjective and unique to everyone. Some cultures identify tarnished or dusty mirrors as being synonymous with the ephemerality of life. The vibrancy of reflected light gradually fades echoing life's own declining energy and impermanence (Werness, 1999).

Yet, interestingly, prematurely aged, mottled modern-day mirrors, such as *Cloud Mirror* 2024, designed by Mia Jung, or *Don't Fade Away* by Gregory Nangle, have become popular in contemporary art and design practice and arguably do not carry negative or melancholy associations. UK Glass Centre,

a trading name of Cornwall Glass and Glazing Ltd, produces ‘Antique Mirror Glass’, a deliberately tarnished mirror popular in domestic interiors.

Many civilisations, including Indigenous peoples, the Ancient Egyptians, the Greeks, and the Romans, felt that a symbolic connection emerged between the mirror, the moon, and female energy (Gregory, 1998; Werness, 1999). As passive reflectors of light, mirrors were thought to echo the moon’s role in reflecting sunlight. The cyclical death and rebirth of the lunar cycle was associated with femininity, particularly women’s fertility and menstrual cycles.

These associations extended to the mirror itself in its ability to replicate or "double" the world, and they were thought to link cosmic and creative forces (Werness, 1999). In this context, mirrors were not just reflective objects but powerful symbols of creation. As seen in Figure 13, early metal-looking-glass mirrors often featured ornate depictions of female deities such as Venus, Aphrodite, and Demeter. These representations served as reminders of the mirror's intrinsic connection to feminine strength and generative power. Mirrors allow us to perceive that which we cannot, our image.

Although mirrors became symbols of foresight and truth within mystical traditions, their capacity to reflect an image that is both a likeness and a distortion gave rise to beliefs that they could capture the soul. In centuries past, Irish, Jewish, Chinese, Russian Orthodox and Victorian Britain covered

mirrors after a person's death. This was to prevent the soul from becoming caught in the reflective world, thereby preventing it from continuing its journey to the afterlife. It was also felt that mourners should be guarded from vanity and seek strength from others (Hammer, no date; Muise, 2010; Schlueter, 2017).

Superstitions surrounding mirrors today are rooted in a complex fusion of religious beliefs and folklore, appropriated and passed down through generations. The connection between looking glasses and the divine persists, with mirrors playing a significant role in sacred literature. The reflected self has been linked to the concept of divine twins in Jewish-Christian dogma, a premise whereby each of us has a heavenly double who serves as our perfected self, acting as a spiritual guide throughout life (De Conick, 1996; Sullivan, 2010).

In this instance, the mirror becomes a threshold between two aspects of being: the mortal and the divine, the physical and the spiritual. This dual symbolism resonates with the theological notion of Angelo-morphism, wherein human beings, through spiritual transformation, become angelic or divine-like (McShannon, 2025). Thus, the continued use of mirrors in sacred contexts reinforces their role not only as physical objects but as metaphysical instruments, mediators between the material world and higher realms of existence, transformation, and transcendence.

The act of contemplation is closely tied to the way we perceive ourselves in reflective surfaces (Manousis, 2009). Smart Martin (2003) draws on the multiple meanings of the word reflection, highlighting the physical and metaphorical dimensions evoked by shiny materials. She does this through her overview of furniture, silver and paintings in early America, an exhibition she curated at the Elvheim Museum of Art through the University of Wisconsin-Madison in 2003.

Reflection, on the one hand, describes the interaction of light on surfaces and, on the other, the process of thought. These two registers converged in the intellectual climate of the *Enlightenment* in the eighteenth century, when advances in science, art, and philosophy cultivated a more systematic understanding of the world (Smart Martin, 2003). Isaac Newton's pioneering work in optics exemplifies this development (Smithsonian Libraries, no date). As Smart Martin (2003, p. 3) observes, "Seeing has become the predominant sense (as compared to hearing, smelling, and touching) of our time, the visual is increasingly significant". This underscores the centrality of vision, both in literal terms and as a metaphor for clarity of thought.

Mirrors have long been associated with light and with the illusion of expanded space. Before the advent of electric lighting, materials such as cut crystal, polished metal, and mirrored glass were strategically employed to channel

daylight into dim interiors, intensify the glow of candlelight, and signal their owners' status (Smart Martin, 2003).

The Hall of Mirrors at the Palace of Versailles, constructed for Louis XIV, the "Sun King," between 1678 and 1684, is among the most renowned examples of amplified space, wealth and power. Extending 73 meters, the hall is lined with monumental mirrors that serve as a visual multiplication of the palace walls. These reflective surfaces expanded the spatial and symbolic radiance of the setting, reinforcing the monarch's self-fashioning as a luminous and exalted figure at the centre of his court (Gregory, 1998; Melchior-Bonnet, 2001; Pendergrast, 2003; Werness, 1999).

Kit Maxwell, curator and editor of the exhibition and accompanying publication *In Sparkling Company: Glass and the Costs of Social Life in Britain during the 1700s (2021–2022),* held at The Corning Museum of Glass, USA, explored the significance of polished surfaces in Georgian Britain. He highlights how the aristocracy curated an image of refinement and prestige by surrounding themselves with gleaming materials such as mahogany, gilded wood, and mirrors, objects that signified both economic success and elevated social status. Maxwell notes that the term polite is derived from the Latin *politus*, meaning "smooth" or "polished," suggesting that the material culture of the time was deeply interwoven with social ideals (Maxwell, 2020).

The polished aesthetic extended beyond décor, becoming embedded in the codes of dress, behaviour, and social interaction among the elite. While such opulence may appear ostentatious by contemporary standards, Maxwell argues that in the 18th century, smooth, gleaming surfaces, whether transmitting or refracting light, came to embody an artificial simplicity, refinement, and cleanliness that defined polite culture and contributed to what he calls “the cult of the polished” (Maxwell, 2020).

In the contemporary world, the rich symbolic associations that once defined our relationship with mirrors have, in many ways, been supplanted by digital screens. These modern surfaces have become our primary reflective interface, tools through which we not only see ourselves but also engage with others in increasingly mediated forms. Where once a fleeting glimpse in a polished surface offered rare, contemplative encounters with one’s image, today our likeness is endlessly replicated across phones, tablets, and monitors.

Hari, 2022 and Sina et al., 2023 raise questions about this shift in the saturation of visual selfhood through digital media, and whether such constant exposure has dulled our capacity for reflection, both literally and metaphorically. Yet, despite online saturation, mirrors continue to hold a distinct and enduring space in our perception of self in domesticity. As reviewed through previous paragraphs, they offer moments of stillness and

intimacy, sites for self-awareness, ritual, and imagination that echo their historical roles as mediators between the material and the spiritual, the visible and the unseen. In this way, the mirror persists not only as an object of function or decoration but as a powerful cultural symbol, continually evolving in meaning and use across time.

2.4 Mirrors in Contemporary Art

Glass and non-glass mirrors, along with a wide range of reflective materials, are widely used in contemporary art. This is evidenced by sculptures, two-dimensional wall works, performances, and videos that incorporate iridescent and reflective surfaces, exhibited in public spaces and museums internationally. Yayoi Kusama's *Infinity Mirror Rooms*, dating back to 1965 and still produced and exhibited today, are iconic works in which reflections create immersive, disorienting environments that challenge perceptions of space and self. This shift marked a move beyond the domestic use of mirrors, enabling artists to explore themes of identity, perception and viewer interaction.

Similarly, Danish Icelandic artist Olafur Eliasson has employed mirrors and mirrored glass in large-scale installations to investigate spatial awareness and phenomenological experience. Works such as Your Spiral View (2002) and The Weather Project (2003) use reflection not only to distort and multiply the

viewer's image but to prompt critical engagement with the architecture and temporality of the viewing space. These artistic strategies highlight the mirror's potential as both material and metaphor, an approach that resonates with this research's aim to interrogate and reimagine the reflective properties of cast glass.

While commercial mirrors continue to play a significant role in artistic practice, the availability of silvering chemicals from suppliers such as Angel Gilding and Peacock Labs in the USA has enabled studio artists to mirror their own glass creations. This has expanded the creative possibilities of mirrored glass, allowing for greater experimentation and control over how reflective elements are integrated into artworks.

The Rakow Commission is a distinguished annual invitation for an artist to create a piece of work for the Corning Museum of Glass, Corning, NY USA. Anjali Srinivasen's *साँस {Saans} eyes of the skin سانس ({Saans})* 2020-22 (Figure 19) was the 35th Rakow commissioned artwork. It highlights the use of silver nitrate mirroring on thin bubbles of blown glass to create a flexible panel of intricately assembled mirror shards adhered to silicone.

Inspired by the immersive experience of visiting the Sheesh Mahal as a child, an interior covered with intricate mirror mosaics, Srinivasen entwines spectacle with poetic resonance. Bound to sensors and motor devices, the screen gently inflates and contracts, responding to its audience's movements as though alive. Curator Susie J. Silbert remarks, the piece " reminds us, in glittering respiration, of our essential humanity and our ability to affect change in the world around us (Corning Museum of Glass, 2022).



Figure 19. Anjali Srinivasen's *साँस {Saans} eyes of the skin سانس ({Saans})* 2020-22. Corning Glass Museum, NY, USA. Image taken by Joanna Manousis

For artists, the use of reflective materials offers a potent means to engage viewers, not only by capturing attention but by invoking metaphors associated with mirrors historically. They resonate with themes of vanity, desire, power, superstition, and identity (Petry, 2024). The following sub-sections discuss the use of reflective materials, their meaning and how viewers interact with them in contemporary art practice.

2.4.1 Non-Glass Mirrors

Glass, while versatile and evocative, can present certain limitations when used in large-scale sculptures or works exposed to the elements. Its fragility, fabrication constraints and risk of thermal shock when exposed to extreme temperature fluctuations have led artists to turn to alternative reflective materials such as highly polished metals, coated plastics, and other media.

Some of these materials require specialised fabrication techniques, while others are commercially available and can be worked with minimal training or machinery. This can lead to greater flexibility and ease in artistic production and experimentation. For these reasons, it is important to highlight how artists use materials with reflective qualities other than glass to engage visual and metaphorical considerations, and how these mirrors have become integral to the contemporary art landscape. In doing so, this overview sheds light on the similarities and differences among these objects, materials, and methods in relation to this research.

Jeff Koons and Anish Kapoor immediately come to mind when deliberating iconic contemporary artists who use monumental non-glass mirrors to convey artistic intent. Skilled artisans create large-scale, highly polished metal sculptures that are durable enough for outdoor environments. Kapoor's *Cloud Gate*, 2004 (Figure 20), affectionately known as "The Bean," stands as one of Chicago's most prominent public art installations. Evoking the liquid surface of mercury, the sculpture reflects the surrounding skyline of Millennium Park, becoming a dynamic point of interaction for visitors. Tourists are often drawn to take selfies, where the city's mirrored surfaces offer a fleeting snapshot of time and place. This creates moments that are as much about personal experience as they are about the art itself.



Figure 20. Anish Kapoor, *Cloud Gate*, 2004, Stainless Steel, 10×20×12.8 m. Millennium Park, Chicago, USA. Image taken by JPellgen

Kapoor, Koons, and many other artists working with mirror-polished metal often choose simple, curved forms with minimal surface detail. This design

choice not only facilitates polishing but also enhances the sculpture's reflective quality. These attributes have been concurrent with the studio practices and forms used in this research. Detailed textures or intricate features can be challenging to tool and polish, and they tend to distort or obscure the mirror image's clarity, diminishing the sculpture's reflective accuracy.

The manipulation of surface and form lies at the core of Adi Toch's practice. Using precious metals like gold, silver, and white bronze (speculum), materials historically employed in mirror-making, Toch creates objects that invite the viewer to see both clear and morphed reflections. She states that the work encourages play in perception, movement, and the exploration of embodied experience (Toch, 2016), touching on the myriad of experiential possibilities that mirrored surfaces can offer.

Through a Metal, Darkly (Figure 21) is a series of hand-held vanity mirrors cast in speculum, a metal alloy composed of two-thirds copper to one-third tin. Like glass, this material is brittle and becomes highly reflective when polished. The mirrors have a rugged quality that evokes a sense of nostalgia, as though they've been unearthed from centuries past. However, only a small flat plane on the metal's surface is polished, which, like *Reaching An Ulterior Realm* (Figure 2), offers a distorted reflection that entices closer inspection.



Figure 21 Adi Toch, *Through a Metal, Darkly*, Cast White Bronze (Speculum), Image Credit: Thom Atkinson

Toch explains that the work emerged during the lockdown period, a time when individuals were "thrown back on ourselves and our inner resources" and compelled to "restrict and reshape our relationships to others and to the world around us" (Thornton, 2023). As with the cast mirror works made as case studies, Toch's work not only attracts attention through its reflective surfaces but also imparts themes relating to the relationships we have with ourselves and others.

German artist Amélie Esterhazy's *Speculum* (Figure 22) series also engage with material and linguistic play, yet she creates work from malleable materials that can be transformed by hand rather than by casting. The title references not only the historical use of speculum metal in mirror-making (as seen in the work of Adi Toch), but also the medical instrument used to inspect the human body, as well as the tools of examination and revelation. In this series, Esterhazy meticulously folds tin foil champagne labels into hexagonal units with triangular creases, assembling them into intricate origami-like blankets mounted on circular canvas boards.



Figure 22. Amélie Esterhazy, *Speculum no 19*, 2017. Champagne labels, newspaper, canvas. 135 cm. Image credit to: Markus Schneider.

Interspersed among the reflective silver components are what she terms as ‘blind spots) crafted from newspaper, which interrupts the uniformity of the surface and questions the reliability of any reflection to offer a true likeness of the viewer. Petry, 2025, p.198, writes that such works open the conceptual space of reflection beyond physical appearance to deeper questions of perception and identity. Esterhazy’s patchwork screens, crafted from discarded, ephemeral materials, are both visually intricate and conceptually driven. Like many of the cast-glass mirrors in this research, Esterhazy’s screen refrains from reflecting a crisp depiction of its surroundings, yet its oval, wall-mounted form and iridescent surface still impart a sense of reflectivity and self-examination.

The Bridge, 2018 (Figure 23), by British artist Deb Covell, comprises a 1.55 x 1.55-metre square of dried silver acrylic paint that acts as a subdued, reflective screen. Installed within a stone cathedral, the piece captures a dim, ghost-like silhouette of its architectural surroundings. As with Esterhazy’s practice and most cast mirrors produced in this research, Covell’s work does not produce a fully legible reflection. Instead, it invites viewers to examine the surface’s subtle painterly textures, traces of brushstrokes and imperfections that resist a seamless mirror image. In this way, the work reframes its environment as an atmospheric painting, reversing the conventional relationship between artwork and setting.



Figure 23. Deb Covell, *The Bridge*, 2018. Acrylic Paint. 1.55 x 1.55 m. Image Credit: Cal Carey

2.4.2 Glass Mirrors

Blown and float glass mirrors inherently possess the clarity, smoothness, and surface uniformity necessary to produce a true, uninterrupted reflection. These material qualities, enabled by industrial advancements in glass production, make glass an ideal substrate for mirror-making, allowing the precise application of reflective silver coatings. Beyond their functional attributes, glass mirrors hold a compelling aesthetic and conceptual appeal. Their ability to capture and reflect light, project their surroundings, and enable

people to see themselves has made them powerful tools in both artistic and design contexts.

Across both historical and contemporary practices, including my own artwork, mirrors function not only as decorative or architectural features but also as mediums that convey meaning, engaging with themes of perception, identity, illusion, and the passage of time. This section examines how artists employ mirrors produced through a range of techniques, including glassblowing, flameworking, kiln-working, and the use of commercially manufactured sheet glass. Attention to these processes reveals how the material can be manipulated to generate visually complex and psychologically charged experiences. Such explorations inform both the practical methodologies and the critical dialogue underpinning the artworks developed in this research.

Hand-mirrored or 'silvered' glass, produced through the chemical silver deposition process, has become increasingly prominent within contemporary studio glass practice, where glass sculptures and artworks are designed and fabricated by individual artists in small-scale workshops rather than industrial settings. Based on my own international teaching and educational experience, this rise in interest may be attributed to the broader dissemination of mirroring techniques within public access studios, university programs, and through demonstrations at glass society conferences. The increased availability of technical knowledge has, in turn, positioned mirrored glass as a

viable and expressive material choice within the conceptual and aesthetic vocabulary of contemporary studio artists and makers.

Angel Gilding, 2018; showcases a wide array of mirrored glass projects that demonstrate the successful application of the chemical silver deposition process. Most of these works are executed in blown or sheet glass, with a few examples of mirrored flameworked and slumped glass. This visual survey reveals a notable absence of mirroring techniques applied to three-dimensional kiln-cast glass forms. Even rarer are works in which the mirrored surface captures and accentuates intricate textures or impressions on the form's interior or exterior. Cast glass would emphasise the material's sculptural potential and its ability to hold complex reflective detail. This gap suggests that cast-glass mirror-making is underexplored in contemporary glass practice.

A leading contemporary artist known for his use of mirrored blown glass in dialogue with diverse fields of study is American artist Josiah McElheny. Renowned for his sculptural installations involving two-way mirrors and mirrored blown-glass forms, McElheny creates complex spatial arrangements that explore themes of perception, history, and knowledge. McElheny discusses the conceptual approaches in his work, describing glass as a material that is "not there", a substance defined as much by its transparency as by its presence (*Josiah McElheny: Libraries*, 2021). This capacity to "see

through" and "see beyond" becomes central to the visual and philosophical experience of the work. The mirrored forms within the cases are endlessly reflected, producing sterile yet serene vistas.



Figure 24. Josiah McElheny. *From the Library of Cosmic Rays*, 2021. Hand-blown, cut, polished, and mirrored glass; low-iron mirror and two-way mirror; electric light; walnut frame. 23 3/4 x 27 7/8 x 21 1/4 in, 60.3 x 70.8 x 54 cm. Photo: Phoebe d'Heurle. Courtesy of NORR COHAN, New York

Presented in a rectangular wall niche, *From the Library of Cosmic Rays*, 2021 (Figure 24) features clear glass cylinders that contain mirrored bubbles, each reflected and multiplied within the enclosed structure. McElheny is influenced by the writings of Argentine author Jorge Luis Borges, particularly his vision of the library as a structure of infinite knowledge (*Josiah McElheny: Libraries*, 2021). McElheny materialises Borges' concept of boundless information

through reflection and repetition. The works operate as enclosed systems. As with self-knowledge, the mirrored glass forms are self-contained and introspective, denying the gaze of the outside world.

Integrating sheet glass mirrors with unexpected materials, *I'll be…* (Figure 25), created by the contemporary British artist Ryan Gander, presents an ornate framed mirror, obscured by a cast-marble composite drape. The work disrupts a full reflection. Ganders trompe-l'œil shifts an everyday material into a realm of wonder, blurring the boundaries between the real and the fake. The power of the series lies in its use of familiar visual tropes, mirrors, drapery, and classical frames, recontextualised to challenge perception and question our habitual encounters with reflection, visibility, and identity.



Figure 25. Ryan Gander, *I'll be… (II),* 2015, Antique Mirror / Marble Resin, 56 1/10" x 65 1/10" x 7 1/10" / 142.5 x 166 x 18 cm. © Ryan Gander; Courtesy the artist and Lisson Gallery, Photograph by Jack Hems

Pollen Pie (2019) by Amy Lemaire (Figure 26) stands out as one of the most intricately detailed and reflective glass works identified in an extensive survey of exhibitions, publications, and catalogues. The sculpture comprises a cluster of enlarged, flameworked glass pollen spores, each individually sculpted by hand with graphite and metal tools in the flame, rather than moulded through kiln-casting techniques. This direct manipulation of molten glass yields transparent forms that can be silvered to achieve reflective mirror coatings.



Figure 26. Amy Lemaire, *Pollen Pile*, 2019, Mirrored Borosilicate Glass, Copper Wire, 12” x 9” x 8” / 30.5 x 23 x 20 cm. Image courtesy of the artist.

The viewer’s reflection is visually distorted, fragmented and skewed by the complex geometry and textural intricacy of each mirrored glass form. In this way, Lemaire’s work, unlike Gander’s, challenges the conventional expectations of mirrors as flat surfaces, instead presenting reflection as a dynamic and interpretive encounter.

Artist Matthew Day Perez works with fractured slabs of refractory material to produce textured glass surfaces for mirroring. *Grade Study,* 2020 (Figure 27), employs hot-slumping techniques rather than casting the glass into a contained mould. Following divestment, the panels are mirrored, resulting in an iridescent finish that accentuates surface details while diffusing light. A

direct or coherent reflection is inhibited by the textural surface of the investment, as well as the fragmented planes. These works emphasise the interaction of texture and light over optical clarity, creating a nuanced, highly decorative engagement with the reflective surface.



Figure 27. Mathew Day Perez, *Grade Study*, 2020, Fused, Silvered, and Coldworked Glass, 22 1/2 x 39 1/2 x 1” / 57 x 99 x 2.5cm. Image courtesy of the artist and Heller Gallery, NYC.

Perez’s wall-mounted panels are shallow rather than fully three-dimensional objects. This distinction is significant because fully enclosed cast glass forms require higher processing temperatures, which increase interaction between the glass and the mould material. As a result, mirrored coatings on such forms tend to yield a more muted or uneven mirror effect. Perez’s choice to work in a shallow format helps mitigate some of these technical limitations,

resulting in cleaner mirrored surfaces that prioritise texture and embellishment over an immersive three-dimensional reflection.

In her *Reveal* series, 2010 (Figure 28), British artist Sally Fawkes produces reflective three-dimensional glass sculptures by meticulously hand-polishing cast forms before silvering. Although the initial shapes are cast using refractory moulds, any surface texture from the mould material is entirely removed through an intensive cold-working stage, yielding a sleek, highly polished finish that supports a clean, reflective mirror finish.



Figure 28. Sally Fawkes (Artist), *Reveal VI* (Green), H19.0 x W12.5 x D13.5 cm, *Reveal VII* (Blue), H12.0 x W9.5 x D10.0 cm, *Reveal VIII* (Purple), H15.0 x W9.0 x D9.5 cm. 2010. Photo credit: Richard Jackson. Image courtesy of Sally Fawkes.

While similarly scaled solid glass forms could, in theory, be produced through hot sculpting techniques using furnace glass, achieving precision and mass typically requires mould processes. In such cases, cold-working manufactured glass blocks, or casting, becomes the most viable approach for producing dense, optically pure volumes, albeit ones that can introduce additional technical challenges, particularly when preparing the surface for mirror coatings.



Figure 29. Joanna Manousis / Brian Gillespie. *Morpho-Eugenia*, 2020, Blown / Press-Moulded Glass, Mirror, Stainless Steel, Aluminium, 509cm x 158cm / 200.5” W x 62.25” H / (16.7’ x 5.19’) Photo Credit: Joanna Manousis

Morpho Eugenia, 2019 (Figures 29 and 30), is a collaborative work by Brian Gillespie and me that integrates mirrored surfaces inside three-dimensional press-moulded and blown glass forms. The piece employs CNC-milled graphite moulds for blowing and press-moulding, with angular, recessed impressions. Moulds made of graphite offer distinct advantages over refractory counterparts, in that they allow for efficient, expedited production of glass forms that resist sticking and avoid the reactive surface interference encountered with refractory cast glass.



Figure 30. Joanna Manousis installing *Morpho Eugenia*. 2020, Blown / Press-Moulded Glass, Mirror, Stainless Steel, Aluminium, 509cm x 158cm / 200.5” W x 62.25” H / (16.7’ x 5.19’)
Photo Credit: Zac Weinberg

Graphite moulding significantly reduces long-term production time and material waste. Its low reactivity yields glass with smooth, glossy surfaces well-suited for chemical silver deposition. Moreover, it offers ergonomic advantages, as little to no intensive hand polishing is required if the mould is designed correctly.

Yet there are disadvantages when using graphite moulds for glass production. CNC machining and mould fabrication can be expensive, while rapid chilling on the glass’s surface in contact with the mould can cause surface rippling. This micro-texture distorts the mirror finish's clarity, resulting in a softened or fragmented reflection.

There are design limitations when using graphite as well. Forms cannot have undercuts to ensure the glass releases from the mould with ease. It cannot be used for creating complex internal voids with undercuts for these reasons. Large volumes of glass containing voids cannot be cast in graphite because the heat in the glass causes sagging and distortion of the interior and exterior glass when demoulded for annealing. Nevertheless, the process enables the efficient creation of mirrored components at sculptural scale with industrial precision. The benefits outweigh the drawbacks for certain bodies of work,

which is why the boundaries of graphite ‘plunger’ mould use are pushed in the fabrication of *Celeste, as* seen in Chapter 4.

Some contemporary artists and designers intentionally manipulate or contaminate glass surfaces to encourage premature mirror tarnish. This process allows for both controlled and spontaneous visual effects, introducing colour contrasts and patterns that disrupt the traditional expectations of a mirror. *Cloud Mirror* (2021), designed by Mia Jung (Figure 31), exemplifies this approach. Although conceived as a functional mirror to complement a console table, Jung’s design integrates an expressive, gestural surface treatment that invites deeper interpretation. She explains:

“I thought a lot about elemental and natural forces, the power of wind, a leaf quivering, the silent drag of the moon, a heat haze on the horizon creating a mirage-like effect, elements shifting and dancing together, all of which could be captured in the undulating surface of the hand-poured glass and precious metals” (Jung, no date)

This poetic description underscores the designer’s intent to transform the mirror into something more than a reflective tool. Instead, the mirror becomes an active surface that evokes elemental movement and ephemeral

phenomena. By disrupting the clarity of the reflected image, *Cloud Mirror* opens an extended dialogue between materiality and experience, inviting the viewer to a mediated encounter with the object itself.



Figure 31. *Cloud Mirror*, 2021 designed by Mia Jung. Cast Glass / 24 Carat Gold Mirror. 47 “H x 27.5” W / 120 cm H x 70 cm W. Image taken by Joanna Manousis

Mirroring with metal leaf on glass offers a less toxic alternative to traditional chemical silvering methods, as seen in *Everyone Loves the Sunshine,* a silver-and-gold mirror made by British artist Eddy Bennett (Figure 32). Yet,

gilding with metal leaf presents significant limitations, particularly when dealing with complex internal voids that are difficult, if not impossible, to access by hand. For example, the internal cavity of the magpie in *Distilled Portrait I* (Figure 3) is too narrow to access, while its intricate detailing would cause the metal leaf to tear easily.



Figure 32. Eddy Bennett. *Everyone Loves the Sunshine*. Glass, Gold, Silver, Enamel.

This makes leaf gilding unsuitable for creating uniform, reflective finishes inside cast forms with difficult-to-reach internal voids and/or semi-translucent surfaces. Furthermore, both metal leafing and chemical silvering are highly

dependent on the quality of the glass surface; if the investment mould bonds to the glass during firing, it can produce a matte appearance when viewed through the glass, thereby undermining the mirror effect. As such, reflective gilding is only viable on blown or sheet glass unless optimal conditions caused by a non-sticking investment formula, optimal glass composition, firing and fabrication methods are met for the cast glass object.

Research into the diverse approaches contemporary artists employ to create mirrored glass forms reveals a distinct preference for techniques that yield high-fidelity reflective surfaces. Flameworked glass, furnace-blown glass, and press, or blow-moulded glass using graphite moulds consistently produce dimensional forms with optimal clarity and surface gloss, making them highly conducive to silvering processes. In contrast, the use of refractory moulds for kiln-cast glass presents significant technical challenges due to the mould material's reactivity and tendency to leave surface residues and texture, both of which can compromise the quality of the mirror finish.

Despite the material and conceptual richness that cast glass offers, there is a notable absence of documented artworks employing three-dimensional mirrored forms produced through refractory mould casting that intentionally retain mould-derived surface detail. Except for my professional practice, no substantial examples of such works were identified in exhibition catalogues,

academic literature, or professional networks. This gap in practice and scholarship does not suggest that cast-mirrored glass sculptures of this nature are non-existent, but rather that they remain underexplored, underrepresented, or undocumented within the field.

The findings presented in this chapter underscore a broad tension between technical viability and conceptual ambition: while artists such as Josiah McElheny and Adi Toch employ refined, controlled surfaces to manipulate reflection and meaning, the more irregular, expressive textures offered by kiln-cast processes remain largely untapped in mirrored form. This presents an opportunity for further material experimentation and critical inquiry, one that challenges the conventions of optical perfection in favour of embracing surface complexity and the sculptural potential of mirrored cast glass.

2.5 Optimal Surface Reproduction in Refractory Cast Glass for Mirroring

2.5.1 Refractory Ingredients to Minimise Adhesion and Maximise Transparency

This research was initially concerned with achieving surface reproduction and transparency in refractory cast glass to lay the foundation for successful mirror applications. A key challenge lies in overcoming the inherent opacity that arises during the glass casting process. This opacity is often caused by

both surface roughness of the glass from the mould texture and chemical interactions between molten glass and the investment mould at high temperatures, leading to the adherence of refractory particles to the glass. These factors reduce optical clarity and light transmission, compromising the reflective qualities of the mirrored surface.

Such surface contamination interferes with the silvering process, typically manifesting as white or black staining, and reduces the optical clarity of the final surface. Moreover, the surface texture imparted by the mould causes light to scatter irregularly, disrupting the integrity of the reflection. Therefore, a central objective of this study was to identify and test investment mould materials capable of achieving good surface duplication while minimising chemical reactivity during casting.

Whether or not an artist seeks to produce a cast glass mirror specifically, detail reproduction, optical clarity, and the prevention of mould adhesion remain concerns for most practitioners working with kiln-cast glass. Surface interference from refractory materials not only impairs visual transparency but also obstructs light transmission, thereby diminishing the optical integrity of the final piece, which, in some instances, requires polishing to reveal a transparent surface. This is discussed by Charles Bray in ‘Ceramics and Glass: A Basic Technology’, published in 2000:

> “One of the major problems for artists casting glass into moulds or fusing glass together in a kiln is to ensure that the surface of the mould is reproduced as faithfully as possible and that the glass and the contact areas will part cleanly, leaving a surface which needs little or no polishing” (Bray, 2000, p. 184).

This concern is further supported in the commercial market, where companies such as ZYP Coatings Inc. (USA), Ransom & Randolph (USA), and Goldstar Powders (UK) promote refractory products and release agents to preserve mould integrity and enhance glass surface duplication. These materials are formulated to enable clean separation and achieve high levels of surface detail and gloss in cast glass, underscoring their importance within both artistic and industrial casting processes.

When constructing a refractory mould for kiln-cast glass, several critical factors must be considered. Chief among these is the model itself: its size, complexity, and thickness variations, all of which influence the annealing schedule needed to mitigate the risk of thermal shock. The model's geometry also determines the most appropriate mould-making method.

In hand-built techniques, refractory materials are applied incrementally to build up a mould of uniform thickness, offering better control over strength and reducing the likelihood of severe cracking during firing. Alternatively, flask moulding involves pouring refractory material around the model contained in materials such as wooden coddle boards, flexible metal or vinyl sheeting. While this approach is often faster and easier to execute, it tends to be less efficient and may result in uneven wall thicknesses, increasing the risk of cracking and thermal instability during the casting process.

(Kervin and Fenton, 2000) emphasise that the glass formulation itself largely determines the appropriate refractory composition. Factors such as the glass's processing temperature, the desired level of surface detail replication, and the scale of the casting must all be considered when selecting an investment mixture. For example, soda-lime glasses generally require higher firing temperatures than leaded (crystal) glasses. Consequently, the investment must be composed of materials with sufficient thermal stability and minimal reactivity, defined here as unwanted interactions between the glass and the mould that can result in surface defects such as bubbling, sticking, or opacity. Selecting the right refractory blend is therefore essential to achieving clean, detailed, and optically clear cast surfaces.

Kervin, Fenton and Thwaites (Kervin and Fenton, 2000; Thwaites, 2019; Thwaites, Angela, 2002) provide comprehensive guidance on the formulation

of investment moulds for kiln-cast glass, detailing the essential roles of binders, refractories, and modifiers, the three primary constituents of any investment mix. These texts not only explain the material properties and functions of each component but also include a range of tested recipes, highlighting the specific advantages and limitations of each formulation. By outlining how variations in material selection and proportion influence surface fidelity, thermal stability, and ease of demoulding, these sources offer an invaluable foundation for understanding and refining mould-making processes in contemporary glass casting.

What these texts do not explicitly address, however, is the identification of investment materials that facilitate a clean release from the glass surface, thereby enhancing transparency, an essential factor when mirroring cast forms. Thwaites (2011) cites molochite, a calcined white clay (China clay), as a material that can function as either a refractory or a modifier, offering mould strength and yielding a “good quality” glass surface. However, the specific attributes of this surface are not elaborated upon.

While Thwaites suggests incorporating molochite up to 20% of the dry weight of an investment mix, this research has successfully tested moulds containing up to 50% molochite by dry weight. These tests confirm that molochite provides excellent surface reproduction for silvering, particularly with Bullseye glass, although its structural integrity is inferior to that of a comparable mix

containing 50% quartz (silica). To address this, a composite mould structure has been developed in which a face coat composed of 50% molochite is backed by a stronger layer containing quartz. This approach achieves both the fine surface detail required for effective mirroring and the mechanical strength necessary for successful casting.

Thwaites, Kerwin, and Fenton advocate the addition of kaolin (China clay) as a modifying ingredient in investment mixes, suggesting up to 5% by dry weight to reduce the risk of glass adhering to the mould, thereby producing a ‘good’ surface (Kervin and Fenton, 2000; Thwaites, 2019; Thwaites, Angela, 2002). However, there is caution that exceeding 10% kaolin can lead to devitrification, a process of crystallisation that results in increased opacity, surface crazing, or wrinkles, rather than a smooth, glossy transparency.

In this research project, kaolin was incorporated at 6.7% in a standard 50/50 plaster-to-quartz investment mix. While devitrification was observed around the outer edge of the fired tests, interestingly, the ‘open face’ tests conducted with Bullseye glass revealed that this devitrification effect caused tonal variations in the mirrored surface. These variations offer potential for further exploration, potentially leading to the development of new surface effects in cast glass mirrors.

Kerwin and Fenton highlight zircon as a high-temperature refractory material that can effectively reduce glass sticking to a mould. In their discussion of ‘Investment Mix #3’, they recommend a composition of 2 parts binder (plaster), 2 parts refractories (silica), and 1 part zircon, which offers low shrinkage and facilitates easy release from the glass. However, due to limited access to zircon, it was not incorporated into the material tests conducted in this research project (Kervin and Fenton, 2000).

Bray (2000) identifies several separator materials that assist in achieving a clean release of glass from investment moulds. Among these, ceramic fibres are noted for producing surfaces that require "little or no polishing." However, while effective for flat or open-faced moulds, ceramic fibre linings are unsuitable for enclosed forms or those featuring intricate surface detail. Moreover, the fibres can imprint a texture on the glass surface, which would interfere with the smooth finish required for a reflective mirror coating.

Bray notes that thin applications of talc or magnesium carbonate can serve effectively as mould-release agents. Talc is applied directly to the surface of the mould rather than incorporated into the refractory mix. However, based on my practical experience, unbound particulates within an enclosed mould can result in surface contamination of the glass, often manifesting as faint white veils or streaks within the cast form.

Bray is also one of the few authors to reference boron nitride (p. 185) as an “expensive but effective separator” for high-temperature applications (Bray, 2000). Despite its apparent efficacy, Bray offers no further explanation of its application method, compatibility with various glass types, or its behaviour with different investment compositions, an omission that limits its practical utility in studio-based kiln-casting contexts.

Platt and Morales, 1989 offer an informative and technical journal article that seeks to identify an optimal refractory investment, one that is structurally stable, resistant to thermal stress, capable of fine surface replication, and non-adherent to glass.

> “From the beginning, mold materials have been problematic. Since 1984, we have sought to eliminate pasty surface quality and flashing from mold cracks that are common to customary plaster / silica investment molds” (Platt and Morales, 1989. p. 21).

Although Platt and Morales do not specify the model used in their testing procedures, they offer valuable insights into the composition and selection of investment materials that support the desired outcomes of dimensional stability, fine surface replication, and minimal adhesion to glass. In alignment with Thwaites, they emphasise the importance of particle ‘packing’ within the refractory mix. By incorporating a range of particle sizes, a denser and more

structurally cohesive mould is achieved. This densification is crucial during firing, particularly as the gypsum component begins to decompose at approximately 315–426°C (600–800°F). At this stage, the interlocking nature of the variably sized particles helps maintain the integrity of the mould, reducing the likelihood of deformation or failure under thermal strain (Platt and Morales, 1989; Thwaites, 2019).

Platt and Morales note that the specific type of gypsum used in investment recipes is rarely disclosed, posing challenges for reproducibility and consistency in glass-casting outcomes. This lack of transparency is significant, as the market offers numerous gypsum formulations, each with distinct physical properties that can greatly influence the quality of the cast. The researcher's experiments with various commercial gypsum products have confirmed that both surface replication and mould strength are partially dependent on the brand and grade of gypsum employed. For instance, Crystacal R has been observed to produce a noticeably smoother surface finish in cast glass than standard pottery plaster, yet it can be too dense for core-cast work because its durability can create tension in the glass during annealing.

Similarly Kervin and Fenton, 2000, Platt and Morales,1989 discuss the use of zircon ($ZrSiO_4$) as a refractory filler, highlighting its resistance to attack by molten glass (Platt and Morales, 1989, p. 21). They also identify alumina

(Al_2O_3), when used at a fine mesh size (120 mesh), as an effective additive to improve mould durability. Calcium aluminate cements are trialled as secondary binders to maintain structural integrity after the gypsum begins to break down during firing.

Additionally, the authors evaluate Hydroperm, a pre-mixed blend of white Hydrocal, refractory filler, and detergent, known for producing clean surface detail. However, it is also reported to be susceptible to shrinkage and cracking during the extended firing schedules typical in glass casting (Platt and Morales, 1989). While these refractory formulations offer valuable insight into achieving strength and reliable surface reproduction, it is important to recognise the limitations of global material access. The availability of certain ingredients varies widely, and local substitutions may affect both the stability of the mould and the visual quality of the finished glass.

Perhaps the most crucial statement for this research by Platt and Moralles is:

> “Softer glasses fired to lower temperatures for a longer time gave the best results. In fact, we were able to obtain objects with a bright surface using Schott optical glass cullet and firing to 1410 degrees F for 12 hours” (Platt and Morales, 1989, p.37).

Extensive material testing in this research confirms that elevated firing temperatures, along with extended exposure to peak heat, significantly increase surface reactivity, leading to greater opacity in cast glass. Achieving minimal surface adherence and optimal transparency involves multiple interdependent factors. While the composition of the investment mix is critical, equal consideration must be given to the type of glass used, the firing schedule, and the original model's characteristics. Each variable contributes to the final surface quality and the success of the mirror application.

2.5.2 Post–Fire Processes for Surface Brightening

As with the limited availability of published investment formulas aimed at reducing sticking between soda-lime and lead-based glasses during kiln casting, there are also few accessible resources detailing post-firing surface treatments beyond conventional cold-working methods that aid in brightening the surface of cast glass.

Bray provides one of the few overviews of such treatments. He outlines several post-firing techniques intended to enhance the surface finish of cast glass, including acid polishing, the application of oils and lustres, and the use of low-fire enamels that can fuse to the glass at temperatures low enough to avoid structural deformation (Bray, 2000).

Unfused surface treatments, such as oils and lustres, do not chemically bond with the glass but instead form a superficial layer that masks the semi-matte or "pasty" surface quality of cast glass (Platt and Morales, 1989). These materials help unify the appearance of rough or scratched surfaces. Products such as "Liquid Lustre," an air-curing sealant sold by HIS Glass (USA), and Thompson's *Water Seal*, a waterproofing coating for various materials, are sometimes used for this purpose. However, their chemical composition can interfere with the adhesion of mirror coatings, limiting their effectiveness and causing mottling or complete failure in the silvering process.

The use of low-fire enamels presents a more promising approach. If the enamel has a coefficient of thermal expansion compatible with that of the cast glass, it can be fused to the surface without causing cracking or stress fractures. This method has the potential to brighten the surface and prepare it for reflective coatings. Nonetheless, prior experimentation outlined earlier in this review suggests that acid polishing remains the most effective method for enhancing surface gloss in lead-based glasses. Acid treatments can remove residual investment material while creating a smoother, glossier finish that supports more successful mirror applications.

However, acid polishing has several limitations. It is ineffective on soda-lime glass, which lacks the lead content required for the chemical reaction to occur. Additionally, acid polishing is highly toxic, requires temperatures between 40–80°C to be effective, and poses significant health and safety risks. These factors mean it is generally inaccessible to most studio artists and must be performed by trained professionals, usually in industrial settings. Moreover, thicker cast pieces are especially vulnerable to cracking during acid polishing, particularly if submerged without first being gradually brought to the required processing temperature, due to the thermal shock from the hot acid bath. For these reasons, a more in-depth investigation is required to identify process and environmental variables that can produce brighter cast glass surfaces without relying on post-firing treatments.

2.6 Conclusion to the Contextual Review

The integration of cast glass mirrors as a medium within contemporary visual art practice is both timely and significant. Mirrors have long carried symbolic and material importance in human culture: from early obsidian mirrors used for divination to the opulent Venetian traditions of the Renaissance, they have consistently been bound to themes of perception, self-awareness, and spiritual insight. Historically, mirrors have functioned not only as objects of utility or luxury, but as potent metaphors, thresholds between physical and

immaterial realms, tools for introspection, and devices for expanding perceptual experience.

In contemporary practice, mirrors retain relevance, with artists using them to disrupt spatial norms, prompt self-reflection, and create immersive, often participatory experiences. However, much of this work relies on industrially produced sheet glass, blown glass, or other highly polished reflective materials that, while effective, tend to limit the mirror's detail and form and restrict the depth the reflective plane can have within an object.

Core-cast glass introduces a distinctive contribution. Unlike conventional sheet mirrors, it enables the creation of three-dimensional mirrored forms in which reflections are not merely on the surface but are embedded within the volume of the glass object. Informed choices yield unique reflective outcomes in the cast-glass object that merge interiority and exteriority, solid and void, visibility and concealment. The cast mirror thus becomes more than a surface: it is an experiential volume that reconfigures the relationship between seeing and being seen.

This contextual review has illuminated both the technical challenges and breakthroughs of mirror-making, as well as its cultural significance and the symbolic connotations it can induce; A dualistic power, at once associated with illumination and clarity, yet equally with vanity, illusion, and danger.

These historical and metaphorical dimensions directly inform the experimental methods in Chapter 3 (Studio Testing) and the evolution of case studies in Chapter 4.

My perspective as an artist with over twenty years of glassmaking experience has been central in establishing the materials and methods used in this study. Practitioners working in kiln-cast glass frequently strive for optimal surfaces that release cleanly from moulds, and the existence of specialist suppliers such as Ransom & Randolph, Gold Star Powders, and ZYP Coatings testifies to the demand for reliable mould investments and release products. In this research, testing commercial recipes alongside hand-mixed formulations, guided by technical literature and practitioner accounts, has been essential to developing the investment formulas.

Ultimately, this chapter has provided a foundation for understanding the historical, cultural, and material trajectories of mirror-making and situates my own practice within these traditions. It has demonstrated how the emblematic and experiential weight of mirrors, combined with technical innovation in glass casting, informs the inspirations for artworks and material investigations that follow in this thesis.

3 Studio Testing: Cast Glass Mirrors

This chapter details over 150 cast glass mirror tests using open-face and enclosed refractory moulds. Three phases of testing are explored using the recess of an optical flat lens, polished glass bullets and a sculpted clay magpie. A roughness comparator is duplicated as a cast glass mirror for visual analysis, before a conclusion that highlights constituents that affect the reflectivity of cast glass, before moving on to the artworks seen in Chapter 4: Case Studies.

3.1 Introduction to Chapter 3

Understanding and controlling the appearance of a cast glass mirrored surface requires systematic exploration through in-depth studio testing. The intricate relationships between material properties and process variables, such as glass composition, refractory ingredients, boron nitride coatings, firing temperature and duration, the form and surface finish of the original model, and post-firing treatments such as acid polishing, determine the final optical qualities of the work. Establishing these cause-and-effect connections is therefore essential for the practitioner seeking creative and technical control over the reflectivity and aesthetic outcome of cast glass.

This chapter provides the rationale for the practical methodologies employed in this research and presents the results of studio-based experimentation. These results informed the development of scaled-up artworks and provided critical insights into how material and procedural choices influence the appearance of mirrored surfaces in cast glass. The outcomes are

documented both visually, through photographic evidence, and textually, to provide a comprehensive record of the investigative process.

Studio testing addressed the following research questions:

- What factors inhibit and enhance the reflective qualities of a mirror coating on a cast glass surface?
- Can cast glass surfaces made with an investment mould fired in a kiln be reflective once mirrored?
- What are the potential practical and creative parameters of using three-dimensional mirrored cast glass at varying scales and complexities?

By addressing these questions through systematic studio experimentation, this chapter establishes the technical and aesthetic foundations necessary for achieving reflective and non-reflective cast glass surfaces. The insights gained not only inform the practical development of artworks but also contribute to a deeper understanding of how material behaviour intersects with creative intention.

This chapter examines the materials and equipment employed in testing, including glass bodies, investment materials, release agents, post-firing treatments, and kiln processes. It explains the rationale for both the constant

and variable factors used throughout experimentation. A detailed analysis is then provided for Phases 1 (Open-Face Moulds), 2 (Enclosed Moulds), and 3 (Magpie Domes) of studio testing, offering an in-depth account of fabrication methods, materials, and firing schedules. The results are documented through photographs taken before and after mirroring, revealing subtle nuances in glass surfaces and their reflective qualities.

Additionally, a roughness comparator, an industrial tool used to grade surface textures, is replicated as a mirrored impression in cast glass. The chapter concludes with a summary of all testing outcomes, which form the backbone of this material investigation and establish a foundation for Chapter 4: Case Studies.

3.2 Constant and variable factors in the materials and equipment used for preliminary testing

This section begins with an overview of the four glass bodies trialled in this research, the rationale for their selection, and the kiln chosen as the constant variable throughout the project. Sections 3.3–3.5 provide a detailed account of preliminary testing using the impression of an optical flat lens for mirroring within glass forms created with open-face investment moulds.

As the most extensive part of this chapter, these sections establish a wide range of variables for testing. These include comparisons between wet and dry moulds, the influence of temperature and duration on cast glass surfaces, and the impact of both commercially produced and hand-mixed investment recipes. Further experiments explore the application of hBN powders and coatings, as well as acid polishing processes, to either enhance or reduce the reflectivity of mirrored surfaces.

Section 3.6 examines a refined selection of mirror effects using enclosed moulds. Here, the recess of a polished glass bullet within glass domes is used to determine whether the outcomes observed in open-face moulds are consistent with those in forms made with tension-set investment moulds. Section 3.7 narrows these investigations further, applying six mirroring effects to more complex interior forms using a hand-sculpted model of a magpie. This section introduces the hot-billet method, in which glass ingots made of Cristalica (a glass which normally resists flow when fired from room temperature in a kiln) are cast into pre-fired investment moulds. The chapter ends with documentation of a roughness comparator test before presenting a conclusion.

3.2.1 Glass bodies

Cristalica Cullet (Manufacturer: Bomma, Czech Republic), Bullseye Billet (Manufacturer: Bullseye Glass Company, USA), Reichenbach Billet (Manufacturer: Farbglas, Germany), and Gaffer Billet (Manufacturer: Farbglas, Germany) are among the most widely used glasses by casters in the West. This is evidenced by studying and teaching in the United States, Canada, Europe, and Australia, countries with strong glass-art communities. These glasses were chosen for this research so that the results would be relevant to as many artists as possible working with cast glass and would have a greater impact within the international glass art community.

- Cristalica (soda-lime) 'Pre-Melted' Cullet – COE: 96.5
- Bullseye (soda-lime) 'Crystal Clear' – 1401 Billet – COE: 90
- Reichenbach (40% Lead Crystal) Clear – 1500 Billet – COE: 96
- Gaffer (40% Lead Crystal) Clear – G210 Billet – COE: 92

Cristalica (96.5 COE) is a clear 'pebble-like' glass cullet, commonly used as a batch product for furnace glassblowing. Because it is pre-melted, Cristalica is often preferred in university and public-access studios as a safer alternative to batch powder products due to its substantially lower emissions of toxic particulates. Cristalica is also affordable at around £3-4 per kg (ex. VAT), compared to other commercial studio-art glasses such as Bullseye (Clear 1401) at around £31 per kg (ex. VAT).

One major setback when working with Cristalica cullet is its short work time at elevated temperatures. Cristalica has a working point of 995°C / 1823°f and is resistant to flowing in refractory moulds at temperatures below 815°C / 1500°F (as evidenced through the researchers' practice and other students striving to cast Cristalica at The National Glass Centre. Glass technician at The National Glass Centre, Tim Betterton, commented on the Cristalica cullet's inability to flow unless cast at a temperature of between 840-860°C. This can pose challenges, as higher peak firing temperatures sustained for long durations can lead to strain and cracking in refractory moulds (Bray, 2000; Platt and Morales, 1989; Thwaites, 2019). This can lead to crazing, sharp glass fissures that have melted through cracks or to complete mould failure.

Bullseye Glass is distributed worldwide (*Bullseye Glass*, no date) within the glass-art community and sells a wide range of glass products in a wide range of colours. 1401 'Crystal Clear' billet (COE 90) is a rectangular glass slab (127 x 254 x 19mm) that can be broken down into smaller pieces to fit investment mould cavities/sprues. Bullseye 1401 has the brightest clear hue among the four glasses trialled yet has a higher viscosity than Gaffer crystal (Pollock, 2012). For these reasons, Bullseye glass (as with Cristalica and arguably Reichenbach) is often cast at a higher temperature range (815°C – 871°C / 1500°F-1600°F) over longer durations to ensure full glass flow into a mould.

Reichenbach 1500 Clear billet (COE 96) comes in rectangular slabs, like Bullseye 1401 and recent Gaffer G210 production, and must be broken into pieces when loading into small moulds (such as those made during the testing phase of this research project) using a glass cutter and hammer. Reichenbach 1500 has a blue/grey tint compared to the other 3 clear glasses selected for testing. Its recommended casting range is 790°C – 850 °C / 1454°F – 1562°F; however, although Reichenbach contains 40% lead, it does not flow as easily as Gaffer glass and was found to be on par with Bullseye glass in terms of viscosity and flow during flow trials in this research.

Gaffer G210 Clear (COE 92) was produced as oval cabochon-like billets by its founding company in New Zealand. The recipes were sold to Farbglas in Germany (a producer of Reichenbach) in 2021 and are now produced as rectangular slabs. Gaffer has a high lead content (40%) and a lower casting temperature (780-900°C / 1426-1650°F) compared to many other commercial glasses. Its low viscosity / high fluidity led to better surface definition and the ability to flow into complex/thin shapes. Although lead-bearing glasses are softer than soda-lime glasses and easier to polish (cold-work), they are more susceptible to scratching.

3.2.2 Equipment used in Testing

To keep variables to a minimum and maintain consistent results, the same front-loading GTA 80 / 12 KW kiln made by Kiln Care, UK (05/07) (Figure 33) was used for all tests and scaled-up artworks made within this research project. All moulds were supported on a kiln shelf elevated by 5cm / 2” with kiln bricks at all four corners. The kiln incorporates an ST33-3 digital controller for inputting firing schedules and controlling kiln elements.



Figure 33. Phase 1 test moulds ready for pre-fire in Kiln Care GTA 80 / 12 KW kiln made in 05/07

3.3 Phase 1 Studio Testing - Open-Face Moulds

Through previous studio practice and the documented findings of other studio glass artists working in cast glass, it was determined that steaming wax from a mould utilising the ‘lost-wax-casting’ technique causes mould weakness

and surface erosion due to the introduction of excess water and heat (Pollock, 2012; Thwaites, 2018).

To mitigate these adverse effects on the mould surface, which can lead to minor texturing/abrasion that distorts a mirror's reflectivity, wax was avoided wherever possible as an intermediate moulding material in this research. This diversion is relatively simple when utilising open-face moulds without undercuts that do not require a sprue system (a chamber/cavity to hold the glass before melting), but it's technically challenging when creating ‘enclosed’ forms in the round.

Silicone or polyurethane positives can be created from shallow objects that have enough flexibility (shore hardness of 20) to be extracted directly from the refractory mould using compressed air or a tool. The indentation of the original base model in the rubber positive creates a refractory ‘core’ in the investment mould that will later form a recess in the glass object after casting. This becomes the container space for the mirror coating. Enclosed moulds in the round require a multi-part refractory mould system. This is detailed further in section 3.5, Phase 2 Studio Testing – Enclosed Moulds.

For Phase 1 of the studio testing, three forms were initially selected to create silicone positives: an optical flat lens with a pristine, smooth surface; a hand-made model featuring a range of flat, concave, and convex details; and a

metal roughness comparator containing 23 distinct surface profiles, commonly used to visually and tactilely assess surface depth produced by abrasives.

While the hand-rendered model was originally favoured for its variety of surface geometries, the optical flat lens (Figure 34) was selected as the most suitable base model. Its consistent surface enabled the production of refractory cores that produced perfectly flat impressions in the cast glass. These impressions served as reliable indicators for assessing surface texture and opacity variations resulting from differences in glass type, refractory composition, firing temperature, and firing duration.



Figure 34. Optical flat lens used for mould-positive

Four silicone positives were created from the optical flat lens to ensure enough moulds would be available for each of the four glasses when testing with varying refractory mixes. The lens was supported with clay and cast in silicone using a clay flask. AD-Sil 20, a flexible, platinum silicone with a shore hardness of 20 (Figure 35), was used. Each positive has a silicone wall 1cm thick encircling the lens indentations.



Figure 35. Open-face mould set-up for phase 1 testing.

3.3.1 Open-Face Mould Set-Up

Silicone mould positives must be completely clean and free of debris or surface moisture before the refractory mould is poured. This is to prevent unwanted inclusions or residuals from contaminating the mould surface, thereby causing imperfections in the finished casting. Each silicone positive was adhered to a flexible Plexiglass workboard with moist clay to create a

vacuum seal. Clay wall flasks (approximately 1.5 cm thick) were created to contain the outward pressure exerted by the poured refractory. Each investment mould had a wall thickness of 2cm (see Figure 35).

Regular tap water contains minerals and additives that vary by region. When a freshly made mould is heated, water vapour can leave residual impurities on the glass during the pre-firing stage, leading to contamination and veiling. Deionised water was used to prepare all refractory recipes to reduce variables that could lead to inconsistent results. Its use is a key contribution to the findings within this study.

3.3.2 Wet vs Dry Moulds

In the research project *Mixing with the Best: An Investigation and Comparison of Contemporary Working Methods and Mould Making Materials for Use in the Kiln Forming of Glass* (1999–2001), conducted by Angela Thwaites and Keith Seybert at the Royal College of Art, a questionnaire was distributed to experienced kiln-casting artists worldwide to examine similarities and differences in mould-making practices.

One point of divergence was the preference for firing freshly made ‘wet’ moulds versus pre-fired ‘dry’ moulds, with varied reasoning offered for each approach. In response to this inconsistency, comparative tests were conducted in the present research to evaluate whether firing fresh, wet

moulds has a measurable impact on surface quality and structural integrity, using the silicone lens positives as a standardised base form.

A 1:1:1 (by volume) of water, pottery plaster and quartz investment mix was used to create two tests for each glass used in the project. One of the moulds was pre-fired without glass to 593°C / 1100°F for 1 hour, then cooled to room temperature. These moulds were then loaded with glass and fired to a peak temperature of 800°C / 1472°F for 2 hours. The other moulds were fired wet (freshly made) with the glass, moving through pre-fire, firing and annealing in one cycle.



Figure 36. Gaffer Crystal cast from wet mould (left).

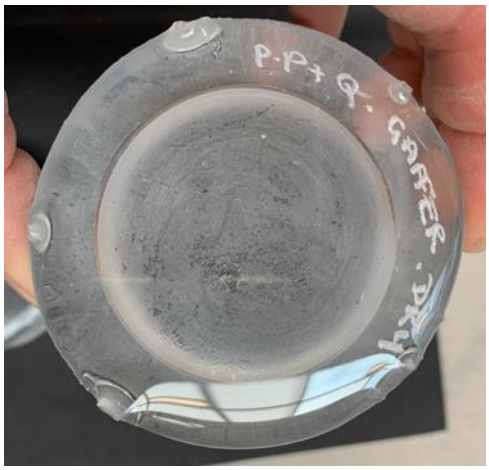


Figure 37 Gaffer Crystal cast from dry mould (right)

The fired tests presented almost identical surface finishes. However, minor devitrification was observed around the outer perimeter of the tests fired in the wet moulds. This was particularly evident when casting the Gaffer crystal. Note the slightly rippled texture around the edge of the glass fired in the wet

mould versus the smooth, glossy surface of the glass fired in a pre-fired mould in Figures 36 and 37.

A large surface bubble was caught in the wet-fired casting pictured on the left. (Figure 36). This could be attributed to several pieces of glass being fired into the mould cavity, which trapped air, rather than steam emitted from the refractory mould itself. Nonetheless, after establishing improved surface performance with dry moulds, a decision was made to carry out all further tests using pre-fired dry moulds.

3.3.3 Pre-firing Moulds

As detailed in the Thwaites/Seybert ‘Mixing with the Best’ project, many glass artists, including Vera Pelantova and Vlastimil Beranek (Beranek S.r.o. Glassworks, Skrdlovice, Czech Republic), Tomas Malek (Czech Republic), Anja Isphording (Canada), and Tessa Clegg (UK), pre-dry moulds to remove moisture before firing glass.

For consistency, the open-face lens moulds were pre-fired in batch firings before glass was introduced, with all moulds cooled to room temperature prior to casting (see Appendices for the full pre-firing schedule). A controlled, gradual temperature ramp was employed to minimise the risk of thermal shock, which can cause mould cracking due to rapid expansion and contraction during heating and cooling cycles.

While firing wet moulds is known to reduce kiln longevity by accelerating the deterioration of heating elements, the pre-firing process offers greater control and predictability when performed within a kiln firing. In contrast, drying moulds over several days in ambient conditions or a heating chamber can produce variable outcomes, particularly when attempting to replicate the process across different climates or with differing equipment setups.

Pre-fired moulds become brittle and delicate after the pre-fire process and should be handled carefully. All dust and debris that may have fallen into the mould cavities are removed with light compressed air before loading the glass. This helps reduce the risk of impurities, dust, or debris being incorporated into the cast.

3.3.4 Firing Temperature / Duration: Flow Tests

Before testing each glass with a range of investment moulds, it was necessary to establish a consistent firing schedule that would enable all selected glass types to fully flow and fill the open-face moulds. Elevated firing temperatures combined with prolonged hold times can compromise mould integrity and increase the likelihood of chemical interactions between the glass and the refractory material, often resulting in surface clouding or increased opacity (Platt and Morales, 1989).

To mitigate these issues, the lowest effective firing temperature and hold duration were sought, ensuring the glass would cast cleanly while minimising adverse effects on both surface quality and mould stability. Lead crystal glasses, which exhibit lower melting points and viscosities than soda-lime glasses, typically achieve full flow at lower temperatures and for shorter durations (Bray, 2000; Platt and Morales, 1989; Thwaites, 2019). However, to limit the number of testing variables and ensure comparability across all samples, a single, consistent firing schedule was applied to all glass bodies.

A flow test was performed in which each glass was held at 676°C / 1250°F for 3 hours before reaching the peak firing temperature. This stage was added to allow soda-lime glasses with a higher melting point to soak, evening out the temperature between the glass and the mould, while aiding the glass in reaching a peak firing temperature more quickly.

Two flow tests were conducted to evaluate the impact of peak temperature on surface quality. In the first set, the glass samples were fired to a high temperature of 815°C (1500°F) and held for 1 hour before ramping down to the annealing phase. The second set was fired to a lower peak temperature of 787°C (1450°F) with a one-hour hold. Across all four glass types, higher levels of surface opacity and devitrification were observed where the glass encountered the investment mould, particularly in the Reichenbach crystal

samples (Figure 38). In contrast, the samples fired at the lower temperature exhibited greater surface transparency, indicating a more favourable outcome.



Figure 38. Results of flow tests using Cristalica, Bullseye, Gaffer and Reichenbach. The top row indicates tests fired at 815C / 1500F for 1 hour, producing a higher opacity, versus the bottom row fired at 787C / 1450F for 1 hour, producing a more glossy, transparent surface.

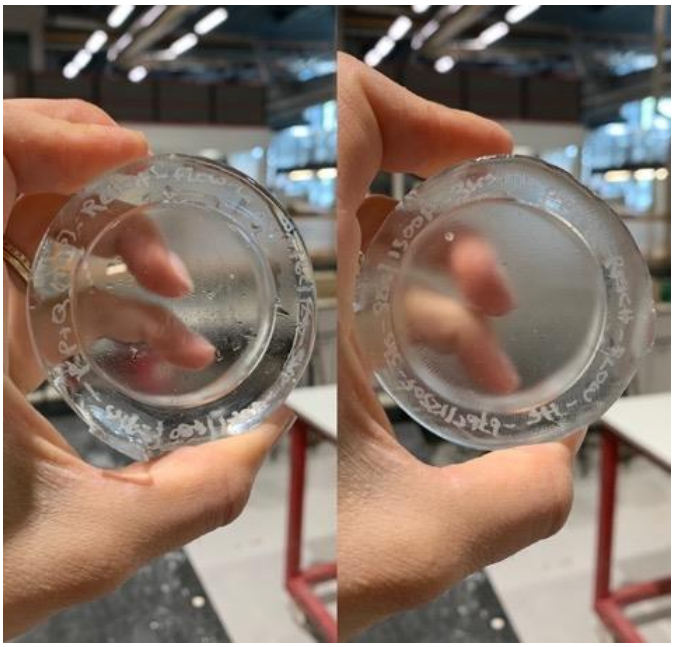


Figure 39. Difference in surface opacity between Reichenbach fired at a low temperature (left) versus the same glass fired at a high temperature (right).

The flow tests confirmed that the Cristalica cullet could not flow adequately and fill the moulds at a high firing temperature of 815°f / 1500°f (Figure 40). Heavy veiling and surface devitrification interfered with the glass's optical clarity. Cristalica was eliminated from testing due to inferior results but was reintroduced into phase 3 using a hot-billet glass process. It was observed that the Bullseye tests needed an extra hour to flow and fill the moulds at 787°C / 1450°F. For these reasons, all subsequent refractory moulds were fired for 2 hours at the lower processing temperature.

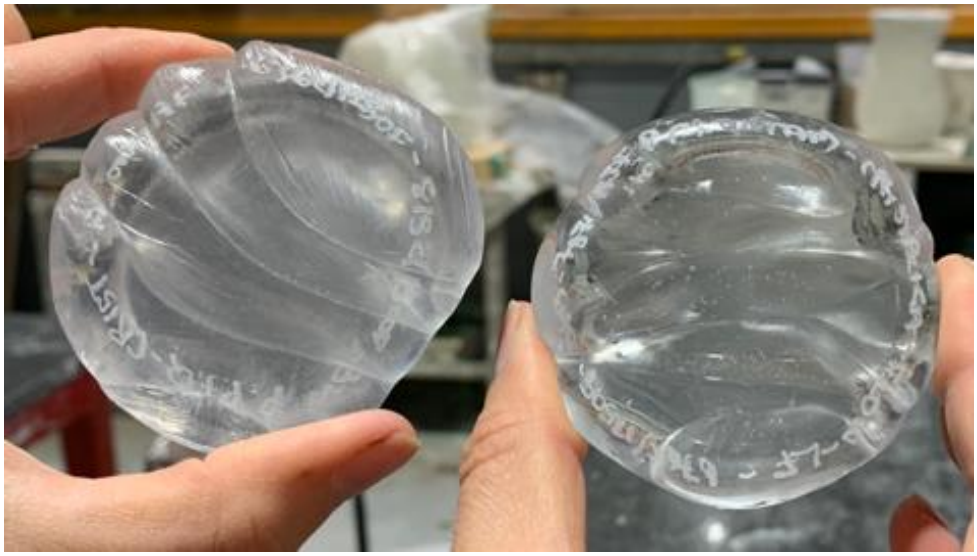


Figure 40. A closer inspection of the flow tests using Cristalica Cullet: The piece on the left shows the test fired at 815 °C / 1500 °F for one hour, versus the test on the right fired at 787C / 1450 °F for 1 hour.

Flow tests confirmed that firing glass at a lower temperature produced greater translucency in all tests than its high-fired counterparts. Overall, Reichenbach achieved the greatest translucency in surface, followed by Gaffer and Bullseye. Although the cast surface of the low-fired Cristalica test appears

smooth and semi-translucent, it was difficult to visually compare it to others due to its rippled exterior.

3.3.5 Further Heat / Duration Testing to See if Variables Affect Surface Opacity and Flow

Although previous testing showed that firing glass at lower temperatures produces less opacity and texture on cast glass surfaces, it was important to determine whether the hold duration at peak firing temperature affects surface transparency. Bullseye and Reichenbach were held at 765 °C / 1410°F and 787°C / 1450°F for 6 and 12 hours, respectively, for these reasons. The outcomes are shown in Figure 41.

Both glasses exhibited distinct shifts in surface opacity when fired to 765 °C / 1410°F for 6 and 12 hours. The tests held for 12 hours had cloudier, semi-opaque surfaces compared with the tests held for 6 hours at the top temperature. The glasses fired at 774 °C / 1425°F and 787 °C / 1450°F for 6 hours showed no significant differences in surface quality. This may be due to the temperatures still being relatively low.

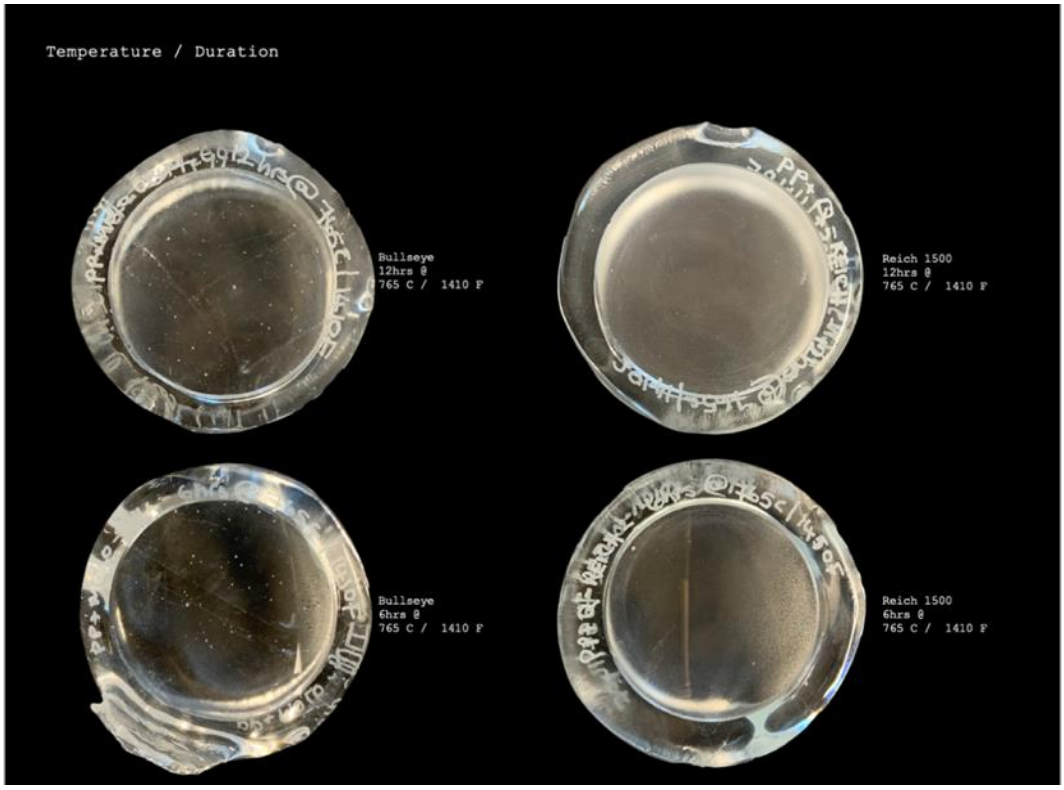


Figure 41. Effect of firing temperature and duration on Bullseye and Reichenbach tests when fired for 6 and 12 hours at 765 °C / 1410°F and 787 °C / 1450°F.

Varying the mould shape, size, and glass body requires different firing temperatures and durations to ensure the mould fills successfully. It, therefore, makes it impossible to suggest an optimal firing program that fits all situations. Carrying out temperature/duration tests demonstrates that lower temperatures and shorter durations will produce optimal surface transparency in the finished casting. A balance must be struck between pursuing surface quality and successfully filling the mould within any given project.

3.3.6 Refractory Mixes

Four different gypsum plasters: pottery plaster (beta / mesh:120), Herculite No. 2 (50:50 alpha: beta/mesh: mixed), Dental SP (alpha/mesh: not stated) and Crystacal R (alpha/mesh: 230) were mixed with an equal volume of quartz made by Sibelco (mesh: 600) or molochite (mesh: 120) and water. Pottery plaster was tested with molochite in place of quartz, along with an adapted face-coat recipe suggested in ‘Mould Making for Glass’ (Thwaites, 2019) that utilises 6.13% kaolin with keramicast plaster and quartz.

GRS Glass Casting Investment's ‘Crystalcast’ was also tested at the ratios suggested by the manufacturer, along with Ransom and Randolph products, 910, 50/50, and Multi-Vest investments. It is important to note that Cristalica is a glass body, Crystacal R is a fine gypsum plaster, and Crystalcast is a commercially made investment material. These products sound similar but should not be confused with one another.

The full list of investments tested is outlined below:

<u>50/50 Powder Ratio Mixes – 1:1:1 by volume (Binder: Refractory: Water)</u>

50% Pottery Plaster: 50% Quartz: 50% Water

50% Herculite No. 2: 50% Quartz: 50% Water

50% Crystacal R: 50% Quartz: 50% Water

50% Dental SP: 50% Quartz: 50% Water

50% Pottery Plaster: 50% Molochite: 50% Water

Thwaites Recipe (Thwaites, 2019)

47.8% Keramicast Plaster: 46.01% Quartz: 6.13% Kaolin: 50% Water

Commercial Mixes

100% GRS Crystalcast Investment: 32% Water (mixed by weight)

100% R&R 910 Investment: 28% Water (mixed by weight)

100% R&R 50/50 Investment: 50% Water (mixed by volume)

100% R&R Multivest Investment: 12% Water (mixed by weight)

3.3.7 Glass vs Refractory: Fired Results

When analysing the surface finish of the tests comparatively, it was evident that the Reichenbach crystal gave the most transparent, refined surface compared to the Gaffer and Bullseye. It was difficult to identify clear differentials in surface quality using varying plasters. However, pottery plaster/quartz gave a marginal surface improvement when using Reichenbach.

Gold and bronze stripes on the top and bottom of the Reichenbach test cast with the *Thwaites* recipe were evident after mirroring. The marks were present in the exact areas where the cut billets had been placed before firing. Devitrification caused by the addition of kaolin in the investment formula may have produced these colour variations, which were not present in other tests.

Thwaites notes that kaolin at 3-5% concentration can prevent refractory from sticking to the glass, whereas higher concentrations can lead to devitrification (Thwaites, 2019).

The following images show the differences between Reichenbach (Figure 42), Gaffer (Figure 43), and Bullseye (Figure 44) when unmirrored (top row) and mirrored (bottom row). Red arrows highlight tests with superior translucency and reflectivity in each group. Ultimately, these comparisons show that Reichenbach 1500 delivered consistent, superior surface translucency.



Figure 42. Un-mirrored (top row) and mirrored (bottom row) tests using Reichenbach glass in phase 1 of studio testing. Red arrows show distinct differentials in surface effects.



Figure 44. Un-mirrored (top row) and mirrored (bottom row) tests using Gaffer glass in phase 1 of studio testing. Red arrows show distinct differentials in surface effects.



Figure 43. Un-mirrored (top row) and mirrored (bottom row) tests using Bullseye glass in phase 1 of studio testing. Red arrows show distinct differentials in surface effects.

Although Gaffer crystal proved to have the best fluidity at low temperatures, its surface quality was less translucent than Reichenbach's. Most tests have a whiter surface opacity with varying pottery plasters and quartz; however, superior translucency was evident in the pottery plaster/molochite and Thwaites mix tests. Reichenbach crystal was prioritised in future tests over Gaffer for its superior surface quality, while Bullseye soda-lime glass was prioritised over Cristalica for its flowability in phase 2 of testing.

The densest surface opacity was observed in the Bullseye glass tests (Figure 44); however, a markedly improved, translucent finish was achieved in the pottery plaster and molochite tests (far right) and in the Thwaites recipe test (far left). The remaining investment mixes left an opaque, uneven surface on the glass, resulting in a contaminated silver coating. These coatings have various cream and beige tones with darker grey/black striations, and do not possess any reflective qualities.

Although the Cristacal R plaster-based refractory moulds produced an opaque white residue on the surfaces of all glass tests, they consistently yielded a smoother, more refined surface finish than the others. Based on these results, comparative tests were conducted using lead crystal glasses (Gaffer and Reichenbach) cast in moulds made from Cristacal R: Quartz and Pottery Plaster: Quartz mixtures. These castings were then subjected to hydrofluoric and sulfuric acid polishing, a treatment known to react with the

lead content in crystal glass, enhancing surface gloss and transparency. Given Cristacal R's fine particle size and structural strength, it is likely that its use contributes to surface smoothness. Consequently, the crystal cast in this plaster may offer optimal reflectivity once chemically polished and prepared for mirroring, due to minimal surface texture resulting from high firing temperatures.

It is important to note that hydrofluoric/sulphuric acids attack the surfaces of lead-bearing glasses, smoothing the surface but also exaggerating crevices. In previous practice, fine, wavy lines on the surfaces of chemically brightened core-cast glass objects were noticed after polishing. This resulted from slight indentations (originally unnoticeable by the naked eye) left from several billets of crystal melting together within a mould to cast a single form. These minor crevices became deeper and more evident after acid polishing.

Chemically polished crystal tends to exhibit a slightly mottled, 'plastic-like' surface quality, which is arguably less visually appealing than the crisp, defined finish achieved through manual polishing with abrasive equipment. For this reason, the external surfaces of cast objects were reworked using linishers and grit wheel machines following acid polishing. Chemical polishing was primarily employed to brighten internal cavities formed by investment cores, areas that were either physically inaccessible for manual polishing or at risk of effacing detail. Nevertheless, all external surfaces of the crystal

forms were consistently cold worked to restore visual clarity and surface refinement.

Acid polishing was carried out on a Reichenbach sample using a Pottery Plaster / Quartz mould (Figure 45) and a Reichenbach sample made with a Cristacal R/Quartz mould (Figure 46). The Pottery Plaster test already looked to have a more granular surface compared to the Crystacal test due to using different plasters. The finished tests after chemical polishing and silvering can be seen below.



Figure 46. Pottery Plaster / Reichenbach Test (Acid Polished / Mirrored)



Figure 45. Crystacal R / Reichenbach Test (Acid Polished / Mirrored)

As demonstrated in Figures 45 and 46, the Cristacal R/Reichenbach test produced a noticeably more refined reflection compared to the Pottery Plaster/Reichenbach test. The influence that plaster compositions have on surface smoothness, and consequently on reflectivity after mirroring, is, in some cases, significant and visually striking.

3.3.8 Goldstar Powders Pro HT Platinum (Phosphate Bonded Investment) / Boron Nitride Tests

When trialling a suitable refractory to cast calcium phosphate glasses for cast glass dentures, Kobayashi and Manabe found that phosphate-bonded refractories with a 10-30% addition of boron nitride (hBN) in a mould face coat yielded higher shine and surface precision than glasses fired in gypsum (plaster)- based refractories.

They state, ‘gypsum bonded investment vigorously reacts with the calcium phosphate type glass at a temperature of about 700°C to discharge SO2 gas’, thus causing air bubbles, lack of overall strength, and reactivity between the investment and glass. This causes divestment difficulties and ‘low-dimensional precision’ (Kobayashi and Manabe, 1986).

This study investigated the use of phosphate-bonded refractories with varying boron nitride concentrations. It was thought that combining these materials would improve the cast glass's reflective properties after mirroring. ‘Pro HT Platinum’, a phosphate-bonded refractory made by Goldstar Powders, was sourced and mixed in its dry state with hBN to create a face coat in the silicone positive of the optical flat lens.

A hBN powder with a particle size of 5 microns was sourced from Hagen Automation, UK. The powder is fluffy and light, resulting in a high volume-to-

weight ratio compared with the 250/325-mesh pottery plaster and quartz used for investment mixes in prior testing. Therefore, a higher volume of di-ionised water was required to mix 30% hBN by weight with Pro HT Platinum to create a liquid that could be easily brushed onto the mould.

The Pro-HT Platinum/hBN tests were conducted using the same clay wall mould setup as in previous trials. However, the moulds exhibited severe cracking during the divestment of the silicone positives (Figure 47). According to technicians at Goldstar Powders, Pro-HT Platinum requires curing within a metal flask to achieve full structural strength. While commercially manufactured metal flasks, commonly used in centrifugal casting in the jewellery industry, may provide the necessary containment, their use is limited for glass casting. Specifically, they limit the scale and complexity of cast forms and are prone to damage when silicone positives are removed, making them unsuitable for larger or more intricate kiln-formed glass applications.



Figure 47. Failed moulds using Pro HT with HbN (unable to achieve strength through not using a metal flask for containment).

Some of the cracked Pro HT/Hbn moulds were salvaged and cast despite inherent weaknesses; however, all resulting glass tests adhered strongly to the investment (Figure 48), resulting in black-contaminated mirror coatings when silver nitrate was applied.



Figure 48. Plaster / Quartz and Boron Nitride (Powder) Tests

Due to setbacks resulting from reduced mould strength when using the phosphate-bonded investment, additional tests were conducted using boron nitride (hBN) at concentrations of 10%, 20%, and 30% mixed with pottery plaster and quartz for the face coat. These were supported by a standard 1:1:1 backing mix of pottery plaster, quartz, and water by volume.

A higher volume of de-ionised water was required to mix the powders into a brus-hable state, given the volume of the hBN powder. The amount of water

was kept to a minimum to prevent loss of strength. The percentage of each investment ingredient can be seen below:

30% hBN: 35% Pottery Plaster: 35% Quartz: 30% hBN: 74% Water

20% hBN: 40% Pottery Plaster: 40% Quartz: 20% hBN: 66% Water

10% hBN: 45% Pottery Plaster: 45% Quartz: 10% hBN: 50% Water

All of the mould ratios listed above could withstand the divestment of the silicone-mould positives with compressed air, however, some minor chips of investment came away from the edges of the hBN face coat applied to the 'core' area of the refractory moulds. This was more pronounced in the 30% hBN moulds, which were likely the result of decreased binder (plaster) to accommodate a higher hBN content, along with excess water needed to mix the investment to a liquid consistency.

The hBN:plaster: quartz moulds were subjected to the same pre-fire schedule and firing temperature as previous tests. The moulds adhered strongly to the glass (Figure 49), regardless of hBN content, leaving a distinct white coating that resulted in a black, contaminated mirror after the silvering process. Due to these setbacks, further tests would be performed using a purer-grade hBN powder supplied by Zyp Coatings in conjunction with 'Multi-Vest', a phosphate-bonded investment made by Randsom and Randolph as a face coat with a pottery-plaster: quartz investment backing. This would determine if

differentials in hBN and phosphate-bonded investment can glean better results.

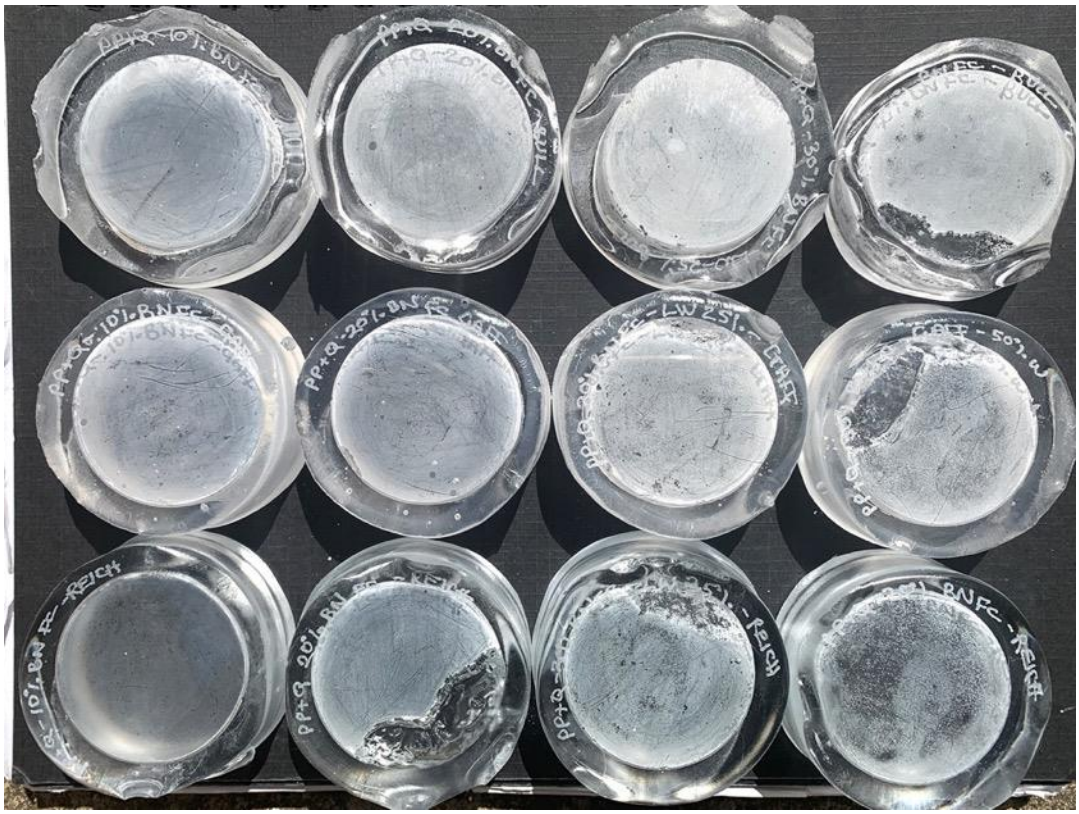


Figure 49: Image of Bullseye (top row), Gaffer (middle row), Reichenbach (bottom row) fired in plaster/quartz moulds with the addition of hBN in percentages of 10, 20 and 30% (low water content) and 30% (high water content).

3.3.9 ZYP Coatings (Phase 1: Product Testing)

ZYP Coatings Inc. specialises in boron nitride coatings that are stated to be "non-wetting to molten metal and act like a high-temperature version of TEFLON" (*ZYP Coatings - World Leader in Boron Nitride Coatings*, no date). These specially engineered coatings are said to produce superior finishes on a range of mould-formed materials, including glass and metal.

The company manufactures boron nitride-based aerosols and brush-able release agents, primarily for kiln-formed glass (slumping and fusing). These are formulated for a firing range of around 650°C – 700°C / 1200°F – 1300°F, temperatures that are too low for enclosed moulds, which require higher casting temperatures to reach full fluidity. Casting temperatures are typically between 787°C and 871°C (1450°F and 1600°F), depending on the glass body used.

ZYP Coatings Inc. supported this research with material concessions to ascertain if their products would enhance the transparency of glasses cast at higher firing temperatures. Experimentation of this kind had yet to be carried out and would be of value to the glass-casting community at large. Five hBN coating samples commonly used in metal and ceramic industries, ‘Type ZO, BN Lubricoat ZA Paste, BN Lubricoat Paste, BN Lubricoat ZS and ZBN Release, along with 4kg of pure-grade boron nitride powder, were donated for this research.

Zyp Inc. hBN coatings cannot be combined with the lost wax casting method. Excess heat and water will weaken the coatings, flake off, and reduce performance due to contaminants introduced by the water supply. Ways of counteracting this include using silicone positives for open-face moulds (as seen in phase 1 testing) and applying the coatings to pre-fired moulds (Figure 50). If creating enclosed ‘core’ moulds, in which the core is held within a

refractory mould with a sprue reservoir, cores should be pre-fired separately, sprayed with the Zyp coating, and invested into a multi-part refractory mould under tension. More about this process will be discussed in 3.5 ‘Phase 2 Material Testing – Moulds in the Round’.



Figure 50. Open-face refractory moulds and Zyp Coating products are ready for application.

Gaffer, Reichenbach, and Bullseye glasses were cast in open-face lens moulds painted with Zyp Coating products. Following the pre-dry firing schedule, the surfaces of the refractory lenses, made from a 1:1:1 mixture of pottery plaster, quartz, and water by volume, were coated with three layers of ZYP boron nitride paste, each diluted with 15% deionised water by weight.

The application was carried out using a soft, flat brush. Each lens core was pre-wetted with two to three liberal coats of deionised water before applying the boron nitride paste. This facilitated even coverage and prevented the coating from forming chalky streaks or beading due to rapid absorption into the dry refractory.

BN Lubricoat ZA Paste (BNZA) exhibited a poor performance among the 5 coatings. The material stuck to the surfaces of all 3 glasses, causing a black, contaminated mirror coating. ZBN Release (ZBN) ranked second to BNZA for poor results due to sticking, which created a black, contaminated mirror. Improved surfaces were seen in the Reichenbach tests. See Figure 51 for visual comparisons.

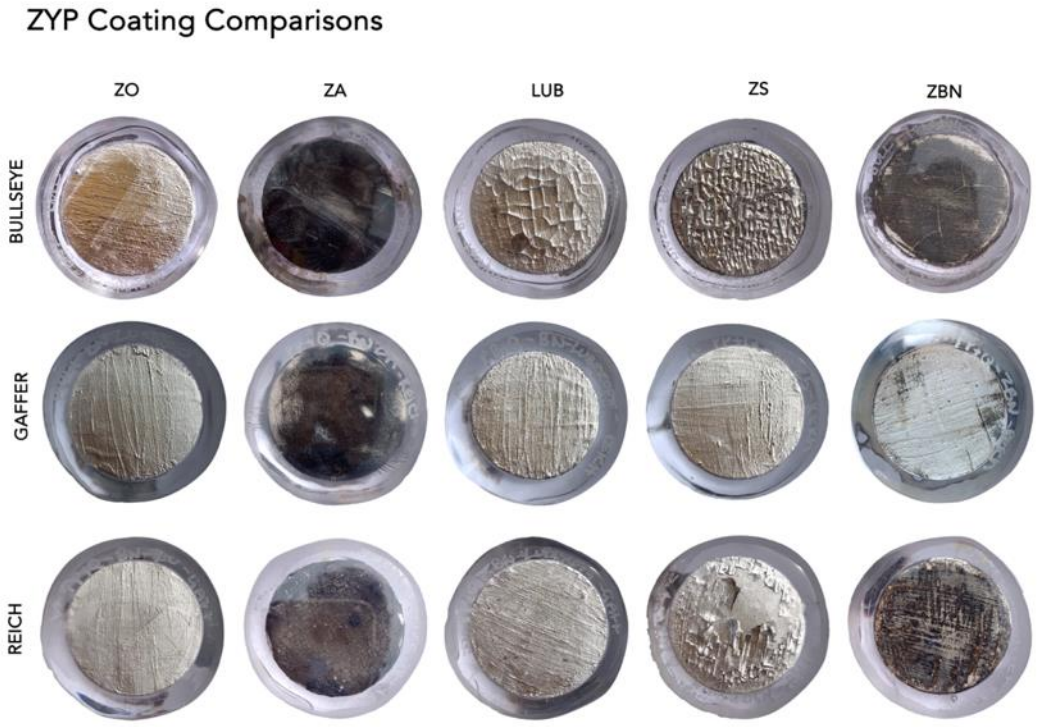


Figure 51. Open-Face Tests using ZYP Coatings with Bullseye, Gaffer and Reichenbach.

Promising results were observed across all three glass types, Reichenbach, Bullseye, and Gaffer, when using BN Lubricoat-ZS (BNZS), BN Lubricoat (BNLUB), and Type ZO (BNZO) coatings. Both the Reichenbach and Bullseye tests produced a bright, iridescent silver surface with a non-reflective finish, while the Gaffer samples yielded slightly duller results. Several tests showed a cracked surface, most prominently in the BNZS samples. This was attributed to the thickly applied boron nitride paste, which cracked during the firing, thus leaving visible impressions on the glass surface (Figure 52).



Figure 52. A cracked surface effect on Gaffer glass caused by a thick application of ZYP BN ZS coating on a dry pottery plaster/quartz mould.

Consistent with earlier test results, Gaffer glass produced slightly duller mirrored surfaces when used with boron nitride coatings than Reichenbach. While Bullseye had previously yielded poorer surface finishes, it demonstrated noticeably brighter silver mirror when cast with BN coatings. As a result, Bullseye has been selected for continued testing in Phase 2 for boron nitride applications.

Further testing was deemed necessary using BN Lubricoat (BNLUB), Type ZO (BNZO), and BN Lubricoat – ZS (BNZS), with controlled application methods using both brush and spray gun, to determine whether thickness and application method influenced surface irregularities. In addition, exploratory tests were conducted to assess the potential for creating painterly effects by applying text directly to the mould surface with hBN coatings. This approach aimed to exploit the contrast between the matte surface resulting from direct glass contact with untreated investment and the more reflective areas created by the hBN coating, thereby introducing a new aesthetic within cast mirror surfaces.

3.3.10 ZYP Boron Nitride Coatings (Phase 2: Thickness and Application)

To identify the threshold at which surface cracking or crazing occurs due to the thickness and method of hBN coating applications, a second round of

tests was conducted using BN Lubricoat, BN ZO, and BN ZS. Each coating was applied in one to three layers with a soft brush, and an additional set was applied using a compressed-air spray gun. A further variation involved painting the word ‘magic’ with the hBN coating in tandem with the mould’s raw surface. Bullseye and Reichenbach glass were used exclusively for this round of tests. Five distinct application methods using three hBN coatings yielded 30 individual tests using two glasses.

The Bullseye tests fired with one coat of hand-painted BN-Lub and BN ZO created similar mirrored results, while BN ZS stuck to the surface, causing white contamination marks in the mirror. Reichenbach combined with BN-Lub gave the clearest results, with some surface opacity seen with BN ZO and some surface sticking occurring between the coating and glass surface using BN ZS.

Surface crazing and cracking resulting from the residual impregnation of hand-applied coatings was observed around the edges of the two-coat BN-Lub tests using Bullseye glass (see Figure 53). In contrast, full-surface cracking was evident in samples with three hBN coats. Minor surface cracking also appeared in the three-coat BN ZS test using Reichenbach glass. These results indicate that thicker applications of ZYP coating products are more prone to surface cracking during firing, which leads to impressions on the finished glass surface.



Figure 53. Bullseye test with thick application of BN ZS

No surface sticking or cracking occurred during tests using a compressed-air spray gun for the hBN application. The three Zyp-coatings were diluted with 10% di-ionised water by volume, the maximum dilution advised by Zyp-coating Inc. to avoid reducing the coating's performance. Even at a 10% dilution, the coatings remain relatively thick, resulting in a grainy surface texture reminiscent of a 60-grit-polished piece of glass that retains a shiny clarity rather than being opaque (Figure 54).

Overall, the Bullseye test using BN-Lub had the best translucency and mirror reflectivity compared to Reichenbach. However, all three coatings exhibited a shiny appearance. Reichenbach tests revealed a slightly opaque/matte finish, likely due to a reaction between the glass's lead content and the coating suspension's ingredients.



Figure 54. Un-mirrored Reichenbach test with spray application of BN ZO made by Zyp Coatings Inc.

The hand-painted BN ZO test, in combination with the natural, untreated surface of the mould, produced a pronounced contrast when using Bullseye glass with an investment composed of pottery plaster and quartz. This particular investment composition has previously been shown to yield a dense, white opaque surface when used with Bullseye. Following the mirroring process, raised, reflective marks became visible against a matte grey background (Figure 55). The mirrored surface appears to be painted onto the glass, a technique referred to here as ‘mirror-drawing.’ This represents a novel method for achieving hand-rendered mark-making with cast-glass mirrors.



Figure 55. Un-mirrored (left) and mirrored (right) Bullseye test using hand-painted BN ZO

3.3.11 Further Testing with ZYP Coatings

While this section of the thesis primarily outlines the step-by-step progression of studio testing, insights gained during Phases 2 and 3 prompted a return to earlier investigations involving ZYP coatings and open-face moulds. A pivotal moment occurred during the mirroring of an enclosed casting produced in Phase 2, in which Bullseye glass was cast into a core mould coated with BN Lubricoat (see Section 3.5.2, *Applying Mirror Coatings to Enclosed Castings*). The glass surface exhibited a high degree of reflectivity, clear enough to reveal a distinct reflection of a viewer. A new batch of BN Lubricoat was purchased and used on a scaled-up test using a core detail of a magpie encased within a glass dome (see Section 3.7, *Phase 3 Testing: Magpie Domes*).

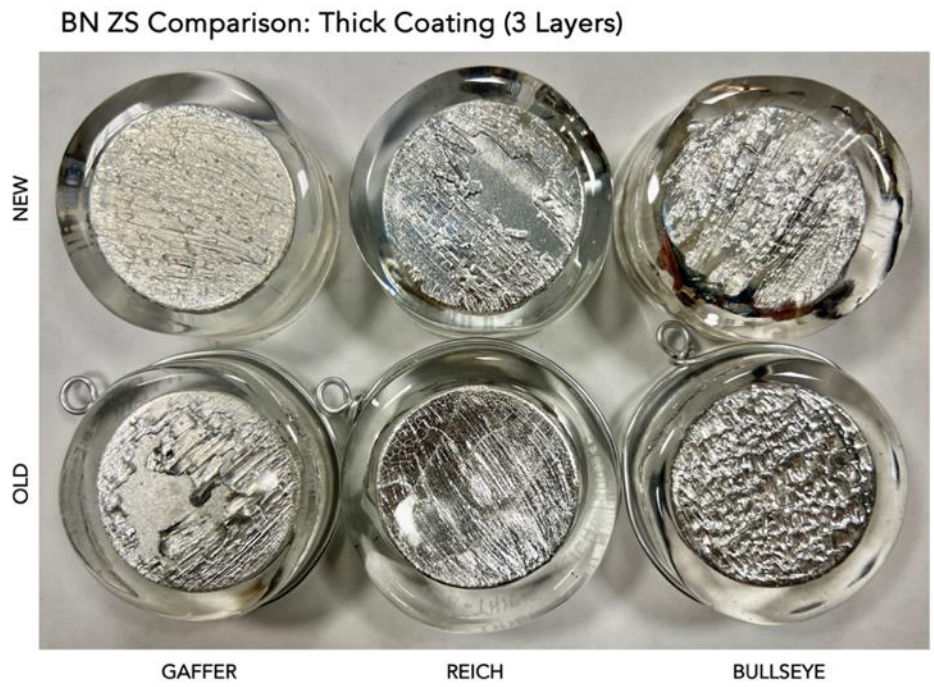
BN Lubricoat was strategically applied to one wing of the magpie core (pottery plaster and molochite), while the remaining surface was left untreated. Following firing, divestment, and the application of the mirror coating, the Bullseye glass casting exhibited an opaque black surface in the area where BN Lubricoat had been applied (Figure 87). This result indicated significant adhesion between the glass and the hexagonal boron nitride (hBN) coating, a stark contrast to the bright, reflective surface observed in the Phase 2 test, where no such interaction occurred.

The shelf life of hBN ZYP coatings can significantly impact their performance. Some of the samples tested in 2021 were several years old. For instance, the BN Lubricoat sample had a production date of 08.12.2016, while the new batch was produced on 06.21.2023. This age discrepancy prompted a re-evaluation to confirm that the superior performance observed with the initial sample was not due to its age, but rather a consistent characteristic of the product.

ZYP Coatings supplied new samples of hBN Type ZO (produced 10/18/22), Lubricoat ZS (produced 08/14/23), and BN Lubricoat (produced 08/22/24), as well as two additional formulations: 'BN Glass Release Spray', provided in a non-aerosol spray, and 'DMX Powder', which requires mixing at a 1:9 ratio with isopropyl alcohol. To evaluate their performance, fifteen new tests were

conducted, applying these coatings to moulds fired with Reichenbach, Gaffer, and Bullseye glass.

The BN ZS coating exhibited significant cracking in all three tests (Figure 56), whereas minor cracks were observed in the BN Lubricoat tests (Figure 57). In contrast, the Type ZO (Figure 58), DMX, and Spray Release coatings (Figure 59) demonstrated durability, with no visible cracking. The mirrored results, presented in Figures 56-69 below, were consistent with those from previous tests using the same products. ZYP Coatings Inc. has expressed uncertainty regarding the inconsistencies observed with the large batch of BN Lubricoat. Based on these findings, it is recommended that all products be tested before casting larger pieces to ensure consistent and successful results. The tests fired with DMX Power proved to be the most durable and produced the best transparency and reflectivity across all three glasses, with slightly superior results for Bullseye glass. See Figures 59 and 60.



BN

Figure 56. BN ZS (ZYP Coatings Inc.) using old and new batches with Gaffer, Reichenbach and Bullseye



Figure 57. Lubricoat (ZYP Coatings Inc.) using old and new batches with Gaffer, Reichenbach and Bullseye



Figure 58. BN ZO (ZYP Coatings Inc.) using old and new batches with Gaffer, Reichenbach and Bullseye.

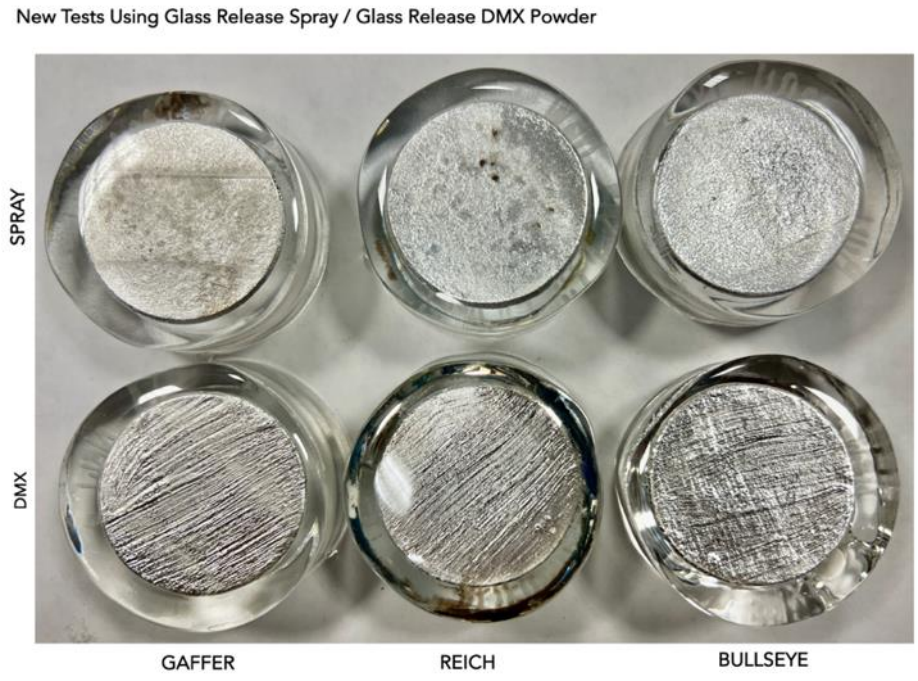


Figure 59. Open-face test using Bullseye glass (left) with DMX coating (right)



Figure 60. Glass Release Spray / DMX Powder (ZYP Coatings Inc.) batches with Gaffer, Reichenbach and Bullseye

3.3.12 Commercially Produced Investment Mixes used in Testing

Given the number of artists in the UK and the United States who utilise commercially mixed investment powders for specific properties, such as mould strength, high-temperature resistance, permeability, and surface reproduction, it was valuable to test several leading brands in this research. The aim was to assess whether these products could produce superior, translucent surface finishes on cast glass, thereby enhancing reflective results after silvering.

Commercially mixed investments are convenient because they only require adding water to form a liquid, unlike hand-mixed recipes. However, the high cost of these materials, including shipping fees, is a significant consideration

when compared to the more economical option of hand-mixing raw ingredients. For these reasons, testing was limited to three commercially mixed products, using Reichenbach and Bullseye glass. These products are listed below:

- Glass Casting Crystalcast (Gold Star Powders, UK)
- Glass Cast 910 Investment (Randsom and Randolph, USA)
- Mold-Mix 50/50 Investment (Randsom and Randolph, USA)

Crystalcast is celebrated for its mould strength, surface reproduction and finish. Gold Star Powders' website boasts that its powders can withstand temperatures up to 900°C / 1652°F for up to 10 days, depending on the mould size. Mixed at a water-to-investment ratio of 32:100, the investment should cure for 3 hours before steaming and should not be steamed over long periods, as this will cause surface erosion and mould weakness.

Glass Cast 910 is used predominantly by artists for its mould strength. Randsom and Randolph state it to be the 'strongest mould material available for glass casters on the market today'(*Ransom & Randolph | Glass-Cast 910 investment*, 2022). Mixed to a water-to-investment ratio of 28:100, the product can be applied in layers as a hand-built mould or by the 'poured' technique using a flask to retain the investment. One great attribute of Glass Cast 910, is that it can retain good strength when applied in thin layers to small, intricate

forms, thus allowing the heat to penetrate the mould easily and ensure glass flow. Glass Cast 910 can be fired to a maximum temperature of 838°C / 1540°F, and as with Crystalcast, the product is eroded and weakened by steaming over long periods.

Mold-mix 50/50 has similar properties to a regular 50/50 plaster/quartz recipe and is mixed as 1:2 water-to-investment ratio. Artists use this product for ease of use. The investment is thoroughly mechanically mixed to ensure an even distribution of ingredients, with gypsum as the setting agent.

The surface qualities of the mirrored tests using the three commercial investment materials using Reichenbach and Bullseye glasses were not superior to those achieved with some of the hand-mixed investments used in earlier trials. Specifically, molochite with pottery plaster, as well as the Thwaites recipe, produced a shinier mirror finish when cast with Bullseye and Reichenbach. However, it is acknowledged that commercial products offer superior strength to these hand-mixed formulas and may yield better results when applied to curved forms rather than flat planes.

3.3.13 Reichenbach C1500 versus C1800

In 2021 Farbglashütte Reichenbach GmbH, the manufacturer of Reichenbach crystal took over the production of Gaffer glass, producing and distributing its range in 2022. Farbglashütte Reichenbach ceased producing its clear C1500

40% lead crystal (3.6 g/cm³) due to increased marketing demand for Gaffer G210 (clear) and opted to produce C1800, a clear crystal with a lower 15% lead content (2.8 g/cm³).

Although Farbglashütte Reichenbach indicated that C1500 could be produced with a minimum order of 200kg, it was deemed important to test C1800 as well to compare its cast surface quality. A series of open-face tests were conducted, melting 15% C1800 lead crystal into open-face lens moulds made from various investment mixes, following the same firing schedule as in previous tests. When mirrored, the surface quality of C1800 exhibited a deeper, mottled hue in contrast to the bright silver mirrors produced with C1500 (40% lead). C1500, however, demonstrated superior translucency and less interaction with the investment moulds, resulting in a higher-quality surface finish when cast.

The following section outlines the process of mirroring cast glass, in which a series of chemicals is applied to divested, cleaned glass, resulting in a thin layer of silver deposited on the glass, which, if transparent and smooth, will create a reflection.

3.4 Mirroring Cast Glass Using the Chemical Silver Deposition Method

Mirroring glass can be challenging, especially when striving for reflective qualities on cast surfaces that can be textured and/or opaque. During the casting process, molecular interactions between the investment materials used to form the mould, high firing temperatures, and the glass's composition contribute to varying degrees of adhesion between the glass and the mould. This adhesion often results in a semi-white surface layer that can contaminate the mirror finish upon application of a silver nitrate solution. Even when mirroring pristine, transparent blown or sheet glass, the surface must remain free of impurities, as they can cause tarnishing and degradation.

The process requires different considerations in both preparation and technique compared to blown or sheet glass. Mirroring techniques fall into two distinct categories: the ‘spray’ method, in which chemical agents are applied to the glass using a compressed-air gun or a hand-pressurised spray. This method is common practice for sheet-glass mirrors, where the glass area to be silvered is exposed and accessible.

The ‘pouring’ method is used for silvering vessels when access to the internal surfaces is limited. The process involves pouring a series of silvering chemicals into the glass vessel and manually agitating/rotating them over the

interior surface. This is the method commonly used for blown-glass mirrors and for mirroring the core-cast glass objects in this research.

Commercial mirror-makers position the glass within a spray booth with adequate extraction to remove harmful vapours; however, a chemical cartridge respirator, along with chemical-resistant gloves and eye protection, must always be worn when performing any mirroring process.

The glass must be meticulously cleaned and rinsed with de-ionised / distilled water before applying a layer of tin salt stannous chloride solution ‘tin for silver’, which enables metal crystallisation. After coating the glass surface with the tin solution for 30 seconds, the glass is rinsed again with distilled/de-ionised water before applying a chemical cocktail made in equal parts of ‘silver solution’ (silver nitrate and ammonium hydroxide), ‘reducer’ made of inverted sugars (dextrose or fructose), hydrazine or gluconates, and an ‘activator’ (sodium hydroxide).

The chemical solution is agitated and evenly dispersed across the glass surface, changing from transparent glass to dark purple/black before finally reaching silver. Depositing takes 2-5 minutes, depending on the size and complexity of the surface area. After the silver deposits, the waste chemicals are poured into a bucket/container for future treatment to remove heavy metals. The glass is rinsed again with de-ionised water, then a second

coating of the three silvering solutions is applied, followed by thorough rinsing and drying. A strong air-drying backing paint that is suitable for protecting mirrors (available through A.P. Nonweiler in Wisconsin, USA) is then applied to the dried silver to prevent corrosion.

Residual minerals from tap water during cold working can deposit on the glass, making them difficult to remove. Several companies selling mirroring chemicals, such as Peacock Labs (USA) and Angel Gilding (USA), market cleaning solvents to remove impurities; however, stubborn residues may require multiple attempts to remove.

It is frustrating when dark spots emerge from a mirror coating on a cast glass surface. It means that there are contaminants, perhaps grease or impurities left from the casting process, that are embedded and a ‘given’ in creating inconsistencies in the mirror coating or are dissolvable by using cleaning agents. Either way, striving to remove blemishes is a taxing process of stripping the silver away with chemical silver removers and re-cleaning before starting the silvering process again.

3.5 Conclusion: Phase 1 Testing

The initial goal of this research was to identify the factors, both material and environmental, that would produce a fully reflective cast glass mirror. While this objective remains central, the research has shifted to explore a diverse

range of silvered surfaces. These effects transform the mirror from a fully reflective plane to one that mimics the appearance of other materials (see Figure 61). These tests are viewed as a palette with endless possibilities for artists, makers, and designers to incorporate into their practices.



Figure 61. Varying surface qualities seen in open-face testing

Through Phase 1 of testing, it became clear that no single method or ingredient consistently produces uniform cast surfaces or mirror qualities across all glass bodies. Variations in factors such as the base model, glass volume, or firing temperature, for instance, can lead to drastically different results. This variability should always be considered when attempting to replicate or adapt the processes explored in this research.

The results of Phase 1 testing are summarised in the following list:

- Variables must be kept to a minimum to obtain consistent results. For example, using de-ionised water for investment mixes, using the same kiln and investment ingredients.
- Avoid using the lost wax casting process by using silicone positives for open-face moulds. Steaming investment moulds to remove wax causes rougher surface textures due to erosion on the mould, which transfers onto the glass cast surface.
- Use a smooth object as a base model to create investment cores to achieve smooth surfaces on cast glass.
- Surface textures and a semi-opaque film on the glass left from the interaction of glass with its investment mould at high temperatures decrease the reflectivity of the glass when silvered.
- Pre-firing investment moulds reduces de-vitrification caused by the interaction of glass with its investment mould at high temperatures.
- Pre-firing investment moulds reduces overall mould strength.
- Firing glass at lower top firing temperatures prevents glass from sticking/reacting with an investment mould compared to firing at higher temperatures. This leads to higher translucency and reflectivity when silvered.

- Holding an investment mould at 676C/1250F for 2-4 hours prior to coming up to top temperature will help glasses with a high viscosity flow into a mould at lower casting temperatures.
- Firing glass for shorter durations at the top firing temperature prevents the glass from sticking/reacting with an investment mould, compared to firing for longer durations, even at low temperatures. This leads to higher translucency and reflectivity when silvered.
- Cristalica batch does not flow well at a temperature range of up to 815 /1500F
- Reichenbach 1500 had the best non-reactive/translucent cast surface qualities using all investment formulas compared to Gaffer and Bullseye glasses
- Bullseye glass had the worst reactive/opaque cast surface qualities across all investment formulas except those made with 50% molochite and pottery plaster.
- Reichenbach 1500 (40% lead) has a superior translucent surface finish compared to Reichenbach 1800 (15 % lead)
- The addition of kaolin at 6% by weight with 47% pottery plaster and 47% quartz prevented moulds from sticking to the glass but can cause higher levels of devitrification on the glass surface.
- Refined/fine-mesh plasters such as Crystacal R create smoother surfaces on cast glass while still retaining high surface opacity.

- Loose BN Powders mixed with gypsum plasters or phosphate-bonded plasters severely react and stick to cast glass
- hBN ZYP Coatings BN ZS, BN ZO, BN Lubricoat, Glass Release Spray and DMX Powder can help prevent the wettability/surface sticking of Gaffer, Reichenbach and Bullseye Glasses when applied to an investment mould.
- hBN Zyp Coatings ZBN Release and ZA Paste were severely stuck to all cast glass surfaces, causing heavily contaminated mirrors
- hBN Zyp Coatings BN ZS and BN Lubricoat crack when applied thickly to an investment mould causing glass surface textures
- DMX Power was the most durable hBN ZYP Coating product used in testing, resisting cracking/flaking, and achieved the brightest results with Bullseye Glass
- BN Lubricoat, Type ZO and DMX Powder can be applied to an investment mould with a brush to create a two-tone painterly effect in cast glass mirrors
- There can be inconsistencies between ZYP Coating batches creating different results. This was seen using ZYP BN Lubricoat. A test should always be carried out to ensure desired effects.
- The shelf life of ZYP Coating products can affect performance
- ZYP Coatings are relatively thick and leave surface textures on a mould when applied with an aerosol gun or brush.

- Randson and Randolph 910 and 50/50, along with Gold Star Powders Crystalcast do not give superior mirrored surface finishes compared to other hand-mixed recipes but do increase mould strength when using Crystalcast or 910.
- Acid polishing gives the best reflective/iridescent surfaces on cast lead crystal when mirrored.
- Cast glasses are prone to surface contamination/mottling when mirrored due to residues left from casting/cleaning processes
- The poured mirror method is best for mirroring vessels/dimensional objects.
- A strong backing paint must be applied to a mirror to prevent deterioration.

It was necessary to investigate whether enclosed moulds with a reservoir and sprue would produce variations in the mirrored surface effects observed in Phase 1. Enclosed forms require alternative mould-making strategies and, in some cases, higher firing temperatures to enable the glass to flow more effectively from the reservoir into the complex mould cavities.

Figure 62 shows most open-face tests after divestment, while Figure 63 shows the same tests after the silvering process. Twenty-five of the most visually diverse samples (both reflective and non-reflective) from Phase 1,

including Bullseye, Reichenbach 1500, Reichenbach 1800, and Gaffer glasses, were repeated using an enclosed-mould system (Phase 2). This approach allowed for an assessment of whether the cast surfaces and mirror qualities remained consistent with a different mould setup. While Reichenbach 1500 produced brighter mirrored surfaces than Reichenbach 1800 and Gaffer, Gaffer remained in trials as it is one of the few 40% lead glasses available in the studio-art glass market today.

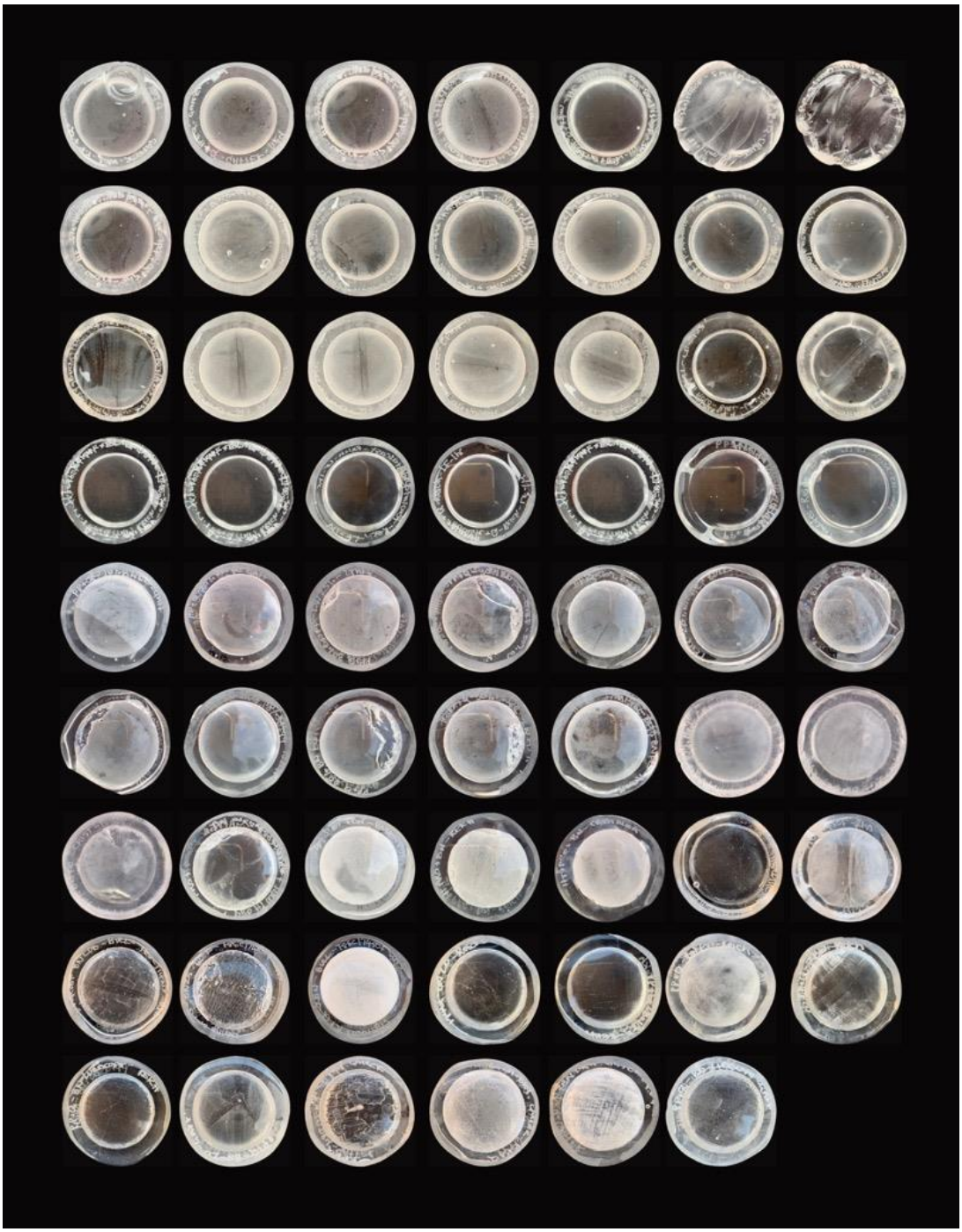


Figure 62. Full Sample Palette (Un-Mirrored).



Figure 63. Full Sample Palette (Un-Mirrored)

3.6 Phase 2 Studio Testing – Enclosed Moulds

3.6.1 Enclosed Mould Set-Up



Figure 64. One side of the ‘tension-set’ investment mould contains a bullet-shaped core painted with hBN coating.

Phase 2 tests were made using the recessed detail of a bullet-shaped, hand-polished piece of glass, enclosed as a core within a cylindrical glass dome. A tension-set process was used, in which an investment mould containing the recesses of the dome and reservoir was divided into two halves and duplicated using rubber ‘mother’ moulds. This process allowed identical moulds to be cast, which were then used to grip and encase the refractory bullet shape without needing wax as an intermediary modelling material (see Figure 64).



Figure 65. Detail image of ‘tension-set’ investment mould containing a bullet-shaped core

A final coating of investment material was then applied to set the two halves permanently for the duration of the firing (Figure 65). Although the process is tedious and time-consuming, it eliminates the need for wax steaming, which can shed off hBN coating applications and corrode the surface of the investment mould.

A greater glass volume was needed to fill the enclosed moulds, which were subjected to a longer pre-firing cycle to ensure that the glass would flow at 787°C/1450°F for 2 hours (the same peak firing temperature and duration used for the open-face samples). After annealing and divesting (Figures 66 /

67), each enclosed sample was cold worked to a full polish to assess the investment core's clarity.



Figure 66. Fired glass during the divestment of the investment mould



Figure 67. Fired glass before divesting the investment core

As with phase 1, the addition of 6% kaolin to 47% quartz and 47% pottery plaster by weight as an investment mix created a good release against the glass, resulting in a more translucent surface finish. Figure 68 shows the fired core next to the glass dome that encased it. Surprisingly, the core slipped out of the glass with ease without needing tooling. Working with cores containing textures and undercuts would not have pulled away as easily.



Figure 68. Intact core removal using ‘Thwaites Mix’ and Bullseye Glass

Figure 69. shows the same test (left) next to a sample fired with Bullseye using a regular 50:50 quartz and pottery plaster investment mould. The contrast in surface clarity with kaolin is significant, and this was observed across Bullseye, Gaffer, and Reichenbach 1500. Figure 70. shows the surface quality of three Gaffer test using the kaolin recipe (left), 50:50 pottery plaster and quartz (middle) and 50:50 Crystacal R plaster with quartz (right).



Figure 69. The variance between investment sticking (left) compared to repelling (right) using Bullseye glass with an enclosed mould.



Figure 70. Three tests using different investment mixes, ‘Thwaites Mix’ (left), 50:50 Pottery Plaster: Quartz (middle), and 50:50, Crystacal R Plaster: Quartz (right) with Gaffer glass.

3.6.2 Mirrored Enclosed Test

Similar surface results were achieved in the enclosed mould samples compared to their Phase 1 counterparts, cast with the same investment recipes, after coldworking (Figure 71). However, the curved surface of the bullet-shaped recess led to higher reflectivity in some instances than in the flat, open-face tests. It is difficult to say with certainty what the reason is for this, other than that the flat surfaces are more vulnerable to sticking to an investment mould, resulting in a decrease in translucency and reflectivity. Figures 71, 72 and 73 show enclosed tests next to their open-face counterparts.



Figure 71. A test from Phase 1 and 2 cast in moulds painted with 3-coats of Zyp Coating BN ZS using Bullseye Glass.



Figure 72. A collection of Phase 1 and 2 Mirrored Tests



Figure 73. A test from Phase 1 and 2 cast in moulds painted with Zyp Coating BN ZS in unison with the natural, raw surface of the mould using Bullseye Glass.

The most promising reflective outcome was found on a Bullseye glass test cast with a core coated liberally with 4 coats of BN Lubricoat (Figure 74). The raised surface textures left by applying the coating with a brush were gently smoothed out by hand while wearing nitrile gloves. This was done after the coating had fully dried before installing it within the tension set mould. Although slightly streaky surface impressions were left on the core, a very reflective area was realised after mirroring. As mentioned in the documentation for phase 1 testing, BN Lubricoat was trialled further in open-

face and enclosed moulds following an adverse result observed in a scaled-up casting in Phase 3 of testing (Figure 87).



Figure 74. A finished Bullseye test from Phase 2 cast using a core painted with 4 coats of BN Lubricoat (ZYP Coatings)

Figures 75 show all enclosed tests before mirroring, while Figures 76 and 77 show those same tests after mirroring.

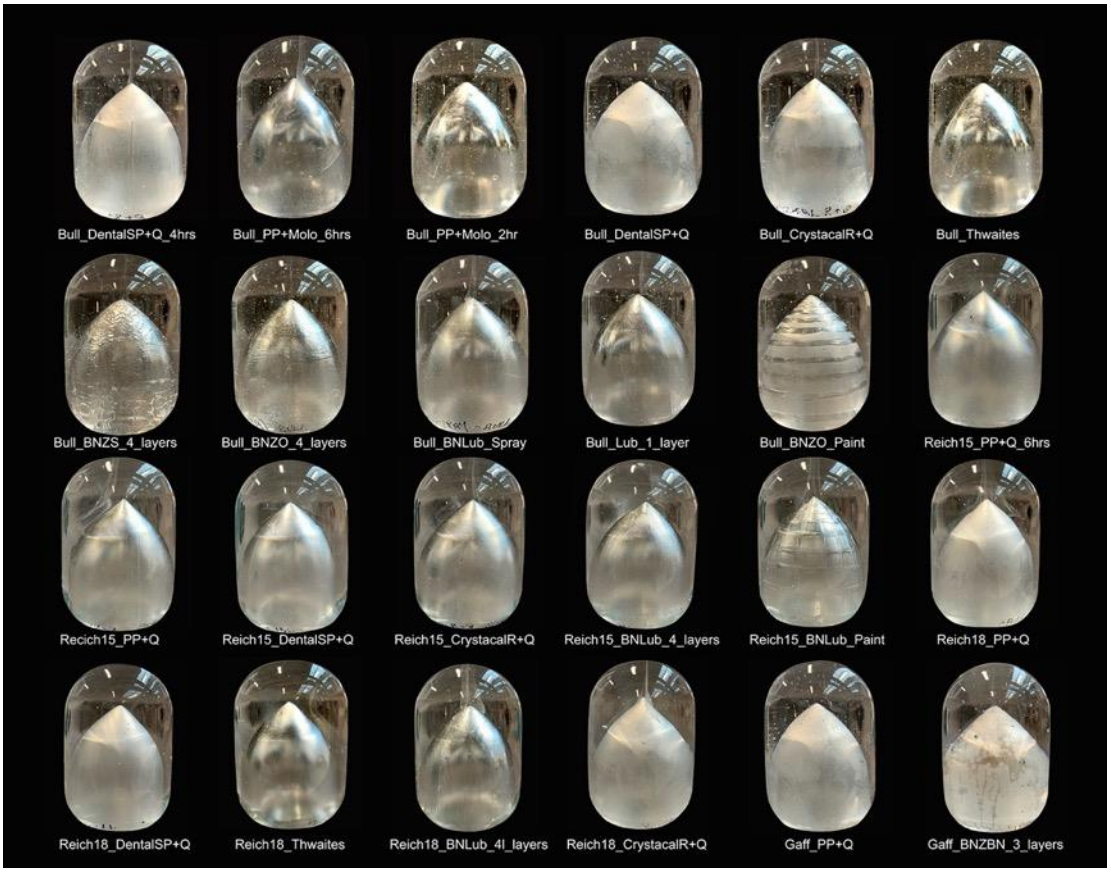


Figure 75. Unmirrored enclosed tests from Phase 2 testing



Figure 76. Mirrored enclosed tests from Phase 2 testing



Figure 77. *Mirror Palette: Phase II* (2021-23), Joanna Manousis

3.6.3 Conclusion of Phase 2 Testing

While Phase 1 of testing provided general insights into the reflective properties of cast glass surfaces, it was necessary to account for potential variables introduced by utilising a form that required an enclosed mould system incorporating a sprue and an extended core. This approach necessitated modifications to the firing schedule, mould configuration, and glass volume. Furthermore, additional cold-working processes were required to ensure the cores were visible through the glass forms.

The following bullet points present the findings for Phase 2:

- Thickly applied hBN ZYP Coating ZA flakes off curved investment cores more than on flat core surfaces.
- Small, enclosed tests within phase 2 were fired at the same casting temperature as in phase 1, but with a longer hold at 676°C / 1250°F to ensure flowability.
- All Phase 2 tests exhibited a similar surface quality/mirror effect to Phase 1 tests.
- Some curved core surfaces exhibited slightly better reflective qualities than their flat core surface counterpart from Phase 1.
- The addition of kaolin at 6% to an investment formula helped prevent glass from sticking to the investment mould.
- Molochite at a 50% volume ratio in an investment mix prevents Bullseye from sticking to a mould at low temperatures.
- Molochite has less strength compared to quartz and is, therefore, easier to remove from enclosed core moulds.
- Crystacal R plaster creates a strong, dense investment mix, which is difficult to remove from an enclosed core investment mould and can set up tension within the glass during annealing.

The optical flat lens and glass bullet used as a core/recess for Phases 1 and 2 of testing were both relatively small in scale, and the subsequent cast forms did not require large glass volumes. Cores were relatively easy to extract from the glass in both phases due to their shallow, smooth surfaces, free of

undulations and undercuts. Phase 3 of testing will use larger, more complex forms to see whether deviations in the mirrored surface appear.

Mirror Palette: Phase II (Figure 77) was selected for the *2024 British Glass Biennale* Exhibition at the Ruskin Glass Centre from 24th August to 28th September 2024. This series of tests was selected over two finished artworks, *Iris Obscura*, 2024 (Figure 99) and *Distilled Portrait I: Series II* (Figure 117). This may signal that studio testing can create comparable engagement to works considered as being resolved with a conceptual underpinning.

3.7 Phase 3 Studio Testing: Magpie Domes

3.7.1 Mould and Model Setup

To investigate whether variations in investment core size and complexity, along with overall glass volume, would affect cast surface quality and a mirrored finish, the scale and intricacy of the form were increased. Within Phase 3 of testing, the negative space of a sculpted magpie enclosed within glass domes (25 cm H × 12 cm W × 12 cm D) was employed. This phase provided the pivotal steps necessary for the creation of the final artwork, *Distilled Portrait I: Phase II* (Figure 117, p. 271).

The change in scale and shape was intended to determine the following:

- If the tension-set investment mould method used in phase II of testing could be scaled up.
- The level of difficulty in removing an investment core with undulating surfaces that are broader and deeper within the glass casting.
- If higher temperatures and longer durations at peak firing temperature are needed to fill larger moulds.
- If the core investment mixes yield a similar mirror aesthetic in larger works, then compare them against previous tests.

It had already been determined from previous studio research that the interior model/form used to duplicate investment cores with a mother mould needed to be as smooth as possible, with wide surface areas that allow mirror coating to reflect their environment. Textured surfaces on the investment mould are more likely to adhere to cast glass, increasing the risk of contamination and blemishing a mirror coating by investment residues. Textured glass surfaces also disperse light in multiple directions, thereby obscuring a mirror's ability to fully reflect images.

A magpie with smooth contours was sculpted in clay (Figure 78) and subsequently reproduced in glass using the lost-wax casting process. Casting the form in glass enabled further refinement through cold working, particularly on the wing surfaces. This stage ensured that the final mother mould used to

produce investment cores possessed optimal surface smoothness (Figure 79), a quality that would be transferred directly to the investment core from which the final glass piece would be cast.



Figure 78. Sculpted clay magpie standing next to the interior mould of a mason jar.



Figure 79. The core investment of the magpie bird

A two-part investment mould with a dome recess large enough to contain the bird and a reservoir sufficient to contain the glass volume for the dome was made. This was the same tension-set process used for phase 2 of studio testing. Figure 80 shows the base model for the dome investment mould, while Figure 81 highlights the completed 2-part investment mould with the magpie core inside.

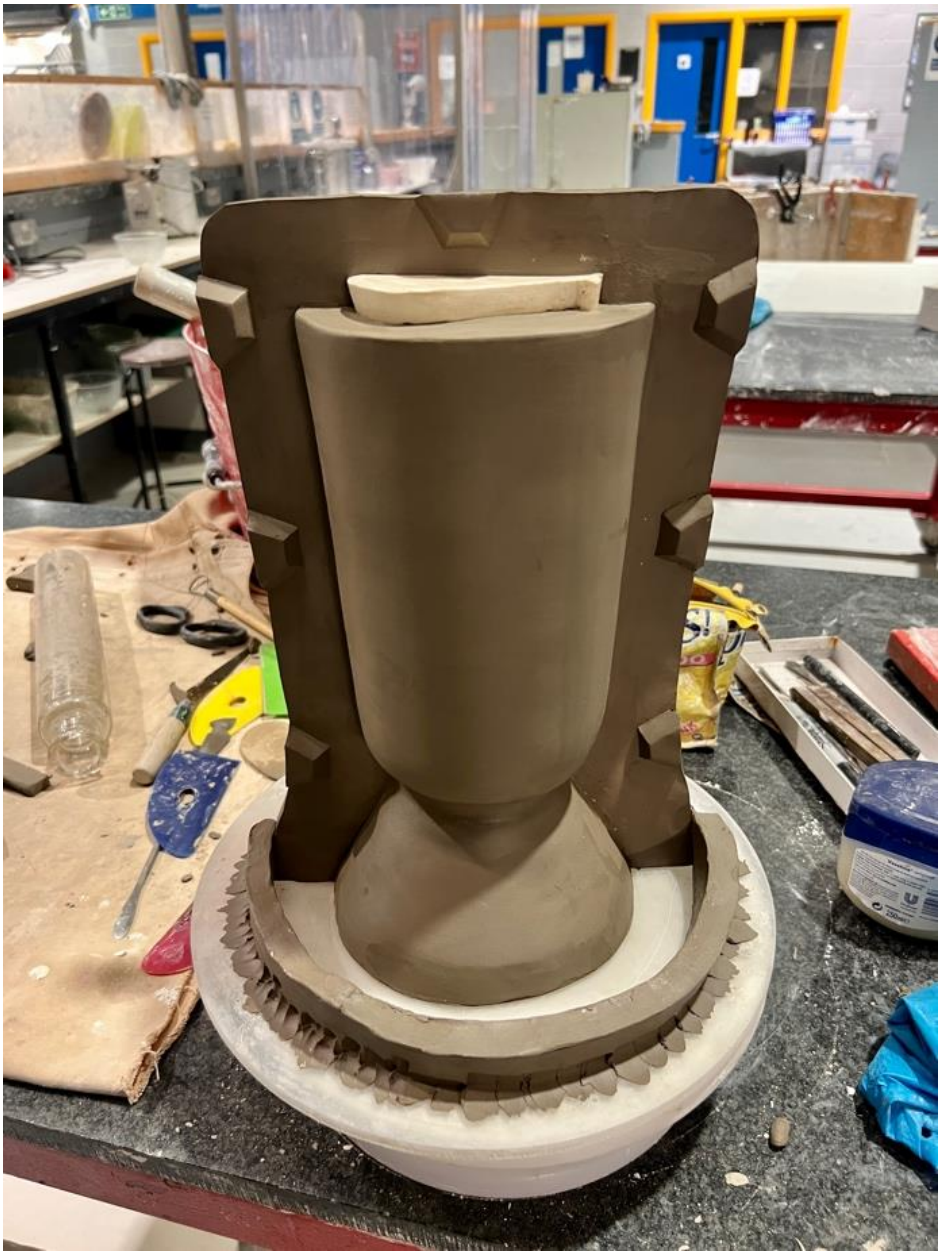


Figure 80. Set up of clay dome used for a 2-part investment mould



Figure 81. Finished magpie dome investment mould ready for firing

3.7.2 Hot Billet Casting

Six cast glass magpie domes were made in this exercise to assess nuances and deviations in surface results using larger, more complex forms. Cristalica batch was omitted from Phases 1 and 2 of testing due to its inability to flow at low casting temperatures. That said, with Cristalica being the primary furnace glass at The University of Sunderland, it made sense to use it to make cost-effective, larger-scale prototypes. Hot billet casting is a method in which glass is formed into solid forms in the hot shop and loaded into a mould, which is brought up to a temperature of between 800-850°C in the kiln (see Figure

82). Due to the glass and mould being of an equally high temperature, the glass has a higher probability of filling the mould.

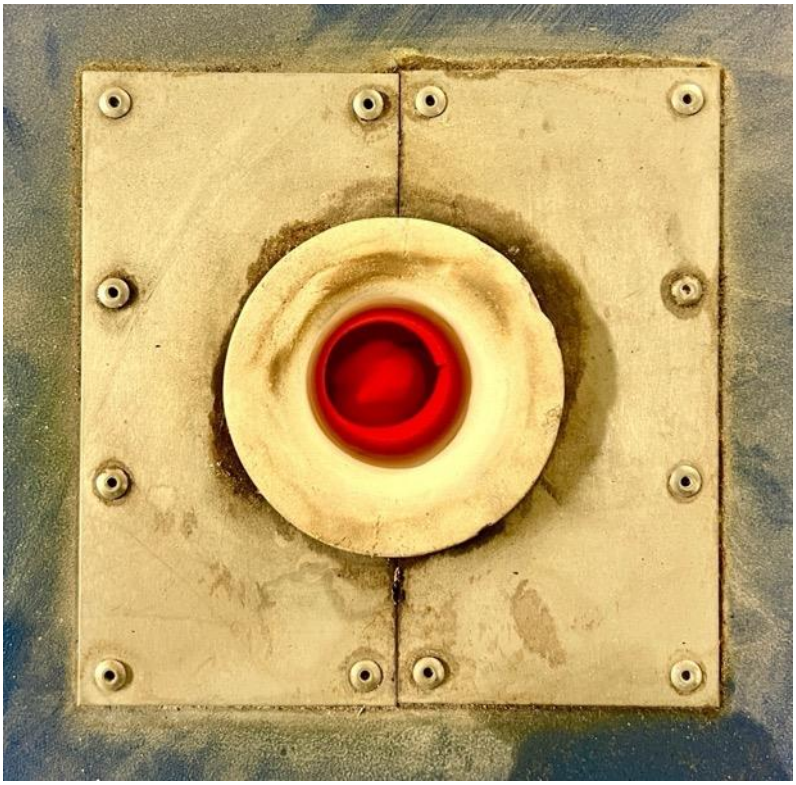


Figure 82. Tension set investment mould with magpie inside the kiln (view from kiln vent)

An initial test was made with a core and a 2-part outer mould using 50:50 pottery plaster and molochite, bound together with glass fibre sheets saturated in investment, and an outer mould layer of 1:1:0.5 pottery plaster: quartz: cordierite (grog sand). The mould filled in its entirety using this method. Figure 83 shows the finished hot billet casting after divesting the outer mould.



Figure 83. Divested Cristalica hot billet casting of magpie dome

Large bubbles trapped in the glass casting may have had difficulty rising and escaping due to Cristalica's viscosity, as well as the short 1-hour soak time at the top firing temperature. The casting was fired to 840°C to ensure glass flow, a significantly higher temperature than the top firing temperature (815°C) used to cast other bird domes using Reichenbach, Gaffer, and Bullseye.

Core-investment mixes were selected that had non-sticking characteristics in Phases 1 and 2 of testing and were easy to extract after annealing. These recipes were 50/50 pottery plaster: molochite, the Thwaites recipe using 47:47:6 pottery plaster: quartz: kaolin, and combinations using ZYP Coatings BN Lubricoat. Along with ease of extraction, softer investment mixes were chosen to minimise glass stress/tension during the annealing process, which can lead to cracking.

3.7.3 Firing Outcomes

The casting method, investment recipe, surface treatment, firing schedule and glass body used for each 6-bird dome test are outlined in the following list:

Bird 1

Glass: Cristalica Batch

Method: Hot Billet Cast

Core Investment Mix: 50/50 Pottery Plaster + Molochite

Surface Treatment on Core (Pre-Firing): None

Outer Mould Investment Mix: 50/50 Pottery Plaster + Molochite (First Layer 2-Part Sleeve) / 1: 1: 0.5 Pottery Plaster: Quartz: Grog Sand

Top Firing Temperature: 840°C (2 hours)

Glass Surface Treatment: Hand-Polishing



Figure 84. Phase 3 test using Cristalica ‘hot billet’ after divesting and cold working

Outcome: The core was soft, crumbly, and easy to remove from the glass. The glass surface left a brushed matte-silver mirror after silvering. Air entrapment left large bubbles within the glass body due to the glass’s high viscosity and a limited time frame at the top temperature.



Figure 85. Phase 3 test using Cristalica ‘hot billet’ after divesting, cold working, and mirroring.

Bird 2

Glass: Reichenbach 1500 (40% Lead Glass)

Method: Kiln Cast with Cold Billets

Core Investment Mix: 50/50 Cristacal R + Quartz

Surface Treatment on Core (Pre-Firing): None

Outer Mould Investment Mix: 50/50 Pottery Plaster + Molochite (First Layer 2-Part Sleeve) / 1: 1: 0.5 Pottery Plaster: Quartz: Grog Sand

Top Firing Temperature: 815°C (3 hours)

Outcome: The casting failed due to severe cracking after divestment. This may have been caused by the core investment being too dense/strong due to the use of Crystalcal R plaster, or by the contamination of 1500 and 1800 fired together unknowingly. Unmarked billets had been sent from the manufacturer and could have been mixed up. Cristacal R forms a strong, dense investment mix that may have been too durable for the glass to withstand during annealing. Reichenbach has been removed from further testing due to compatibility and annealing issues in large volumes.

Bird 3

Glass: Bullseye

Method: Kiln Cast with Cold Billets

Core Investment Mix: 50/50 Pottery Plaster / Molochite

Surface Treatment on Core (Pre-Firing): BN Lubricoat applied with a brush to the wing and leg of the bird core

Outer Mould Investment Mix: 50/50 Pottery Plaster + Molochite (First Layer 2-Part Sleeve) / 1: 1: 0.5 Pottery Plaster: Quartz: Grog Sand

Top Firing Temperature: 815°C (4 hours)

Glass Surface Treatment: Hand-Polishing



Figure 86. Phase 3 test using Bullseye glass with 50/50 pottery plaster and quartz core painted with hBN Lubricoat (Zyp Coatings) after divesting and cold working

Outcome: Light opacity was evident on the interior surfaces of the glass where it had encountered the investment mould. BN Lubricoat severely stuck to the glass and had to be soaked with brick acid overnight to soften. Even with an attempt to chemically clean the glass, a thin coating remained on the surface. This is at odds with the Bullseye enclosed tests using BN Lubricoat,

which repelled the glass well and has good transparency. There may be a deviation between the two BN Lubricoat batches, or, that the higher casting temperature and/or larger glass volume caused the glass to react with the coating. The core surface has a brushed matte-silver aesthetic when mirrored, with dark staining/contamination where the BN Lubricoat was applied. No large bubbles were caught in the glass casting, however seed bubbles present in the billets remained in the body of the casting.



Figure 87. Phase 3 test using Bullseye glass with 50/50 pottery plaster and quartz core painted with hBN Lubricoat (Zyp Coatings) after divesting, cold working and mirroring

Bird 4

Glass: Cristalica

Method: Hot Billet

Core Investment Mix: 50/50 Pottery Plaster / Molochite

Surface Treatment on Core (Pre-Firing): BN Lubricoat applied to the wing and leg

Outer Mould Investment Mix: 50/50 Pottery Plaster + Molochite (First Layer 2-Part Sleeve) / 1: 1: 0.5 Pottery Plaster: Quartz: Grog Sand

Top Firing Temperature: 840°C (2 hours)

Glass Surface Treatment: Hand-Polishing

Outcome: The core was easy to remove from the glass. Light surface opacity on the interior surface of the glass is evident due to the glass's interaction with the investment mould. As with the Bullseye magpie test, BN Lubricoat adhered strongly to the glass and required soaking in brick acid overnight to soften. The glass has a brushed matte silver aesthetic once mirrored, with darker staining where the Bn Lubricoat was applied. The staining was so severe that the mirror was neutralised and is not pictured. A single large bubble (2.5cm) was caught at the top of the dome in the sprue area due to the glass’s viscosity and the edge of the sprue creating a protrusion that the bubble couldn’t pass.



Figure 88. Phase 3 test using Cristalica (Hot-Billet) casting with 50/50 pottery plaster / molochite core and hBN Lubricoat after divesting and cold-working

Bird 5

Glass: Cristalica

Method: Hot Billet Cast

Core Investment: 47% Pottery Plaster: 47% Quartz: 6% Kaolin (Thwaites Mix)

Surface Treatment on Core (Pre-Firing): None

Outer Mould Investment Mix: 50/50 Pottery Plaster + Molochite (First Layer 2-Part Sleeve) / 1: 1: 0.5 Pottery Plaster: Quartz: Grog Sand

Top Firing Temperature: 840°C (2 hours)

Glass Surface Treatment: Hand-Polishing



Figure 89. Two views of Phase 3 test using Cristalica (Hot-Billet) casting using Twaites mix core after divesting and cold-working

Outcome: Some light surface opacity on the interior glass surfaces is evident where the glass interacted with the investment mould, along with wavy lines of devitrification. These devitrification patterns seem to be prevalent when kaolin is used as an additive in the investment mix and have been observed in other castings with kaolin as an additive. Once mirrored, the core has a brushed matte silver aesthetic, with white, wavy lines caused by devitrification. A dark brown stain in the beak area was prevalent in this test after mirroring caused by investment contamination. The beak area is narrow and difficult to clean. Attempts to neutralise and clean the residues in this area were made before mirroring using brick acid, followed by calcium dissolver; however, these attempts proved unsuccessful. Several bubbles were trapped within the glass body, also.



Figure 90. Detail of investment contamination from Phase 3 test using Cristalica (Hot-Billet) casting using ‘Twaites mix’ core after divesting and cold-working



Figure 91. Detail of investment contamination from Phase 3 test using Cristalica (Hot-Billet) casting using 'Twaites mix' core after divesting, cold-working and mirroring

Bird 6

Glass: Gaffer

Method: Hot-Billet Cast

Core Investment Mix: 25% Cristacal R Plaster: 25% Pottery Plaster: 50% Molochite

Surface Treatment on Core (Pre-Firing): None

Outer Mould Investment Mix: 50/50 Pottery Plaster + Molochite (First Layer 2-Part Sleeve) / 1: 1: 0.5 Pottery Plaster: Quartz: Grog Sand

Top Firing Temperature: 840°C (2 hours)

Glass Surface Treatment: Hand-Polishing and Acid Polishing



Figure 92. Phase 3 test using Gaffer cast using 25% Cristacal R, 25% Pottery Plaster, 50% Molochite after divesting, cold-working and acid polishing

Outcome: The core was easy to remove from the glass, unlike a 50:50 Cristacal R plaster:quartz mix, which divides the plaster content 25:25 between Crystacal R and pottery plaster. This softened the density and strength of Crystacal R while retaining the refined glass surface texture Crystacal can provide. The glass surface was smooth and semi-white, having interacted with the investment mould. Large sucker marks were present on

the core surface of the bird. Suckers usually result from the glass pulling away from the investment mould/core during annealing. This could be due to the glass cooling too quickly from top temperature to annealing temperature, yet sucker marks were not prevalent in the other bird-dome tests using the same firing schedule.



Figure 93. Phase 3 test using Gaffer cast using 25% Cristacal R, 25% Pottery Plaster, 50% Molochite after divesting, cold-working, acid polishing and mirroring.

Suckers have been observed in a large casting using Gaffer glass in this research project, yet the cast used the Thwaites mix rather than the 25:25:50 Cristacal R: Pottery Plaster: Quartz mix. It is difficult to tell at this stage if the sucker marks are due to rapid cooling, the investment mix, or the glass body.

3.7.4 Exhibiting Studio Tests



Figure 94. *Mirror Palette: Phase III* at *Iris Obscura* exhibition in Sunderland, 2024.

Four bird domes were exhibited in *Iris Obscura*, a solo exhibition of works made during this PhD project at the Athenaeum Building in Sunderland from 26th April to 24th May 2024 (Figure 94). They were grouped as a collection and served to visually connect with a range of finished artworks created in this research project (see Figure 117, *Distilled Portrait I: Series II*). The

domes incorporating heavy staining in the beak area, and those with large bubbles, were omitted from the show.

Alongside Phase 3, Phases 1 and 2 of testing were presented as progressions toward finished pieces in the exhibition. Many visitors gravitated to the test groupings, offering direct feedback that they considered them artworks. It could be argued that the tests were proposed as artworks within the context of the exhibition. However, statements were made available to remind viewers that the palettes were a means of getting to the finished artworks, which were installed in three groupings on a segregated wall.

3.7.5 Conclusion of Phase 3 Testing

The studio testing conducted in Phase 3 marked a critical progression in the investigation of large, complex core-cast mirrored glass forms. Scaling up both the investment core and glass volume introduced a range of technical challenges that required modified firing schedules, higher temperatures, and longer durations, each of which contributed to inconsistencies compared with the more controlled results of Phases 1 and 2. The integration of new materials, particularly the Cristalica batch, necessitated a fundamental shift in casting methodology. Charging hot billets into pre-fired moulds, rather than employing conventional cold-loading techniques, revealed an alternative strategy for kiln casting that may significantly enhance glass flow and form fidelity in large-scale applications.

Despite the variability introduced by these changes, the findings in Phase 3 offered critical insights into material behaviour, process optimisation, and the limitations of current casting technologies at larger scales. Key discoveries, including the variable flow characteristics of different glass batches, the interaction of investment materials with thermal conditions, and the nuanced surface effects produced by acid polishing, provide a foundation for future refinement of mirrored glass casting techniques. These results underscore the necessity of adopting flexible, responsive studio strategies when working at scale, and they highlight the interplay between technical precision and material unpredictability that defines advanced kiln-casting practice. Collectively, these outcomes not only expand the methodological framework for casting complex mirrored forms but also contribute valuable knowledge to the broader field of contemporary glassmaking.

Key results found in Phase 3 testing are listed below:

- Cristalica batch does not flow well at a temperature range of up to 815°C/1500°F, but can be cast successfully when charged as hot billets into pre-fired moulds brought to 840°C/1544°F.
- Crystacal R mixed as a 25% investment component with 25% pottery plaster by weight helps to reduce the density/mould strength of a core leading to easier divestment and reduced thermal shock.

- Gaffer glass has the lowest viscosity of all the glass bodies used in this research project and contains the least air entrapment of all the cast glasses used.
- Chemical polishing can cause thick crystal castings to crack due to the high temperatures required for hydrofluoric/sulphuric acids to react with the lead content in the castings.
- Cast crystal should be brought slowly to a temperature of 40-50°C to resist thermal shock when acid polishing
- Acid polishing exaggerates surface textures on the crystal
- Acid polishing produces a plastic quality on crystal surfaces that is less refined than hand-polished / cold-worked glass.
- There can be inconsistencies between batches, creating different results when using ZYP BN Lubricoat, a test should always be carried out to ensure the desired effects.
- Brick acid, calcium, lime, and a rust-removing agent can be used to remove investment or hBN coating residues from the glass.
- Exaggerated points left as negative-core impressions in glass have a higher tendency to stick/react with the glass at high firing temperatures, causing residual blemishes and staining on a mirror when silvered.

3.8 Roughness Comparator

Although a substantial series of tests had been completed across Phases 1, 2, and 3, a further investigation was undertaken to examine visual differentials in mirrored surface quality by comparing a fully reflective manufactured mirror with a core-cast duplicate. The aim was to evaluate the extent to which surface clarity, reflectivity, and fidelity could be replicated through the core-casting process when positioned alongside an industrial precision standard.



Figure 95. Metal Roughness Comparator made by Yusa International Inc.

To support this comparative analysis, a roughness comparator was introduced as a reference tool. These are calibrated metal samples exhibiting incrementally varied surface textures, arranged in order of increasing

roughness and complexity. Commonly used in industrial contexts, they serve as a benchmark for assessing and grading surface finishes. Each texture is indexed with a unique combination of letters and numbers, facilitating standardised comparison. As shown in Figure 95, the roughness comparator produced by Yuasa International Inc. includes a range of finishes; the area marked "2L" in the top right corner represents a flawlessly polished metal surface capable of producing a mirror-like reflection, thereby providing a point of reference for evaluating the mirrored qualities of cast glass surfaces.

The face of the comparator was moulded as a shallow, open-faced investment core using a 50:50 mix of Cristacal R plaster and quartz (Figure 96) and subsequently cast with Gaffer glass (Figure 97). This durable investment formulation had previously demonstrated superior performance in producing smooth, reflective surfaces when used with both Reichenbach and Gaffer crystal during acid polishing stages in Phases 1 and 2 of studio testing.



Figure 96. (Left) Investment mould taken from a roughness comparator before pre-firing / Figure 97. (Right) A fired mould using a core impression of a roughness comparator with Gaffer glass.

The exterior surface of the glass roughness comparator was ground an 800-grit finish using loose silicon carbide grit, then chemically polished to remove residual opacity. Acid polishing creates a translucent surface on the crystal, regardless of its roughness; however, a viewer cannot see through the casting clearly if the exterior surface is not brought up to a grit level of 600 or higher.

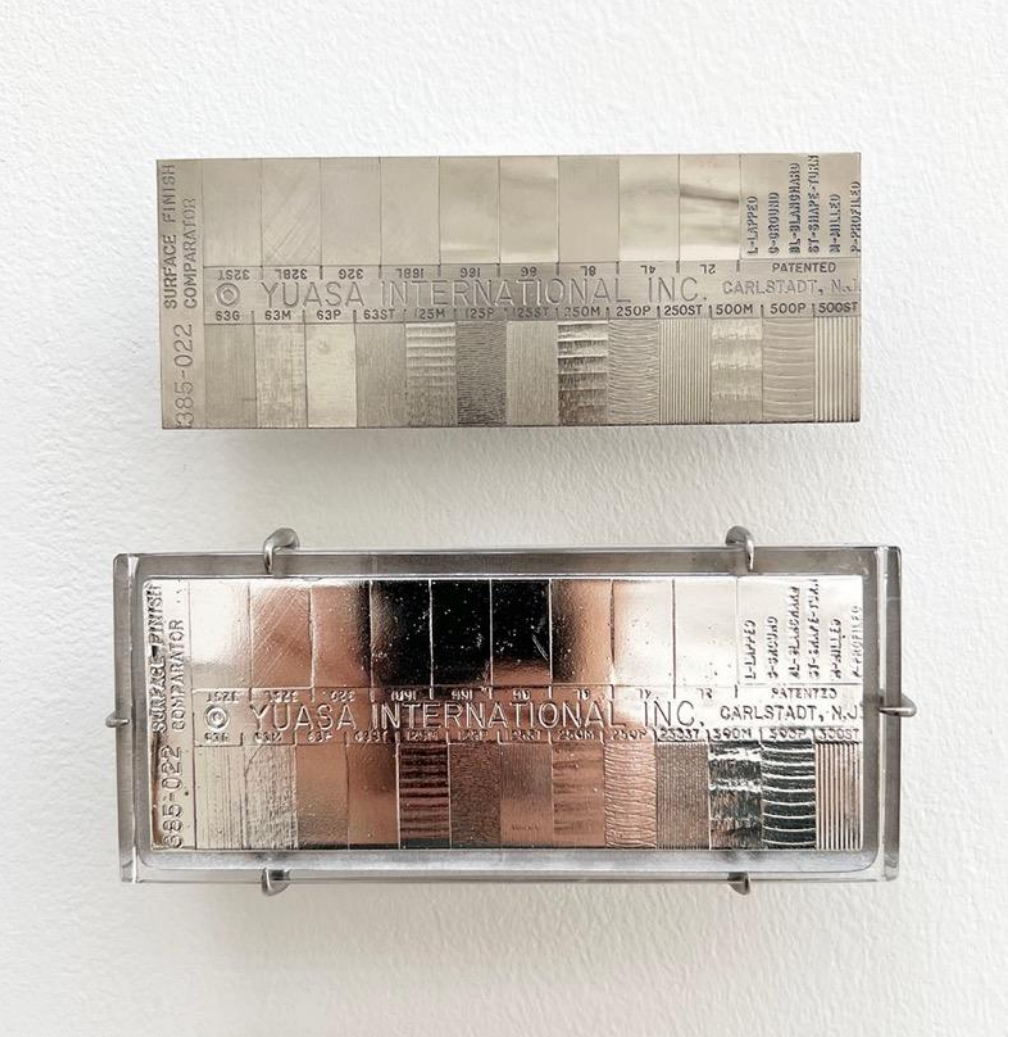


Figure 98. Joanna Manousis, *Roughness Comparator*, 2023/24. Cast Crystal / Stainless Steel / Mirror 6.5cm H x 15cm W x 1.5cm D

Figure 98 shows the completed crystal casting after mirroring (bottom), and the original roughness comparator (top). The silver mirror coating on the glass looks significantly brighter than the metal, yet 2L does not reflect fully. The cast glass surface contains pits, likely due to the investment mould deteriorating during the firing and the investment not fully achieving the metal's smooth profile. The width of the 2L surface is only 1cm. If the surface

were broader, a higher level of reflectivity may have been achieved, as seen in the acid-dipped optical flat lens tests conducted in Phase 1 using Reichenbach crystal with a core of Crystacal R plaster and quartz (Image 46).

3.9 Conclusion of Phases 1, 2 and 3 of Testing

A reflective mirror, by definition, produces a recognisable, reversed image of whatever is in front of it. The term reflective can also be used to describe shiny objects or materials that reflect light. For example, a silver coin can have a high level of reflectivity when light bounces off its surface yet cannot be used to reflect the self as a mirror would. Similarly, most cast mirrors made during Phases 1, 2 and 3 of testing are iridescent and can reflect light, yet do not mirror their environment.

Exceptions to this were seen in Phase 3 of testing, when the negative space of a magpie inside a glass dome was cast using a tension-set mould set-up using Gaffer crystal. This piece was chemically polished using hydrofluoric and sulfuric acids before the mirroring process, resulting in a bright reflective mirror in which a viewer can identify their reflection. Although this cast-mirror sample does not have the crisp reflection seen in a commercially made sheet-glass mirror, the object is inarguably reflective, both in its ability to diffuse light and in its ability to provide a mottled reflection of its surroundings.

The outcomes of testing directly address the research questions and sub-questions outlined in the introduction of this chapter. Factors that affect the final surface of a cast piece of glass, and subsequently, the hue, texture and reflectivity of a mirror coating include the:

- shape and surface quality of a mould's base model
- glass body used for the casting
- investment mould ingredients
- fabrication method
- application of hBN coatings
- temperature and duration of a firing
- post-firing polishing using hydrofluoric/sulfuric acid

As noted in the previous sections on testing outcomes, each core model and glass form requires different practical methods to create suitable mother and investment moulds. Overall, silicone positives are a good way to create shallow bas-relief investment moulds for open-face glass tiles, while a two-part investment mould process, in which a core is held with tension, helps to negate the need for wax as an intermediary modelling material.

Molochite proved to be a successful non-sticking investment ingredient when used with pottery plaster to enhance the level of reflectivity on cast Bullseye, a glass that had performed poorly with all other investment mixes, resulting in

high levels of opacity. The addition of 6% kaolin by weight to an investment mix of 50:50 pottery plaster/quartz also gave superior non-sticking results in all glass bodies tested. These investment recipes were therefore prioritised when creating artworks that required an iridescent brushed-silver effect.

Although Reichenbach 1500 (40% lead) excelled in exhibiting low surface opacity and shine with most investment recipes, giving it precedence over Reichenbach 1800 (15% lead), Gaffer Crystal (40% lead), Bullseye and Cristalica, it was not used to make finished artworks within this research. This is due to it no longer produced by Farbglas Reichenbach. Bullseye and Gaffer were used to cast moulds in a kiln coming up from room temperature, while Cristalica was cast in pre-heated moulds using the hot billet method.

Within Chapter 4: Case Studies, multiple investment recipes are used within a single mould for *Iris Obscura I* (Figure 99, p.235), to see if varying mirroring effects can be combined in a single artwork. The use of strategically painted hBN ZYP coatings onto investment moulds to dictate how/where a cast surface reflects when silvered is also a source of experimentation. The testing phase seen in this chapter is expanded in Chapter 4, whereby differentials in size, form, firing cycle and making method set up a range of opportunities and limitations.

4 Case Studies

This chapter presents six artworks, Iris Obscura I, Iris Obscura II, Silver Thread, Distilled Portrait I, Celeste and Persephone as individual case studies. They draw inspiration from the Contextual Review (Chapter 2) and artworks made before initiating this research. Several mirroring effects found in Studio (Chapter 3) are utilised within finished works. The final case study documents a teaching placement at The Birmingham School of Jewellery. This class demonstrates how makers without prior glassmaking experience incorporate cast mirrors into their work, highlighting how these processes can be adapted to intimate-scale forms for adornment.

4.1 Introduction to Chapter 4

Extending the experimental approach of the previous chapter, the artworks and jewellery made as case studies in this thesis investigate how physical, technical, and material conditions shape the reflective potential of cast glass, while intersecting with historical and contemporary understandings of the mirror as object and metaphor. Changing the scale and complexity of cast glass mirrors can introduce opportunities and obstacles that require problem-solving. New methods of mould construction, changes in firing schedules, and alternative post-firing processes shed light on whether the mirror effects seen in Chapter 2: Studio Testing remain consistent.

For the first two years of this PhD, identical forms were produced to test influences on the reflectivity of mirror coatings applied to investment-cast glass. Within this chapter, techniques and imagination are stretched using cast glass mirrors. The knowledge gleaned from the material testing phase is

interwoven with the mirror's symbolic resonance. This instilled meaning is imparted to the viewer through emblematic forms entwined with reflective and non-reflective mirrored surfaces. This is seen in *Distilled Portrait* I (Figure 3, P.30), where a magpie, a bird closely associated with collecting and self-identification in mirrors, is represented as a reflection within a cast-crystal jar.

Case study outputs include wall-mounted and freestanding cast-glass sculptures that integrate selected mirror effects**.** Each artwork is discussed through a visual analysis, situating material outcomes within broader aesthetic and conceptual frameworks. An analysis of methods outlines the technical steps used to create each artwork and whether the observed reflective properties are consistent with earlier experiments. Each case study concludes with key insights drawn from fabricating, exhibiting, and disseminating the works through slideshows and lecture series.

In expanding the ambition of cast-glass mirrors, this chapter positions the studio as both a site of technical experimentation and of conceptual inquiry. The artworks function as reflective thresholds, objects that not only capture and distort their surroundings but also engage with the cultural legacies of self-perception, surveillance, and material transformation. By situating cast mirrors within the lineage of reflective art practices, from Renaissance optics

to minimalist and post-conceptual art, the research underscores how the act of casting mirrors can materialise the tension between image and object, visibility and opacity. This dual focus on process and perception anchors the chapter's contribution to understanding cast glass mirrors as both sculptural artefacts and philosophical propositions about reflection itself.

4.2 *Iris Obscura* Series

4.2.1 Introduction: Iris Obscura I



Figure 99. Joanna Manousis, *Iris Obscura I,* Core-Cast Glass / Mirror / Stainless Steel /, 8.5" x 6.5" x 2.5" (each) / 21.5 cm x 16.5 cm x 6.5 cm

Iris Obscura I (Figure 99) is both a finished artwork and a scaled-up departure from studio testing. For centuries, the mirror has been considered a passive reflector of light and an all-seeing eye. The mirror was said to remind humans of their likeness to God and God to them (Melchoir-Bonnet, 2001), thereby reflecting all of nature in its environment. The mirror acts as an eye for what we cannot perceive, ourselves. Imagining this idea visually and thematically, dimensional concave lenses taken from the interior surfaces of blown-glass bubbles were cast as negative impressions within solid cast-glass ovals. Each piece serves as a study, creating a push-and-pull between the visible and the invisible.

4.2.2 Visual Analysis: Iris Obscura I

Three wall-mounted ovals, cast in clear glass, are arranged in a line, spaced 5 cm apart. Reminiscent of human eyes, each piece contains the negative impressions of concave lenses coated in silver mirror. Measuring approximately 21 cm wide, 16 cm high, and 6 cm deep, each glass oval is affixed to the wall with four stainless-steel claws mounted on a stainless-steel plate. Reminiscent of oversized gemstones clasped in a jewellery setting, the pieces look to survey the room, quietly observing their surroundings.

The central oval with a frosted, semi-opaque surface contrasts with the two highly polished ovals it’s nestled between. Though the frosted glass obscures

full visual access, it reflects a soft silver light. A luminous halo forms around the outer edge of the silvered lens inside the glass, imbuing the piece with a sense of depth and radiance. The central glass oval anchors the composition. To its left, an oval containing a matte silver lens has fine white striations across its surface. From a distance, it appears symmetrical and flawless, yet upon closer inspection, subtle variations that evoke the contours of a unique landscape become apparent. The oval to the far right looks to contain a fractured lens, split horizontally into two halves. Its matte silver surface is punctuated by the highly reflective fracture, introducing a sharp interruption in what would otherwise be a muted surface.

The inclusion of the cracked lens introduces a symbolic charge that resonates beyond material form. A crack, particularly in reflective surfaces, has long served as a universal emblem of bad luck. Shattering a mirror was believed to disrupt the unity of reflection and self, thereby disrupting the soul. Rather than signifying loss or misfortune, the cracked lens becomes an aperture through which new meaning emerges. It transforms the idea of damage into an active visual element, one that unsettles the polished symmetry of the surrounding form. In doing so, superstition is transformed into speculation, suggesting that imperfection can serve as a basis for deeper reflection and that life itself can never be perfect.

4.2.3 Analysis of Method: *Iris Obscura I*

The *Iris Obscura* series was created using polyurethane ‘mother-moulds’ to form 3-part investment moulds that do not require wax as an interior former. Two different investment mixes, known to produce different mirror effects, were merged within the recess of a lens. This created distinct shifts in opacity and texture on the glass surface cast from the mould, and in the hue of the applied mirror coating.



Figure 100. Artist: Joanna Manousis*, Iris Obscura I,* Core-Cast Glass / Mirror / Stainless Steel /, 8.5" x 6.5" x 2.5" / 21.5 cm x 16.5 cm x 6.5 cm

White iridescent ‘waves’ became apparent on the complete (unfractured) lens, which would not have been evident without mirroring. These patterns were caused by devitrification on the glass surface during interaction of molten glass with the investment mould at peak firing temperature. The striations imbue a moment frozen in time and the uniqueness of silvered cast glass, which contrasts with the flawless reflectivity of commercially made mirrors. Figure 100 shows these subtle variations.



Figure 101. Internal view of a fractured cast lens after the mirroring process.

Figure. 101 shows the interior of a mirrored lens containing a splintered crack. The triangular section within the crack has good reflectivity when viewed through the glass from the front. To shift the negative associations of broken

mirrors into a visual positive, several convex lenses were cast in plaster and deliberately cracked before taking mother-mould impressions that integrate intentional flaws.

Each lens in *Iris Obscura I* was cast in Bullseye, a glass with a relatively high viscosity. As a result, shiny, transparent surfaces were achieved in cracked details. This is due to the glass's inability to flow into thin crevices at relatively low casting temperatures over short durations of time. The glass did not interact with the investment mould in these areas, therefore retaining a glossy, transparent surface. Once mirrored, the cracks achieved high levels of reflectivity, a striking contrast to the matte silver aesthetic surrounding them.

As seen in Figure 102, the smooth surface of the investment core, cast from a blown glass lens is punctuated by the rugged impressions of chipped plaster. This is caused by the thin edges of the investment mould lens cracking off when removing the mother mould, which is brittle and prone to damage under pressure. The duality of these surfaces' calls attention to the materiality of the making process, which in turn feeds into themes associated with fragility, transience and decay. A material decline that is embodied within glass mirrors.



Figure 102. Open-face mother mould of fractured lens used in Iris Obscura

It took several months to create the two ‘enclosed’ 2-part mother moulds and the single open-faced mother mould required to cast a single investment mould (Figures 103 and 104). Setbacks were caused by fine, delicate rubber details (taken from the cracks) tearing as they were peeled away from the investment mould. Rubber details taken from wider fractures proved more successful, both in their ability to capture the impression of a crack in the

investment mould and in their resistance to breakage. Wider cracks also yielded greater reflectivity in the finished glass piece.



Figure 103. Multi-part mother mould for the exterior investment mould of Iris Obscura lens mould



Figure 104. Internal view of a 3-part investment mould used to create a single casting for ‘Iris Obscura’.



Figure 105. *Iris Obscura I*, Core-Cast Glass / Mirror / Stainless Steel /, 8.5" x 6.5" x 2.5" / 21.5 cm x 16.5 cm x 6.5 cm

Iris Obscura I (Figure 105) was exhibited at the *Collect* art fair at Somerset House, London, with Bullseye Projects from 1st – 5th March 2023. *Collect* showcases some of the best examples of international art, design and craft, ranging from sculpture to furniture and jewellery. The tryptic of lenses was later accepted into *Transitions in the Kiln,* a juried exhibition with Bullseye Projects at The Bellevue Arts Museum in WA, USA, from the 31st of May 2024 to the 5th of January 2025. The piece won third place within the 'Student Award' category. These inclusions show the relevance of this research within art, design, craft, and glass-art communities.

4.2.4 Iris Obscura II

4.2.5 Visual Analysis: *Iris Obscura II*

Four wall-mounted cast-glass ovals are positioned in a line at eye level, spaced 7 cm apart. Seemingly identical to the glass forms in *Iris Obscura I* (Figure 105), the internal impression of a concave mirrored lens reveals subtle variations both internally and externally (Figure 106).



Figure 106. *Iris Obscura II,* 2024. Cast Crystal / Glass / Stainless Steel / Mirror, 16.5cm H x 113cm W x 6.5cm D

The interior lens surface in the oval to the far left has a soft, stippled silver texture. Rather than offering a reflection, its surface scatters light, revealing distinct iridescent striations that are more pronounced than those in the intact lens in *Iris Obscura I.* In contrast, the second lens from the left reflects light vividly. Although the lens surface shows slight inconsistencies, it produces an

inverted reflection of both the viewer and the surrounding environment (Figure 107).



Figure 107. Detail of *Iris Obscura II*. Bullseye ‘Thwaites Mix using Pottery Plaster lens (left). Acid-polished ‘Thwaites Mix using Crystacal R’ Gaffer lens (right)

The third lens, with its sandblasted outer surface, is white and opaque, denying a clear view of its interior. The fourth and final lens, at the far right, contains a deep horizontal crack dividing it into two halves, which recalls the fractured lens seen in *Iris Obscura I*.

4.2.6 Analysis of Methods*: Iris Obscura II*

Further investigation was needed to determine whether a reflective lens could be obtained using acid-polished lead crystal and to ascertain whether devitrification patterns would appear on the concave lens due to the interaction between molten glass and the investment mould at high temperatures.

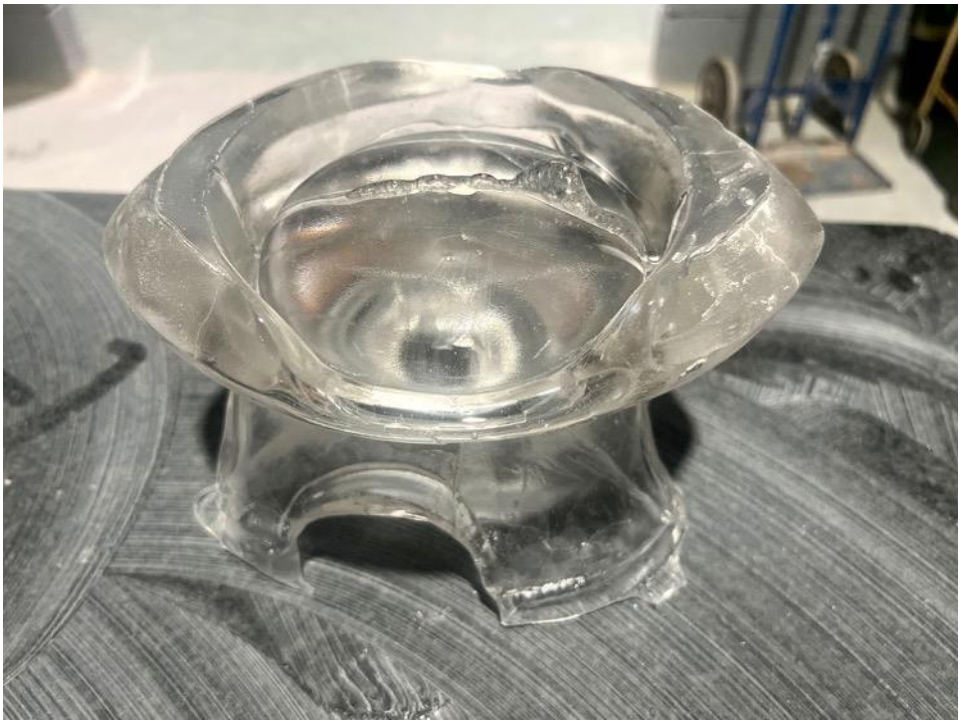


Figure 108. Divested ‘unfilled’ casting using Bullseye glass.

Bullseye glass was used to cast the cracked lens and the intact lenses that were not acid polished. A preliminary test piece was fired to 787C °C for 2 hours; however, the glass did not fully fill the mould due to its high viscosity at low temperatures (Figure 108). Subsequent lenses were made with Bullseye and fired to 800 °C for 3 hours to ensure good glass flow.

Thin layers of investment stuck to the rubber mother mould, removing patches of the core's smooth surface to reveal a mottled texture. Variations between the sealed surface (which came away cleanly from the rubber) and that of a more stippled surface, where the investment was pulled away, were clearly visible. It was anticipated that these texture variations would be evident on the glass surface cast from the mould, therefore causing deviations in mirror quality (Figure 109).



Figure 109. Investment mix stuck to mother-mould surface causing surface textures on investment mould.



Figure 110. Investment mix stuck to the surface of a mother-mould

Figure. 110 shows this occurrence on the surface of a magpie core. A mottled texture is visible on the inner right wing. Figure 111 shows the same issue on a cracked lens mould used in the *Iris Obscura* series



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Figure 111. Glass casting of cracked lens with stippled surface before mirroring.

After casting, polishing the outer surfaces, and mirroring the glass lens cast from the mould seen in Figure 109, a stippled texture was evident in the interior lens surface. This resulted in a brushed, varied aesthetic in the mirror coating. Figure 111 shows the cracked Bullseye lens before it is mirrored. Light hits the raised surface texture, visible just under the triangular

fissure/crack in the image. Figure. 112 shows the completed piece after mirroring. It is difficult to highlight subtle variations in surface quality in photographs, but these marks are apparent when assessing the work in person.

The Thwaites investment mix (47% Pottery Plaster: 47% Quartz: 6% Kaolin), said to offer a ‘good’ surface reproduction, was used for the intact and broken lenses in *Iris Obscura II* (Thwaites, 2019). A deviation of 3% kaolin by weight was used in the cracked lens, while 6% kaolin was used in the full lens. The full lens showed similar devitrification lines seen in the bird-dome test made with the Thwaites mix, while the cracked lens was free of devitrification. Lowering the kaolin content could help prevent devitrification on the cast surface; however, this cannot be stated with certainty without further testing.



Figure 112. Cracked lens*, Iris Obscura II* after mirroring.

A lens cast in Reichenbach 1500 glass with a sandblasted exterior surface was displayed in *Iris Obscura II*, alongside an intact lens made from acid-polished Gaffer crystal, with a core composed of the Thwaites Mix (Crystacal R plaster, quartz, and 6% kaolin). Acid polishing enhanced the reflectivity of the lens once the mirror coating was applied. A small, raised impression, caused by investment debris settling on the lens surface prior to firing, is visible; however, this imperfection did not significantly compromise the mirror's optical quality.

Unlike the crisp reflections characteristic of blown or sheet-glass mirrors, the cast mirror produces a softened, inverted reflection of the viewer. This echoes the inversion of images projected onto the retina at the back of most animal eyes (Figure 107).

4.2.7 Conclusion: *Iris Obscura* Series

The *Iris Obscura* series was the first body of artworks to evolve directly from studio testing. The formation of the eye shape, containing a concave lens, not only references the mirror as an eye through which we perceive our own identities but also echoes the form of early blown glass mirrors. These examples were made from blown-glass bubbles, cut and inlaid with molten metals such as tin, which often produced obscure and distorted reflections (Melchoir-Bonnet, 2001)

The following observations emerged during the fabrication and circulation of the *Iris Obscura* series:

- Surface striations: Broadening the cast surface for mirroring revealed intricate white and silver striations on the interior surfaces, caused by the interaction of molten glass with the investment mould at high temperatures. These patterns are unique to each piece.

- Composite investments: Combining investment recipes with differing mirror qualities within a single core produces subtle shifts in the reflectivity and tone of the mirror coating.
- Surface translation: Even when duplicating a cast surface from a polished glass original using a tension-set mother mould, slight textural variations occur. These arise from translating a hard, polished material (glass) into a powder-based investment subjected to extreme heat.
- Acid polishing: Acid-polished lead crystal yields the most reflective results, as the chemical process effaces the glass's natural satin surface, creating a high polish before mirroring.
- Limitations of cast mirrors: Cast glass mirrors can never achieve the same clarity or crisp reflection as commercially manufactured mirrors made from blown or sheet glass.
- Mould integrity: Creating deep, fine crevices in investment moulds duplicated from rubber mother moulds can compromise the rubber's longevity. The rubber often tears when the investment is demoulded.
- Air entrapment: Wide, shallow castings are prone to trapping air bubbles beneath the lip of the reservoir. Stabilising, tilting, and re-firing the mould, if structurally sound, can allow the trapped air to escape.
- Viscosity and contrast: Using high-viscosity glass, such as Bullseye, in moulds with deep, fine crevices can produce translucency contrasts. Short firing durations at lower temperatures prevent the glass from

filling thin details, as seen in the deliberately cracked lenses of *Iris Obscura I* and *II*.

- Texture differentials: When the surface of the investment core sticks to a rubber mould, slight variations in surface texture can occur. These differentials affect how the mirror coating adheres, creating tonal variations across the reflective surface.
- Firing schedules: Bullseye glass did not flow sufficiently at 787 °C for two hours in larger moulds that require a larger glass volume but cast successfully at 800 °C when held for three hours. Testing firing schedules for each glass and mould type is essential to ensure successful casting outcomes.
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Overall, *Iris Obscura* revealed a range of nuances not evident during preliminary testing. Mirroring investment-moulded glass exposes inherent surface inconsistencies that would otherwise be invisible to the naked eye. Rather than seeing these occurrences as faults in surface reproduction, variations present opportunities for innovation. Controlled manipulation of cast glass surfaces can yield novel aesthetic results. For instance, applying an investment mixture known to adhere to the glass and produce a blackened mirror directly onto selected areas of a rubber mould, alongside an investment yielding higher reflectivity, could allow a single casting to produce painterly, tonal mirror effects.

4.3 Silver Thread

4.3.1 Introduction*: Silver Thread*



Figure 113. Joanna Manousis, *Golden Thread*, Core-Cast Glass / 24 Carat Gold Mirror, 16.25" x 9.75" x 3" / 41.3 cm x 24.8 cm x 7.6 cm

In 2019, *Golden Thread* (Figure 113) was created using a tryptic of solid-cut crystal decanters. Each contains hollow impressions of knotted rope, mirrored with 24-carat gold, creating an iridescent, shiny surface that looks like solid gold.

Lead-bearing Gaffer crystal was used to cast this work, enabling the opaque satin surfaces of the core details to be chemically brightened with hydrofluoric/sulfuric acid. While acid polishing can yield superior reflectivity in cast mirror-making, the chemicals are highly toxic and pose significant health risks. For these reasons, it is difficult to access specialist chemical polishing services globally, which are in decline in the UK. It was therefore necessary to find alternative ways to achieve a similar mirrored aesthetic on cast glass surfaces that eliminate the need for chemical polishing.

Secret Knots, 2019 (Figure 114) was cast using Bullseye *Crystal Clear* billet glass, yet the cast surfaces produced a white, contaminated finish when a mirror was applied. The glass was left unmirrored for these reasons. The following subsections outline a visual analysis of Silver Thread (Figure 115), a continuation of the *Secret Knots/Golden Thread* series, using Bullseye glass to yield reflective results, informed by Chapter 3: Studio Testing. This is followed by an analysis of the methods used and a conclusion.



Figure 114. *Secret Knots* (2019), Core-Cast Glass, Hand-Polished, 16.25" x 15.5" x 3" / 42 cm x 39.4 cm x 7.6 cm

4.3.2 Visual Analysis: *Silver Thread*

Positioned in a linear sequence, five solid cast-glass decanters, vessels traditionally used to contain spirits, contain threads of knotted silver rope. Spliced between the bottles, the rope appears continuous, each end aligning from one decanter to the next. Polished to a high shine, the glass surfaces are embellished with cut lenses and star motifs; yet the areas framing the silver rope remain smooth, deliberately allowing uninterrupted visual access to the mirrored rope details. Although a viewer's reflection does not appear in

the rope due to fine surface textures, its bright silver surface captures and disperses light as a mirror would (Figure 115).



Figure 115. Joanna Manousis, *Silver Thread I* (2022), Core-Cast Glass, Hand-Polished, 16.25" x 15.5'" x 3" / 42 cm x 39.4 cm x 7.6 cm

Silver Thread continues the *Golden Thread* (2019) series, its title referring to an idea or feature that runs through all parts of something, holding it together and imbuing it with meaning. Metaphorically, the term has been used to suggest that all of nature is bound by invisible links, and that every action can impact across time and space. The continuous, knotted rope seen in *Silver Thread* and its golden counterpart becomes visible only when the cast-glass decanters are arranged in sequence, transforming the linear display into an interconnected landscape.

The work gives tangible form to the unseen threads that bind us. In the words of Valentine Worth, “the physical and the immaterial are all connected, each exerting influence on the next, bound, as it were, by chains of analogy, magnetic chains. Every decision, every action mirrors, ripples, reflects and echoes throughout the whole of creation. The world is indeed bound with secret knots” (*The Museum of Jurassic Technology*, n.d.).

4.3.3 Analysis of Method: *Silver Thread*

Bullseye glass in combination with a ‘core’ investment using the ‘Thwaites mix’ at percentages of 47% pottery plaster, 47% quartz and 6% kaolin by weight was used for each decanter form. This investment mix was particularly successful when using Bullseye glass in phases 1 and 2 of testing, producing good light reflecting properties when coated with silver nitrate (Figure 111).

A tension-set investment mould was not used in this work because the investment-cast rope is so delicate and would likely crack under pressure. Striving to reduce the surface texture caused by wax steaming was unnecessary, as the rope details were not smooth or free of texture to begin with. A fully reflective surface in which a viewer can see themselves clearly would not be attainable in such detailed voids. For these reasons, the rope investment cores were carefully positioned within hollow wax decanters and sealed before the final exterior moulds were made.

Along with the ‘Thwaites’ mix used for the core investment, a 50% molochite to 50% pottery plaster mix was used for the face-coat of each decanter investment mould, with a stronger backing mix made with equal volumes of pottery plaster, quartz, and water. Additionally, cordierite, also known as grog sand, was added to the outer layer for strength.

After firing, improved surface clarity and shine were observed on the exterior surfaces of the decanters, yet the addition of molochite in the face coat led to surface cracking due to reduced strength compared to quartz. For these reasons, molochite was used only as a face-coat on larger moulds, with quartz added in the subsequent outer layers for its greater strength.

4.3.4 Conclusion: *Silver Thread*

Silver Thread holds bright silver core-cast mirrors that reflect light. The following insights were gained through this study:

- Reflectivity and glass type: Soda-lime glasses such as Bullseye can produce highly reflective mirror coatings when cast against investment mixtures that resist chemical interaction and adhesion at peak firing temperatures, such as the Thwaites mix, or a 50/50 blend of pottery plaster and molochite.

- Comparative brilliance: While certain investment mixes are less prone to surface adherence, yielding reflective finishes, they are not as optically brilliant as acid-polished lead crystal.
- Structural integrity of investments: A 50/50 pottery plaster/molochite mix produces surfaces that resist sticking but are mechanically weak and prone to cracking. When using this mixture, it is advisable to back it with a stronger supporting layer made from quartz and cordierite.
- Casting methods: The lost-wax casting method is effective when working with cores containing intricate surface detail, particularly in cases where achieving the highest possible surface quality is not the primary objective.
- Optical effects of polishing: Polishing glass on a curved surface magnifies the residual details of the core within.
- Surface interference: Any impressions or textural variations on the glass surface, whether translucent or opaque, can obscure visual access to the interior of the piece.

4.4 Distilled Portrait I: Series II



Figure 116. *Distilled Portrait I: Series II*, 2023-24, Core-Cast Crystal / Stainless Steel / Mirror / Taxidermy, 40cm H x 20cm W x 13cm

4.4.1 Background: *Distilled Portrait* Series

Out of all the experiences in my life, my childhood memories of going to my Nana's flat are the most visceral. An avid smoker, crafter, and hammer-horror film fan, everything within her domain was tinged with the smell of tobacco. I recall her eating oysters on beach trips, pots of pigs' trotter soup boiling on her stove, and multiple cans of what she described as 'hair lacquer' in the kitchen to maintain the beehive that, for her, had never gone out of style since the 1960s. I will always remember her as a loving and warm person.

I am interested in how sensory experiences, sight, sound, smell, and touch can leave lasting imprints on the psyche. The *Distilled Portrait* series (Figure 117) explores how memory and materials intersect, particularly through the recollection of my grandmother. In these works, solid, crystal-clear glass jars become vessels for preserving the impressions of familiar objects such as cotton spools, oysters, and pigs' feet. These act as portraits, highly personal to the maker, yet carrying a universal resonance. They function as windows into absence, encapsulating entities that no longer exist, yet remain psychologically and emotionally present.



Figure 117. Joanna Manousis, *Distilled Portraits*, 2012, Core-Cast Crystal / Stainless, (x3) 16” x 6” x 6” / 40.5 cm x 15 cm x 15 cm

One jar in the *Distilled Portrait* series, containing the hollow of a magpie, marked a departure from the others. Naively, I felt that silvering the internal cavity of the magpie would transform it into a mirror. However, contrary to expectations, the silvering process did not produce a functional mirror. Instead, the bird's impression transformed into a static, opaque silver figure, devoid of reflection as seen in *Distilled Portrait I* (Figure 3).

As mentioned previously in Chapter 1, *Distilled Portrait I* initiated a pursuit to create reflective cast glass mirrors. For these reasons, the piece was recreated in this case study to see if a reflective magpie could be achieved in

a larger glass volume using lost-wax and tension-set mould making strategies.

4.4.2 Visual Analysis: *Distilled Portrait II / Series II*

Distilled Portrait I: Series II (Figure 116) incorporates everyday motifs. A utilitarian mason jar, fitted with an original wire lock, is used to preserve and contain food or objects. The magpie is a common species in the British landscape. Famed for its intelligence and ability to mimic sounds, the magpie has long been associated with magic, superstition, and fortune throughout the world.

Reappropriated in solid glass, the jar, with its integrated mirrored magpie, shifts *Distilled Portrait I: Series II* from a commonplace object to something obscure and otherworldly. Bubbles trapped within the body of the crystal jar suggest a liquid frozen in time, echoing the pickling vinegars used for preservation. The jar's curved surface magnifies the magpie mirror's appearance, just as a looking-glass lens allows us to perceive details. The jar serves as a lens to its contents, and the viewer finds themselves bound within a triangulated observation between the magpie and the mirrored bird.

4.4.3 Analysis of Methods: Distilled Portrait II / Series II

4.4.3.1 Phase 1: The Lost-Wax Method

The first magpie, made for *Distilled Portrait I* in 2012, was sculpted in clay but never translated into glass to produce a mother mould capable of achieving a smooth, high-gloss finish. The influence of factors such as investment composition, glass type, firing temperature and duration, as well as the corrosive effects of wax steaming on investment surfaces, was not yet understood.

These technical oversights contributed to residual surface textures and a matte aesthetic. Within this case study, the magpie core was recast using the mother mould developed during Phase 3 of testing. Due to time constraints for the solo exhibition *Iris Obscura* (2024), the outer jar form was fabricated using the lost-wax process rather than a tension-set system.



Figure 118. Hollow wax jars for investing magpie cores.

Two-part plaster moulds were employed to produce hollow wax jars (Figure 118) to encase magpie cores. Two sizes were tested: a 13 cm / 5” mason jar cast in Gaffer crystal with a ‘Thwaites’ investment mix (pottery plaster, quartz, and kaolin), and a 15cm / 6” mason jar cast in Bullseye glass using the same investment formula (see Figures 119 and 120).



Figure 119. An investment mould in progress for a 5” wide mason jar



Figure 120. Mason jar cast in Gaffer Crystal

The larger Bullseye jar cast successfully but was not worth polishing due to an inclusion of investment material and a dense white veil caused by devitrification and trapped debris. Such devitrification marks are commonly seen just under the sprue area of core-cast glass. In contrast, the smaller Gaffer crystal jar cast cleanly, although the bird's interior surface exhibited a raised texture not seen in the Phase 3 test specimens (likely due to wax steaming). The jar was polished with abrasive machinery and later acid-polished internally before applying a mirror-coating. Figure 120 shows the jar pre-polished, while Figure 121 shows the dome and jar cast in Gaffer after acid polishing.



Figure 121. Dome and mason jar cast in Gaffer crystal.

The dome (Figure 121, left) employed a core made of 25% pottery plaster, 25% Cristacal R, and 50% molochite, while the magpie jar (right) was made using the *Thwaites* mix. The dome, produced using a tension-set mould, displayed a notably smoother interior surface. These findings suggest that a tension-set mould system for the jar could refine surface quality further, offering a controlled means to compare textural outcomes against those derived from the lost-wax method.

4.4.3.2 Phase 2: Tension Set Method

Creating tension-set investment moulds for large-scale objects is costly and time-intensive. The polyurethane rubber or silicone mother moulds required to duplicate the investment components utilise a substantial volume of material, often costing several hundred pounds (GBP) for a large mason jar. Additionally, importing crystal from Germany is expensive, and multiple attempts are often necessary to achieve an inclusion-free casting. Veils and other imperfections can obscure the visibility of residual details within the glass body.

Figure 122 illustrates a rubber mother mould in progress for one-half of the mason jar investment. A clay blanket is applied over the model to act as a spacer between the half-mould and the supporting plaster jacket. Once the

plaster jacket is set, the clay is extracted, leaving a cavity that is then filled with silicone/polyurethane rubber to form a flexible rubber layer.



Figure 122. Clay set-up for mason jar rubber mother-mould

Figure 123 shows the final rubber mould in use. Once the investment material has cured, it is extracted and used to tension-set the core with the adjoining half.



Figure 123. A multi-part rubber mould for casting investment mould duplicates of a mason jar and reservoir.

As shown in Figure 124, the magpie core duplicate is positioned precisely within the central recess of the mason jar mould. The second half of the mould is then placed over the first and bound with fibreglass matting and a layer of investment reinforced with grog sand (Figure 125). The entire process must be performed continuously from start to finish to prevent the components from drying. This ensures that the mould parts adhere to the final outer jacket of investment, securing all parts together



Figure 124. Multi-part investment mould of a mason jar and reservoir holding a magpie core.

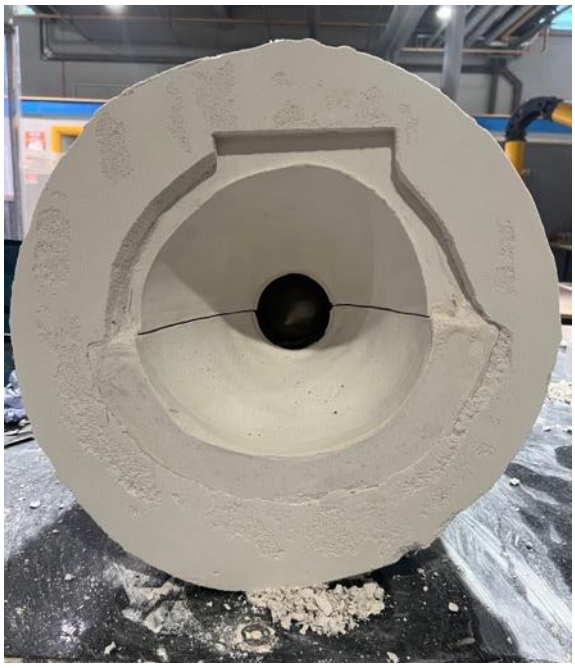


Figure 125. The interior view of a finished tension-set investment mould of a mason jar holding a magpie core.

Annealing the cast glass mason jars takes 2 weeks. The success of each casting is realised only after polishing the exterior of the glass, at which point internal flaws are revealed. The first *Distilled Portrait I*: Series II (Figure 116) cast (made using the lost-wax process) achieved good optical clarity with minimal veiling, inclusions, and bubbles. The tension-set method, however, required additional attempts to achieve a good quality casting.



Figure 126. Two acid-polished mason jar castings produced via the tension-set process, ready for mirror coating.

Figure 126 shows two acid-polished mason jar castings produced via the tension-set process, ready for mirror coating. A faint white haze is visible above the bird's head in the jar on the right. The jars were mirrored and coated with a mirror backing paint. Figure 127 shows the two jars after

mirroring, which, overall, have a higher degree of reflectivity compared to the first *Distilled Portrait I: Series II* sculpture made using the lost-wax technique (Figure 116).



Figure 127. Two acid-polished mason jar castings produced via the tension-set process, after mirror coating.

The process of mirroring glass accentuates surface inconsistencies and textures that might otherwise be unnoticed. The bird on the left in Figure 127 was cast using a magpie core composed of a 50:25:25 ratio of Molochite,

Pottery Plaster, and Crystacal R plaster. Crystacal R was used to refine the surface texture of the investment, as previous tests had produced superior reflectivity following acid polishing. Due to its strength, 25% Crystacal R was used with 25% Pottery Plaster to weaken the mix. This helped to prevent thermal stress during annealing, while also aiding divestment.

The bird on the right in Figure 127 was produced using a magpie core made of a 50:50 mixture of Molochite and Pottery Plaster. Interestingly, this cast demonstrated superior results in both mirrored surface quality and reflectivity, as well as a noticeable reduction in veiling. This outcome underscores the inherent unpredictability of the glass-casting process. Although previous tests had shown that Crystacal R could enhance surface smoothness, it did not give superior results working at a larger scale. This discrepancy may be attributed to variations in glass flow (an area for further research) and the differing thermal resistances of the mould materials. Figures 128 and 129 illustrate detailed views of the mirrored surfaces of both magpie casts.



Figure 128. Detail of mirrored magpie jar cast with an investment core made of 50% molochite, 25% pottery plaster and 25% Crystacal R plaster.



Figure 129. Detail of mirrored magpie jar cast with an investment core made of 50% molochite, 50% pottery plaster

In Figure 128, a rugged texture is visible on the left wing, while the right wing is smooth and more reflective. The bird made with a core of 50:50 molochite and pottery plaster (Figure 129) has a uniform, smooth surface. The crack

seen in the upper wing section has taken on the detail of a fissure in the investment rather than a crack in the glass itself.

Curiously, the bases of both magpies exhibited markedly superior mirror finishes in terms of surface smoothness and reflectivity compared to the head and body of the birds (Figures 130 and 131). This variation may be attributed to molten glass flowing directly over the upper surfaces, causing corrosion. In contrast, the base of each bird was shielded from direct glass flow, preserving the core's smoothness to achieve a more reflective finish. This observation highlights a potential avenue for further research into the dynamics of glass flow and its influence on investment surface quality.



Figure 130. Foot of mirrored magpie jar showing a higher degree of reflectivity. Magpie was cast with an investment core made of 50% molochite, 25% pottery plaster and 25% Crystacal R plaster.



Figure 131. Foot of mirrored magpie jar showing a higher degree of reflectivity. Magpie was cast with an investment core made of 50% molochite, 50% pottery plaster

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4.4.4 Conclusion: Distilled Portrait II / Series II

Distilled Portrait I: Series II is notably more reflective than its predecessor made in 2012 (Figure 3). Yet, while light reflects from the mirrored surface in this piece, the textured surface of the bird form disrupted the clear mirror image that was hoped for. Two further pieces were made using tension-set moulds. This approach produced a more reflective surface finish, though they also fell short of achieving a crisp reflection. The best reflective qualities were seen on the birds' bases, areas less affected by direct glass flow from the mould's reservoir.

Ultimately, the magpie sculptures produced through the tension-set method represent a final attempt to create detailed reflective surfaces within large-scale cast glass forms. The acid-polished crystal bird dome produced during phase 3 of studio testing achieved the highest reflectivity in this study. This differential could be due to more glass being required for the jar forms, which could have had a corrosive effect on the investment core.

The following key observations emerged during the making and exhibition of the *Distilled Portrait* series:

- A hand-sculpted form should be duplicated and refined in glass as a final model for core duplication, to eliminate tool marks and impressions from softer materials such as clay and wax.
- Polishing curved glass surfaces magnifies internal details; this optical effect should be considered in the overall composition of a piece to prevent optical distortion.
- Lost-wax casting can produce grainy surface textures that diminish the efficacy of mirror coatings.
- Deep or pointed negative details in glass are prone to retaining residues, leading to mirror contamination.
- Heavy veiling from devitrification in the mould's reservoir can become trapped within the cast. Overfilling the mould will allow the veil to rise into the reservoir area, which can be cut off the casting after annealing.

- Tension-set investment moulds are labour-intensive and costly but can significantly minimise surface textures caused by steam erosion using the traditional lost-wax method.
- Variations in the detail and scale of a core and the glass that encases it can alter the cast surface and its reflective qualities, even when sample tests appear consistent.
- The highest reflectivity in cast glass typically occurs in areas shielded from direct molten glass flow from the mould's reservoir.

Together, these insights underscore the technical challenges of achieving a mirrored surface in large-scale cast glass sculptures. The *Distilled Portrait* series represents not only a depth of artistic exploration but a technical milestone in the evolution of reflective glass casting within this research.

4.5 *Celeste*: Indra Series

Celeste (Figure 132) reimagines the earlier work *Indra's Web*, 2015 (Figure 7), introducing graphite moulds to create forms with greater reflectivity. The Hindu proverb of *Indra's Net* posited that human beings are jewels in the fabric of society, each reflecting the other. It was therefore important for the piece to read fluently so that viewers see themselves within the prismatic forms used for the *Indra* and *Celeste* series, while also suggesting a star-studded sky.



Figure 132. Joanna Manousis, *Celeste*, 2024, Cast Glass / Crystal / Mirror Stainless Steel / Aluminium, 293cm H x 798.5cm W x 12cm D

The following sections provide a visual analysis of *Celeste*, its inspiration and presentation in a gallery space. A background to using graphite moulds is given, clearly identifying the processes strengths and weaknesses, before finally reviewing the methods used to create the installation.

4.5.1 Visual Analysis: *Celeste*

Celeste (Figure 132) is an expansive 26.2ft W x 9.6ft H wall-mounted sculpture comprised of 440-dimensional glass prisms of varying sizes, each containing a mirrored prismatic void. The application of silver mirror gives visual solidity to the interiors of each piece, which are staggered in size from 3cm to approximately 26 cm in the round.

Three predominant prism sizes are repeated throughout the installation, yet although repetitive in scale, they exhibit distinct differences in pattern and hue. Some interior and exterior facets are smooth and flush, while others have a rippled texture. Five larger investment cast prisms, ranging from 20cm to 26 cm in diameter, break up the monotony of standardised small, medium and large graphite moulded forms.

The investment-cast prisms have a more refined, cut-glass surface with sharp edges and differentials in their mirrored surfaces. From a brushed silver aesthetic to a striking mirror-like quality, each is unique. Unlike most of the prism composition, the five larger ones are held to the backing plates with

stainless steel claws. Like diamonds clasped to a ring, their jewel-like appearance is elevated while also being necessary for weight distribution.

The mass of prisms could be perceived as expanding or contracting. Dense at its centre, the composition has smaller clusters dissipating outwards around the mass's edges. The distribution is light and airy. The space between each prism cluster frames the wall beyond, creating patterns, shadow and an overall lace-like quality. The wall becomes a reflective canvas, continually evolving in colour and light dispersal as it responds to its environment. The piece commands attention in its size and complexity. Figure 133 shows *Celeste* in situ within *Iris Obscura*, a solo exhibition held at The Athenaeum Building in Sunderland from May – July 2024.



Figure 133. Opening reception of *Iris Obscura* on 24th April at The Athenaeum Building, Sunderland, UK through Breeze Creatives.

4.5.2 Analysis of Method/Background: *Celeste*

In 2019, Brian Gillespie, Rhino Project Manager at Robert McNeel and Associates (Seattle, WA), introduced the concept of graphite ‘plunger’ moulds fabricated with 3-D modelling software and milling machines to produce repeatable glass forms that contain residual impressions. Graphite has very low adhesion to glass, producing smooth, translucent surfaces that are imperative for mirroring applications to appear reflective. 2-part ‘plunger’ moulds enable molten glass to be pressed into desired shapes easily and at a faster rate than investment casting, as a single mould can produce hundreds of units with minimal waste.

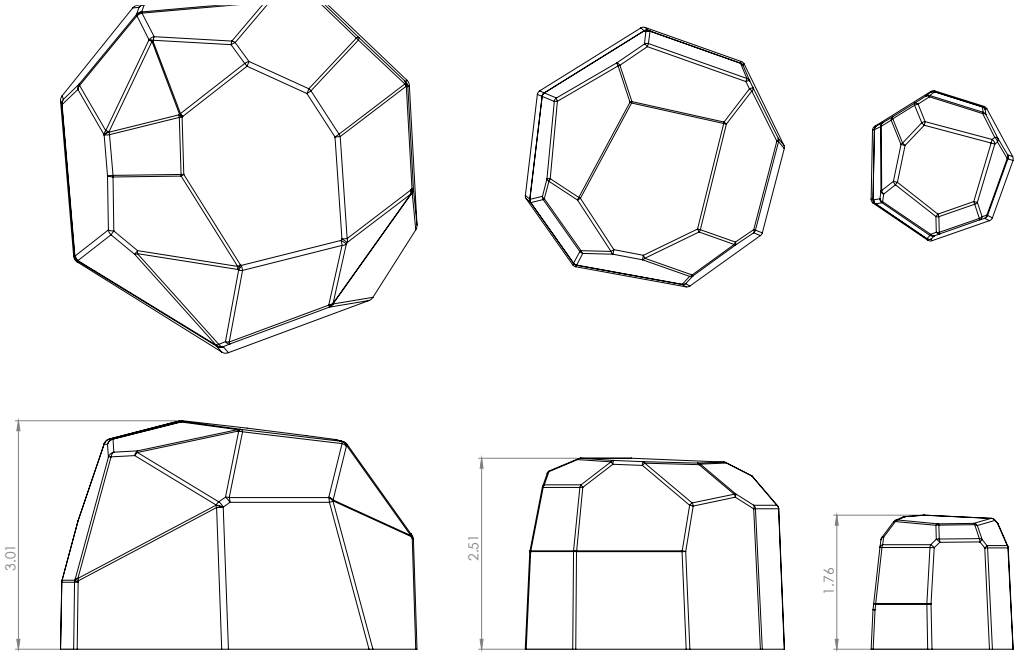


Figure 134. Drawing of prismatic forms used to create graphite ‘plunger’ moulds used for ‘*Indra* series.

Although this study focuses on the use of investment-moulded glass to produce cast surfaces for silvering, it was important to trial other materials and processes to determine whether superior, reflective mirrors could be made within complex, three-dimensional forms. Arts Council England supported the fabrication costs of three multi-part graphite moulds in 2021 that realise complex prismatic glass forms (Figure 134) containing recessed prism details. Given that *Indra's Web* took almost a year to complete, it was important to test the capabilities and limitations of graphite press moulds to expedite the fabrication of complex forms. Figure 135 shows a finished graphite press mould used for the large prisms seen in *Celeste*.

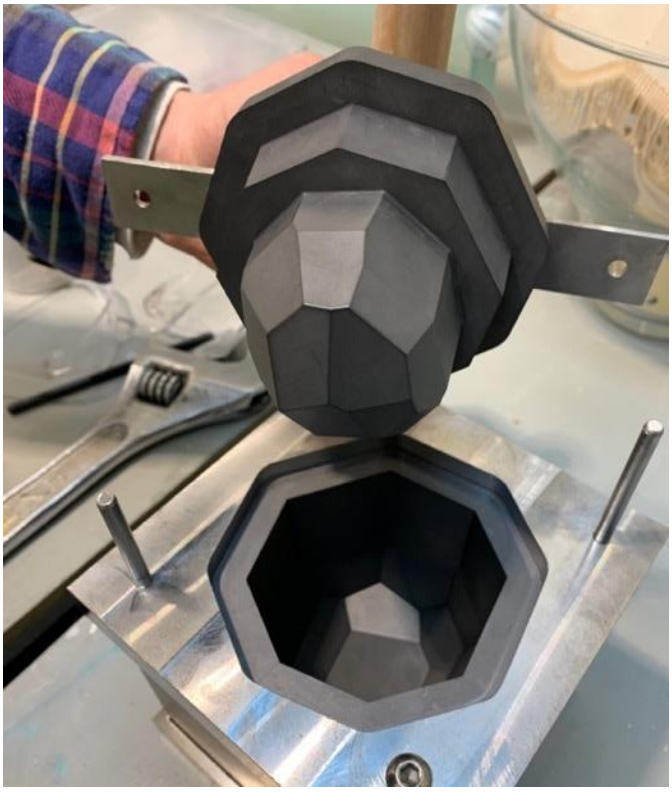


Figure 135. Graphite 'plunger' mould used for the large prismatic forms seen in *Celeste*, 2024

Graphite plunger moulds can achieve many repeated glass forms. Once mirrored, these surfaces produce a reflective mirror quality that does not require chemical or mechanised polishing. They also create less waste than investment cast forms, which use mould materials that need to be broken away from the glass and discarded. As with any fabrication method, there are positives and negatives to this process. The list below highlights the positive attributes of multi-part graphite plunger moulds:

- Sophisticated forms that are challenging to achieve by hand
- Optimal surface clarity for mirroring applications
- Expedited processing time
- Minimal waste
- Higher profit-to-expense ratio
- Greater yield
- Processes that are less impactful on the body

The disadvantages of using graphite moulds compared to investment moulds in the kiln are as follows:

- Interior voids cannot contain undercuts to ensure the mould releases from the glass.

- Graphite cast glass can feature rippled textures caused by glass chilling on impact with the mould, which can be visually distracting to the overall form.
- Graphite moulds are expensive to produce, often necessitating third-party fabricators and complex milling machinery.
- Graphite is a delicate material and can crack on impact.
- Graphite degrades over time when used at high processing temperatures.

4.5.3 Analysis of Method: *Celeste*

The investment cast prisms within *Celeste* include x1 hot-billet cast piece using Cristalica furnace glass, x2 kiln-cast prisms using acid-polished Gaffer crystal, and x2 kiln-cast prisms using Bullseye glass. These prisms took significant time and energy to create due to the hand-polishing needed to achieve peak translucency and shine in the exterior facets. Figure 136 shows the angle-grinding process used to remove the glass thickness from the prism before it is ground flat and further refined on a grit wheel. Kiln cast prisms were then ‘hand-lapped’ on sheet glass using loose silicon-carbide grit starting from 320 – 1200 before being polished with cerium oxide on a felt wheel.



Figure 136. Angle-grinding a glass prism with a 60-grit diamond disk to shave off glass thickness before refining the surfaces further through cutting and polishing.

Two phenomena occurred in the investment castings. A prism cast in Gaffer using a ‘Thwaites’ mix core incorporated large ‘sucker’ marks on the interior surfaces. This was caused by the glass being sucked away from the investment mould surface during annealing. Figure. 137 shows a detail of the sucker marks before the prism was acid polished and mirrored, while Figure. 138 shows the same piece after mirror coating. The bird-dome test using Gaffer (core: 25% Cristacal R Plaster: 25% Pottery Plaster: 50% Molochite),

contained similar marks, yet they occurred using different investment formulas.



Figure 137. Prism containing ‘sucker’ surface imperfections, cast in Gaffer glass using a ‘Thwaites mix’ core before mirroring.



Figure 138. Gaffer prism containing ‘sucker’ surface imperfections after mirror

A large prism cast with Bullseye glass using a 50/50 pottery plaster and molochite core showed fine patterns on the edge of the interior void left by the core. Reminiscent of cut ring patterns, Figure 139 shows the opaque curved lines on the glass surface, while Figure 140 shows the interior of the prism after mirroring. These marks look to be caused by devitrification from the interaction of glass flow on the investment surface, rather than investment clinging to the rubber mould and coming away in deposits from the core's surface.

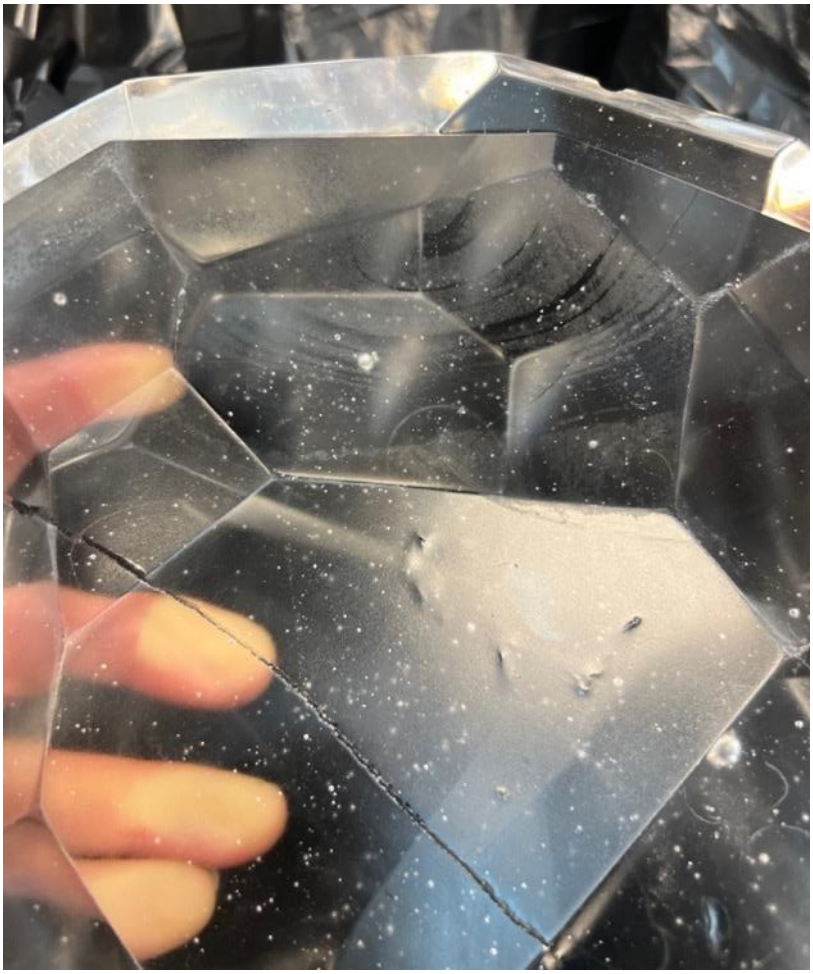


Figure 139. Un-mirrored Bullseye prism containing opaque 'striations' on the interior surface



Figure 140. Mirrored Bullseye prism containing opaque ‘striations’ thought to be caused by devitrification on the interior glass surface.

4.5.4 Conclusion: *Celeste*

Celeste incorporates milled graphite plunger moulds, a new glass-moulding method, in this research. The pros and cons of using graphite have been highlighted. Overall, the system works well when fabricating objects in volume that would otherwise be cost/time prohibitive using investment moulds.

The following bullet points address findings established in this case study:

- Graphite moulded glass has a translucent surface but does not achieve crisp reflective qualities when mirrored. This is due to chill marks on the glass surface resulting from the casting process.
- Casting objects in 2-part plunger moulds are limited by scale and complexity. No undercuts can be present in a form as the glass will not release from the mould. Large volumes can suction around plungers, which resist divestment.
- Creating large investment cast pieces using flat, faceted planes can incur suckers (indentations in the glass, normally caused by the glass cooling too quickly) and devitrification patterns caused by molten glass interaction with the mould.

4.6 Persephone

Persephone (Figure 141) is a multi-part, wall-mounted sculpture comprising 42 pieces. It mimics *Demeter's Rose,* 2015 (Figure 6) in its design but is approximately 2/3 in scale, with the addition of mirror-coated interior forms. Like *Iris Obscura II*, *Persephone* incorporates four distinct silvering effects within a single artwork, its intricately detailed voids designed to create visual contrasts in reflectivity. Variations in mirror qualities strive to evoke the varying light spans experienced through the seasons, which, according to Greek mythology, is caused by Persephone, the Goddess of Spring,

vegetation and fertility, descending to the underworld every six months of the year.



Figure 141. Joanna Manousis, *Persephone*, 2025, 85cm x 85cm x 10cm, Core-Cast Glass, Crystal, Mirror, Stainless Steel, Aluminium

This section presents a visual analysis of the artworks' form, placement, detail and reflective qualities, followed by an analysis of the methods used to create it. Through this, the case study addresses factors that affect the reflectivity of

cast glass, if they can create full reflections and how they can impart a thematic dialogue.

4.6.1 Visual Analysis: *Persephone*

The components in *Persephone* (Figure 141) are arranged in the formation of a rose window, a motif traditionally associated with stained glass in ecclesiastical architecture. Jewel-like due to its highly polished surfaces, with each segment held with stainless-steel claws, the work evokes the delicacy of a brooch. Measuring 85 cm in the round, the installation's composition expands beyond human scale, reinforcing its architectural resonance.



Figure 142. Joanna Manousis, Persephone (Detail), 2025, 85cm x 85cm x 10cm, Core-Cast Glass, Crystal, Mirror, Stainless Steel, Aluminium

Each glass segment contains recessed impressions of hand-sculpted wheat kernels and seed pods in bas-relief. These interior surfaces are mirrored, yet vary subtly in hue, texture, and reflectivity. At the centre, teardrop formations present cracked silver surfaces reminiscent of dry skin, while the wheat kernel forms are smooth and fully reflective. The kernels contrast the brushed silver cavities of lemon-shaped forms, while the outer ring of broader droplet forms contains deep matte-grey interiors, providing a striking contrast to the reflective kernels that lay adjacent.

Across the composition, perceptible differences in light reflectivity animate each segment of the rose window. The polished glass operates to magnify the interior forms. Although the silhouette of both exterior and interior shapes is repeated in a rhythmic pattern, each cast mirrored surface remains distinct and singular. Figure 142 illustrates the variation in mirrored surfaces across the individual glass segments.

4.6.2 Analysis of Method: *Persephone*

Persephone comes from a series of cast glass ocular windows and is the first to incorporate a range of mirroring effects, strategically chosen to exhibit different reflective properties. Four mirror qualities were used for individual forms. The teardrop shapes were cast using Bullseye ‘Crystal Clear’ Glass,

while Gaffer G20 lead crystal was used for the remaining wheat and lemon-shaped forms.

Open-face mother moulds were formed from hand-sculpted clay and polished glass components, creating interior bas-relief details and the investment mould base. The top of the investment mould incorporating a reservoir was made using a three-part mother mould. After the casting process, each glass piece was divested, cleaned, and hand-polished before being coated with a mirror. The elements float out 2.5cm / 1” from the wall using machined stainless-steel armatures.

4.6.3 Conclusion: Persephone

The bulleted list below addresses findings gleaned within this case study:

- A variety of cast mirror effects with different reflective properties was used to address diminished light in the winter months, which has links to the Greek myth of Persephone, and her decent to the underworld.
- Cast mirror effect were consistent with those produced in phases I and II of testing.
- The wheat kernel forms within the sculpture achieve a good reflective quality due to being cast in lead crystal and chemically polished prior to mirror coating. Hazy reflections can be identified, like those seen in the acid-polished eye formation within *Iris Obscura II.* This directly

addresses the research question of whether cast glass mirrors can achieve a reflective quality.

4.7 The Birmingham School of Jewellery Placement

4.7.1 Introduction: The Birmingham School of Jewellery



Figure 143. Interior view of studio galleries at Birmingham School of Jewellery through Birmingham City University

The following section outlines a placement facilitated between Nuala Clooney, Lecturer at Birmingham City University and me at the Birmingham School of Jewellery (Figure 143). As a Northern Bridge Consortium (NBC) researcher, funding was secured to conduct research away from the

University of Sunderland. This opportunity introduced ten undergraduate students in jewellery design to the cast mirror-making process using bas-relief moulds. This directly addressed the research questions of what factors inhibit and enhance mirrored cast glass, and the practical and creative parameters for using mirrored cast glass at varying scales and complexities. It also met the aim to establish how the methods used in this research are translated by others through teaching placements and workshops This experience contributes both to this doctoral investigation ant the development of technical and teaching pedagogy skills relevant to future practice.

Using the Crafts Council England *Handling Collection* to foster idea development, a 10-week intensive workshop focusing on bespoke glass jewellery, integrating cast mirrors, was taught. The following case study details the pedagogical framework, methods of making, and student outcomes, which culminated in a public exhibition of works at the Vittoria Gallery, Birmingham, in 2026**.**

Rather than focusing on my own artwork, this study examines the learning outcomes of other practitioners who engaged with the studio methods developed in Chapter 3: Studio Testing. Through this, it was possible to see whether the cast glass mirror effects remained consistent when working with intimately scaled, detailed surfaces, thereby proving the versatility of the

methods. The class also enabled the technical and conceptual interpretations of other individuals working with core-cast mirrors for the first time to be observed. This ‘think tank’ for cast mirror making and design sparked unique dialogues and perspectives, inspiring and enriching both the students’ creative practice and my own.

Alongside sharing glassmaking and mirroring skills 1 day a week, I participated in the Higher National Diploma (HND) in Jewellery and Silversmithing two days a week. As a student, I participated in tutor-led workshops and practised small-scale metal fabrication. This immersive experience established a range of approaches to setting stones in metal, methods that could translate to glass. This directly informed the technical and conceptual development of a future body of work: intimately scaled cast mirrors designed to adorn the body.

The reciprocal exchange was structured as a research method**.** Student engagement provided insights into how cast glass mirrors can be interpreted, adapted, and hybridised within a jewellery-making context. Despite studying in Birmingham, a city historically central to jewellery production and glass innovation during and after the Industrial Revolution, students had never

previously considered creating their own cast glass stones in their work and were both excited and curious.

4.7.2 Glass Workshop: The Birmingham School of Jewellery

Glass has a long, rich history within the jewellery field. In ancient civilisations, it was regarded as a precious material for crafting beads, amulets, and cabochons that adorned sacred and ceremonial objects. The ability to facet glass allowed it to imitate gemstones, while in Victorian England, the popularity of polished black glass, often referred to as “jet glass”, became associated with mourning jewellery, emulating stones such as onyx and jet.



Figure 144. Angela Thwaites, 2017, *Vessel line up*. Photo D. Lawson

Despite this lineage, the integration of cast glass within contemporary jewellery remains limited. Contemporary artist Angela Thwaites-created what she calls ‘nano’ cast glass objects intended to adorn the body. *Vessel Line Up* (Figure 144) shows small-scale glass castings made for her PhD thesis (Thwaites, 2018). Within this series, hollows were created within cast glass bead forms using CAD software and 3D printing, which could then be strung as pendants.



Figure 145. Linda MacNeil, Waterford Series, Lotus Brooch, No. 1, 1999. Lead crystal and 18k yellow gold. 3 x 2 inches (7.62 x 5.08 cm). Image Credit: Bill Truslow. Private collection.

Few metalsmiths possess the expertise required to cast their own glass gemstones, while many accomplished glass artists lack the technical training to create refined metal settings. Exceptions to this rule are few and far

between. USA based artist, Linda MacNeil creates notable examples of jewellery integrating glass in sophisticated mounts that are unique to each piece (*Linda MacNeil Jewels of Glass*, no date).

As seen in Figures 145 and 146, there is a fluidity in MacNeil's pairing of glass and metal, each medium carefully silhouetting the other. This contrasts with many contemporary jewellery pieces; whereby pre-made metal findings are adhered to the glass piece. Although MacNeil has incorporated mirrored glass within her work, a survey of current glass and jewellery practices revealed that cast mirrored glass retaining the natural surfaces taken from an investment mould remains largely absent in jewellery.



Figure 146. Linda MacNeil, Waterford Series, Lotus Necklace, no. 2,m 1999. Lead crystal, green glass detail, and 18k yellow gold. 7 inches (17.8 cm) (diameter). Image Credit: Bill Truslow. Collection of Currier Museum of Art.

Given that the works in this thesis primarily comprise larger, wall-based or freestanding sculptures, this case study sought to examine intimately scaled castings as potential sites for mirrored surfaces. The workshop introduced students to open-face investment moulding**,** lost-wax casting, and bas-relief casting, using the same processes established in *Phase 1 of the Studio Testing* chapter (Figure 147). These sessions emphasised the potential for crossover between glass and metal practices, encouraging students to experiment with material hybridity and surface reflection.



Figure 147. Joanna Manousis teaching ten jewellery designers at The Birmingham School of Jewellery through Birmingham City University

Thirty objects were selected from the Crafts Council Handling Collection, an archive of over 800 contemporary works in a variety of materials and techniques as a springboard for student ideas (Figure 148). This enabled students to study and handle the objects directly, an approach designed to offer tactile engagement and experience. Each student selected two to three pieces as sources of inspiration for their designs combining metal and cast glass. Several students chose to apply mirror coatings to their work, including test pieces made as a group.

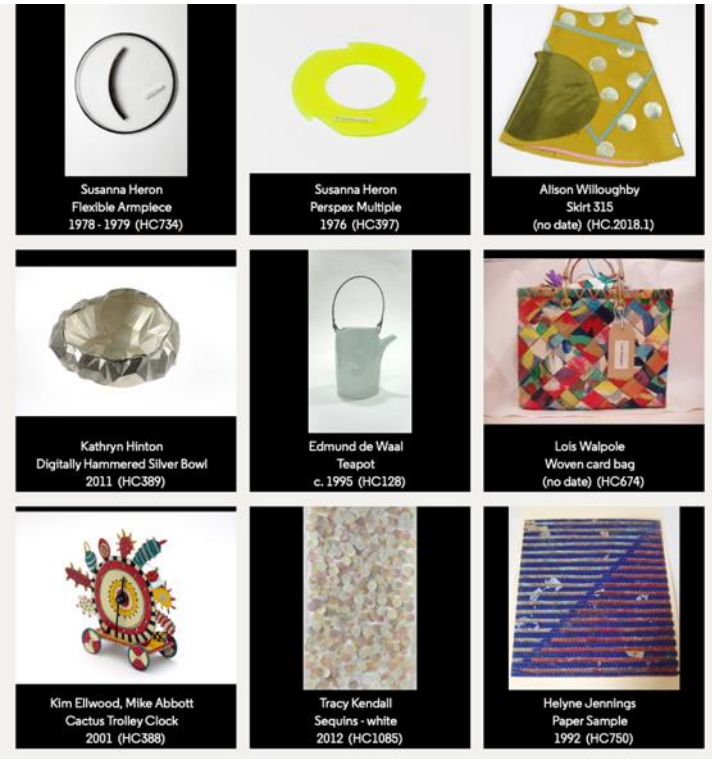


Figure 148. Screenshot of Crafts Council website highlighting select objects from the Handling Collection

Students began by modelling in wax and clay to produce silicone moulds (Figures 149 and 150). These moulds were used either to generate wax

positives for lost-wax casting or as direct silicone positives for bas-relief work. The resulting glass pieces could be polished and silvered to produce mirrored surfaces where appropriate to the design concept. Despite the short timeframe, participants were able to engage in all stages of the making process, developing both technical understanding and aesthetic sensitivity in relation to glass.



Figure 149. Student holding a carved clay fossil used as a base model for a silicone 'mother'

Some material and equipment limitations were mitigated through generous industry support. Bullseye Glass Company provided a range of coloured frits and billets for student use, while HIS Glass (Asheville, NC), in partnership with Covington Inc. and Lap Dancer, donated a portable diamond grinding wheel with interchangeable discs and a faceting arm for satellite casting classes. This equipment extends the project's legacy by enabling continued glass experimentation across future classes focusing on wearable glass.



Figure 150. A student working on an investment mould set-up taken from a silicone positive.



Figure 151. Progress of clay model, with a final glass casting duplicated from the original clay form

Figure 150 shows a student working on an open-face investment mould setup while Figure 151 shows the demonstration piece that guided the students process, a core-cast diamond form inspired by *Parr Diamonds*, 2018 (Figure 152). The diamonds, along with companion elements of pearls and rosettes,

was conceived as a series of individual brooches, dispersed and worn by multiple wearers.



Figure 152. Joanna Manousis*, Parr Diamonds*, 2018, Cast Crystal, Glass, Stainless Steel, Oil Paint, 62 x 37 x 4”

Due to time and efficiency constraints, students were only able to achieve two mirror finishes using Gaffer Crystal and Bullseye Glass. These glasses were cast into moulds using the commercially produced investment mix, Crystalcast made by GoldStar Powders, UK. Having never seen a mirroring demonstration before, the students were curious to see how mirror coatings adhere to glass surfaces. Students prepared and cleaned their cast glass objects, which were mirrored collectively (Figure 153). Most of the mirrored surfaces, using Gaffer glass and Crystalcast investment, were consistent, featuring a bright, matte silver finish (Figure 154).



Figure 153. Students at The Birmingham School of Jewellery through Birmingham City University observing a mirroring demonstration.



Figure 154. A mirrored cast glass fossil made by Birmingham City University student, Ellie Johnson

One piece containing the impression of a hand-sculpted swan developed a more granular, contaminated surface, with brown spots visible against the silver (Figure 155). These contrasts resulted from grog-sand particles in the investment adhering to the glass surface, depositing onto the mirror coating. The student did not mix the investment long enough for the grog to disperse evenly throughout the thicker mixture before pouring it over the silicone positive. As the investment was still thin, the grains settled and accumulated on the investment core, producing surface inconsistencies.



Figure 155. A hand-sculpted cast glass swan with granular brown specks against the silver mirror coating caused by grog sand.

Further explorations using small forms with intricate details were produced by the students. Figures 156 – 158 shows the development of Mantong Jiang's work from idea development to a finished work.

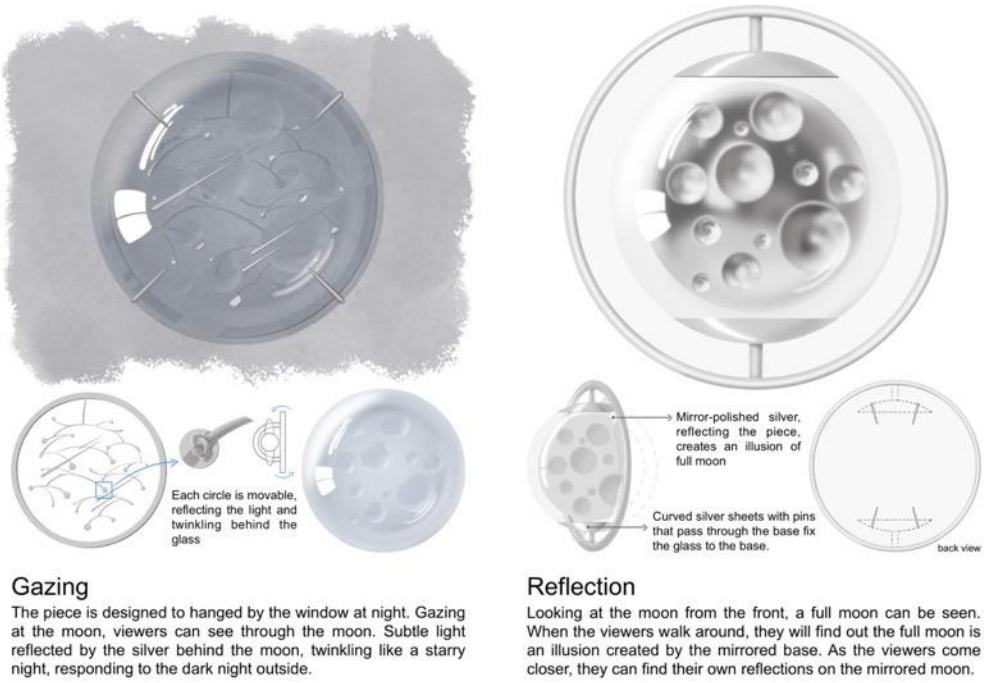


Figure 157. *Moon Brooch* design by Mantong Jiang, The Birmingham School of Jewellery, through Birmingham City University.



Figure 156. Investment moulds of a moon form (top left), and an abstract cityscape (lower middle) made by Mantong Jiang at The Birmingham School of Jewellery through Birmingham City University.



Figure 158. Mantong Jiang**,** *Into the City,* 2025. Glass, Sterling Silver

4.7.3 Conclusion: The Birmingham School of Jewellery

The core details in the student's work at the Birmingham School of Jewellery were hand-formed in clay. The scale and tooling of these forms prevented them from being cast in glass and polished as base models for final mother moulds, as demonstrated in Studio Testing Phases 2 and 3 (Chapter 3). For these reasons, and because Crystalcast was used to make all moulds, the class achieved only one mirror finish. Except for one piece (Figure), the fine detail on many cast surfaces resulted in mirror coatings consistent with those obtained using Gaffer and Bullseye glasses cast with Crystalcast during Phases 1 and 2 of the studio tests.

The Birmingham School of Jewellery placement demonstrated that jewellery students, even with limited prior experience in glass casting, can successfully produce cast mirrors with consistent reflective quality when following established technical protocols. The project further confirmed the reliability of the mirror-coating process across varied surface geometries and reinforced the adaptability of core-casting methods within a jewellery context. By integrating glass-working techniques into a metals-focused curriculum, the workshop not only expanded students' material vocabularies but also highlighted the creative and technical possibilities of cast glass mirrors as wearable objects, an outcome that directly supports the broader aims of this research.

5 Conclusions and Areas for Further Research

This chapter reviews the objectives, aims and research questions outlined in Chapter 1. The extent to which they have been met is addressed, which in turn informs the related contributions to knowledge. Contributions are situated within the history of mirror-making and contemporary art, as stated in Chapter 2: Contextual Review. The study does this by introducing new fabrication methods and offering artists fresh insights into how a diverse range of cast mirror effects can be produced and integrated into glass practice. The chapter identifies potential directions for further research, and how this research has met the PhD learning outcomes established by The University of Sunderland. The thesis ends with closing remarks.

5.1 Introduction to Chapter 5

This final chapter synthesises the study's conclusions, addressing the research objectives, aims, and questions first outlined in Chapter 1: Introduction. It examines the sequence of actions undertaken throughout the research, beginning with the Contextual Review**:** Chapter 2, which examined the history of mirror production, its symbolism and use in domestic interiors, and its relevance within contemporary art practice.

A review of existing literature revealed a notable gap in resources concerning the use of cast glass objects as reflective surfaces. While publications explore the reproduction of glass surfaces and commercial materials for glass casting, they do not address their potential for creating mirrored surfaces. These insights informed the development of making strategies**,** the selection of materials for studio testing, and the creation of artworks presented as Case Studies in Chapter 3**.**

Chapter 3 extended the technical testing phase by introducing new mirrored glass forms at varying scales. By exhibiting these works and disseminating them through publications, lectures and teaching, the study demonstrates the creative potential of cast mirror-making within both the glass art community and the wider field of contemporary art. This dissemination fulfilled the final research objective: to circulate the findings, obtain peer feedback, and identify how the generated knowledge can benefit other practitioners.

In line with these objectives, this chapter presents conclusions relating to each research aim. The first aim sought to establish a range of mirroring effects for creative cast glass mirror-making that could inform both the researcher's own practice and that of other artists seeking to control the optical and surface qualities of cast forms using investment and graphite moulds. The second aim provided practical guidance to improve mirrored and unmirrored cast glass surfaces, as developed through the experiments described in Chapters 2 and 3.

This chapter concludes the interpretative strand of the research by examining the themes and meanings developed through the artworks discussed in Chapter 3. It reflects on how the symbolism and production methods of early mirrors, and their application within contemporary art, inform the aesthetic,

conceptual, and optical dimensions of the artworks created as part of this study. The most critical component of this chapter is evaluating the research questions, determining how effectively the practice-based and written components have met the initial aims and learning objectives.

Following the conclusions of research questions, the chapter identifies the study's contributions to knowledge, which are summarised as nine key features. It then considers areas for future research, highlighting opportunities for further development by other researchers. The chapter closes in evaluating how the project has met the seven PhD learning outcomes set by the University of Sunderland. Finally, closing remarks summarise the key findings and point towards additional specialist materials presented in the Appendices**.**

5.2 Conclusions in relation to Research Objectives

The following research objectives laid out in Chapter 1: Introduction of this thesis are outlined individually. A summary of the study highlights how these objectives were met.

5.2.1 To carry out a contextual review investigating how mirrors were made, used and symbolised throughout history, and within contemporary art practice.

A contextual review was presented in Chapter 2 (pp. 62-124), providing an overview of how mirrors have been made and used throughout history, together with some of symbolic meanings attributed to them. For centuries, mirrors have been regarded as prized possessions, with successive generations striving to improve the reflectivity of blown and sheet glass. Their value extended beyond practical use, functioning not only as tools for self-reflection but also as emblems of status, wealth, refinement, and as conduits to higher spiritual realms (Gregory, 1998; Melchoir-Bonnet, 2001). The enigmatic qualities of early mirrors, which often produced distorted images, fostered dualistic associations (Schechner, 2005). They came to embody both good and evil, while also serving as magical devices believed capable of conjuring angels, such as John Dee's looking glass. These enduring associations have continued to resonate and are reflected in some of the themes examined in Chapter 4: Case Studies.

The review also considered the role of glass and non-glass mirrors in contemporary art, where their ability to generate optical experiences is often intertwined with conceptual and symbolic significance. In particular, the examination of reflective and non-reflective mirrors highlighted the absence of

cast-glass mirror-making within the field, suggesting its potential as a distinctive and valuable method for creating sculptural glass forms that capture negative impressions. Furthermore, the study revealed how non-reflective mirrors have become meaningful artistic choices, a direction explored through the production of numerous non-reflective mirrors within practice and teaching.

Finally, the contextual review identified an emerging community interest in achieving translucent cast-glass surfaces through investment moulds, alongside the ongoing development of materials and techniques designed to minimise glass adhesion, an essential quality for producing reflective cast-glass mirrors. The survey of texts concerned with refining cast-glass surfaces established a foundation for the studio investigations presented in Chapter 3. Through this contextual review, Objective 1 has been addressed.

5.2.2 To investigate through studio testing how base models, glass bodies, investment materials, firing temperatures, firing durations, and chemical polishing affect the surface quality and reflectivity of cast glass.

Over 150 individual tests were carried out to investigate the variables influencing surface quality and reflectivity in creative cast-glass mirror-

making, as documented in Chapter 3: Studio Testing. These experiments informed the artworks and teaching presented in Chapter 4: Case Studies, which extended the testing phase by introducing different scales and complexities in the base models used for casting glass forms and negative impressions.

Phase 1 was the most time-intensive testing stage, as it explored a wide range of variables: wet versus dry moulds, flow behaviour at both low and high firing temperatures, extended versus shorter firing durations, the effects of investment materials and hBN coatings on surface finish, and post-chemical polishing treatments for lead-bearing glasses. Results indicated that pre-firing moulds, followed by casting at lower temperatures with shorter firing times, produced the most successful surfaces. This phase also revealed a series of cause-and-effect relationships among the four glass bodies tested, the investment materials, and the hBN coatings applied.

Phase 2 streamlined the material variables and introduced enclosed investment moulds using a tension-set process. Curved surfaces in the round were compared to the flat mirrors from Phase 1. While differences in mirroring outcomes between phases were subtle, slightly higher reflectivity was

observed in some samples with curved recesses than in their flat counterparts.

Phase 3 narrowed the testing to six samples, incorporating the recess of a magpie within larger glass domes. This stage introduced the hot-billet process and examined variations in results when applying reflectivity was observed in some samples with curved recesses than in hBN Lubricoat. Together, the findings from Chapters 3 and 4 demonstrate that no single method, material, or process guarantees consistent mirroring effects. Instead, outcomes are highly dependent on interrelated factors such as the base model, glass type, investment materials, and firing conditions. Objective 2 has therefore been successfully achieved.

5.2.3 To produce artworks and jewellery using a range of base models that extend the material testing phases to demonstrate the varied potential of cast mirrors within contemporary art.

In Chapter 4: Case Studies, the testing phases were extended through the production of six distinct bodies of work that scaled up cast mirror-making, along with scaled-down jewellery pieces made by ten students during a teaching placement at the Birmingham School of Jewellery. Both reflective

and non-reflective qualities were deliberately explored, not only for their visual impact but also for their thematic resonance.

The artworks made within this thesis draw on the symbolic connotations of reflective surfaces discussed in Chapter 2: Contextual Review. For example, *Iris Obscura I* employed multiple investment recipes to generate subtle variations in the mirror of a single form, while *Persephone* integrated 42 individual castings to combine four distinct reflective and non-reflective effects. Similarly, *Celeste* and *Iris Obscura* demonstrated how the degree of reflectivity can be manipulated to produce nuanced shifts in the mirror's surface. Together, these artworks illustrate the varied potential of cast mirrors within contemporary art practice, confirming that objective 3 has been met successfully.

5.2.4 To explore how cast mirror practices can be integrated into jewellery designs.

This objective was met successfully during a teaching/study placement at The Birmingham School of Jewellery, with support from the Northern Bridge Consortium. Students learned how to create small-scale bas-relief glass mirrors inspired by the Crafts Council England's *Handling Collection*. Students used their established expertise in small metals to create unique settings for their glass forms, which were exhibited at the Vittoria Gallery, Birmingham, in 2026.

5.2.5 To disseminate the results of studio testing and finished artworks to establish research.

This objective has been met successfully by exhibiting case studies, including *Iris Obscura I+II*, *Celeste*, *Persephone*, *Distilled Portrait I: Series II*, *Mirror Palette I, II, III,* and works made by students from the Birmingham School of Jewellery*,* internationally and within the UK. This gave public audiences the opportunity to engage with works, establishing their relevance within contemporary visual art practice and jewellery design.

The dissemination of results from studio testing and the artworks made as case studies took place through a range of exhibitions. These included *This is Becoming a Pattern* at the Pittsburgh Glass Centre, USA; the *British Glass Biennale* in Stourbridge, UK; *Iris Obscura* at the Athenaeum Building, Sunderland, UK; *Three Artists* at the National Glass Centre, Sunderland, UK, and a showcase of student works at Vittoria Gallery in Birmingham, UK. These exhibitions attracted positive responses from both the glass-art community and the wider public, generating further opportunities for lectures, seminars, and teaching.

5.3 Conclusion in Relation to Research Aims

The previous section outlined the conclusions drawn from the research objectives, highlighting how the creative practice and supporting oral research were undertaken and evaluated through planned actions. This section now turns to the research aims that guided those activities and presents the associated conclusions. Each aim is addressed, demonstrating how the corresponding objectives supported its achievement while summarising outcomes.

5.3.1 To establish a range of visual effects in creative cast glass mirror-making.

A broad spectrum of mirror effects was achieved through the three stages of material testing outlined in Chapter 3: Studio Testing and subsequently developed within the scaled-up artworks and scaled-down jewellery presented in Chapter 4: Case Studies. Both reflective and non-reflective surfaces were integrated into finished works. These effects embody a variety of visual qualities, including surface finishes that echo the hues and textures of materials such as coal, granite, brushed and reflective silver.

A particularly significant outcome was the discovery that painterly cast-mirror effects could be achieved by applying Hbn coatings directly to investment moulds using a paintbrush. This process enabled the introduction of gestural

marks and linear qualities into mirrored surfaces, an unexpected yet valuable revelation that extends the expressive potential of cast-glass mirrors. This finding is examined in greater depth in the ‘Contribution to Knowledge’ section of this chapter.

5.3.2 To provide practical guidance for creative practitioners seeking to enhance the surface quality of their cast glass objects and/or those aiming to incorporate cast glass mirrors into their work.

Chapters 3: Studio Testing and Chapter 4: Case Studies both serve as practical guidance for artists looking to control/improve the surface quality of cast glass objects, as well as those looking to incorporate cast mirrors into their practice. As noted previously, changing the model, glass body, investment, firing temperature/duration, and other factors, such as the method of fabrication or the kiln, can alter the surface qualities of cast glass and subsequent mirror coatings. For these reasons, this thesis serves as a basic guide to follow and expand upon, keeping in mind that all explorations with new materials and processes should be tested.

5.3.3 To create cast glass mirror artworks that identify and develop themes and interpretations, drawing on the historical associations of reflective glass.

This aim was achieved through the creation of artworks and jewellery, as seen in Chapter 4: Case Studies. The dualistic symbolism of mirrors, representing both good and evil, influenced *Iris Obscura* I+II. Here, deliberately cracked lenses are reframed as positive attributes, while the glass eye formations reference historical descriptions of mirrors as “all-seeing eyes of God.”

Distilled Portrait I: Series II incorporates the mirrored motif of a magpie, a bird attracted to shiny objects, which, in turn, has the rare ability to understand its own reflection. In *Celeste*, a constellation of reflective prisms that draws inspiration from the metaphor of Indra’s Net in Hindu cosmology.
Finally, *Persephone* employs both reflective and non-reflective mirrors to comment on seasonal cycles of diminishing light. Rooted in Greek mythology, the work references Persephone’s consumption of pomegranate seeds offered by Hades, which binds her to the underworld for half of the year.

Through these case studies, cast-glass mirror artworks have been developed that integrate the mirror effects established in Chapter 3: Studio Testing, while

exploring the historical associations of reflective glass and their resonances within contemporary art practice.

5.4 Conclusion to Research Questions

Conclusions to the research objectives and aims, developed through both creative practice and scholarly investigation, have now been established. This section turns to the four key research questions that form the foundation of this study and underpin its practical and theoretical explorations. Each question is addressed in turn, with conclusions informed by insights gained through the contextual review in Chapter 2, and the studio practice presented in Chapters 3 and 4. Together, these strands of inquiry provide the framework for articulating and evaluating the study's findings.

In the following subsections, each question is revisited, drawing on the outcomes of both practice-based experimentation and theoretical analysis. Collectively, these conclusions demonstrate how the research objectives have been met and how new knowledge has been generated through the integration of making, reflection, and critical review.

5.4.1 What factors inhibit and enhance the reflective qualities of a mirror coating on a cast glass surface?

The factors that inhibit and enhance the reflective qualities of mirror coatings on cast surfaces were addressed through three phases of studio testing, as seen in Chapter 3. When glass is cast at high temperatures in investment moulds, a range of cause-and-effect relationships influence the quality of its surface. These factors determine how the glass takes shape and interacts with the mould's composite materials, producing variations in detail, texture, opacity, and, at times, contamination. Such factors can generate undesirable surface characteristics to produce reflective mirrors. Conversely, these opposing qualities can be valuable when striving to achieve a range of contrasting, unreflective effects that push the boundaries of what mirror coatings can look like, function, and convey.

The bullet-point summary below outlines factors that inhibited the reflectivity of mirror coatings on cast glass in this study:

- A base model used for the core-investment mould with surface texture, and/or protruding points with sharp angles, leads to investment contamination on the glass surface, causing mirror staining and/or light deflection.

- Wax steaming causes surface deterioration and weakened mould strength, resulting in surface textures that negate reflectivity and/or fissures caused by investment cracks on the glass.
- High firing temperatures and long peak firing durations will heighten cast glass surface opacity due to interactions between the glass body and the investment material. This leads to unreflective, matte or contaminated mirror coatings.
- Loose Hbn powder mixed in gypsum-based investments and phosphate-bonded investments causes severe sticking and contamination on cast glass surfaces, leading to black, unreflective mirror coatings.
- BN Lubricoat ZA Paste (BNZA) and ZBN Release (ZBN) made by Zyp Coatings Inc. caused severe sticking and contamination on cast Reichenbach 1500, Gaffer G20 and Bullseye glass surfaces, leading to black, unreflective mirror coatings.
- hBN coatings leave impressions on cast glass when applied with a spray gun or brush to a mould. These textures scatter light, preventing a truly reflective surface even when a mirror coating is applied.
- Adding 6% kaolin by weight to 47% quartz and 47% pottery plaster can reduce glass adhesion on a mould but can lead to devitrification on the glass surface. This appears as silver striations when the glass is mirrored.

- Molochite (50/50 molochite/potter plaster) is a superior refractory for resisting sticking between the glass and investment, yet it is a weaker mould material, leading to investment cracking. This can affect the glass surface, thereby interfering with the reflectivity of a mirror coating.
- Graphite-moulded glass can display chill-marks on the surface caused by hot glass encountering a cold mould. This causes a scattered reflection.

Factors enhancing the reflectivity of mirror coatings on cast glass:

- Base models made from smooth, shiny materials create even surface finishes on or inside cast glass objects. This aids the divestment and cleaning process of the glass, reducing the risk of mirror staining caused by contamination. Reduced texture in tandem with surface translucency can lead to a reflective mirror coating on the glass surface.
- Using rubber ‘positives’ for open-face investment moulds, or multi-part tension-set moulds for enclosed forms, alleviates the need to use wax as a modelling material, which, through steaming, leads to inferior cast glass surfaces. These altered fabrication methods can enhance the smoothness and clarity of the glass surfaces and overall brightness of a mirror coating.

- Lower firing temperatures and shorter firing durations produce a more translucent surface finish on cast glass by reducing interaction between the glass body and the mould investment. This leads to improved reflectivity when a mirror coating is applied.
- Within this study, BN Lubricoat-ZS (BNZS), BN Lubricoat (BNLUB), Type ZO (BNZO), Glass Release DMX Powder and Glass Release Spray made by Zyp Coatings Inc., repelled Reichenbach 1500, Gaffer G20 and Bullseye glass from sticking to a mould, leading to heightened reflectivity when a mirror coating is applied.
- Reichenbach's clear lead crystal (40%) yields the most translucent surface finish among Bullseye, Reichenbach (15% lead), Gaffer, and Cristalica, resulting in matte-iridescent silver mirrors that do not reflect light.
- Adding 6% kaolin by weight to 47% quartz and 47% pottery plaster can reduce glass adhesion on a mould, resulting in smoother, transparent surface finishes that reflect bright, matte-silver mirrors.
- Molochite (50/50 molochite/pottery plaster) is an excellent refractory material for casting Bullseye, Gaffer, and Reichenbach, resulting in less interaction between the glass body and the investment. This creates brighter matte silver surfaces when a mirror coating is applied.
- Graphite moulds give hot-cast glass forms a translucent finish, enabling reflective mirror coatings.

- Curved core surfaces cast in glass exhibit better reflective qualities when mirrored than flat core surfaces.

Establishing the factors that inhibit and enhance the translucency of cast glass, which in turn affect the reflectivity of mirror coatings, gives practitioners greater control when aiming for a particular surface finish. The results of testing and the journey to creating finished artworks, as seen in Chapters 3 and 4, also help situate new methods of artmaking with mirrored-cast glass that may not have been previously considered. For example, the creation of rubber positives, or tension-set moulds to alleviate the need for wax as a model material, or the painterly two-tone mirroring effect that can be created when applying hBN coatings directly to a mould with a paintbrush. All these factors offer original contributions to the field of glass art that have not yet been published elsewhere.

5.4.2 Can cast glass surfaces made with an investment mould fired in a kiln be reflective once mirrored?

As stated in the previous section, three stages of studio testing established the factors that inhibit and enhance the reflectivity of the mirror application. This testing phase was extended to include the fabrication of the final artworks used as case studies in Chapter 4. Scaling up the dimensions and complexity of cast glass clarified the question posed above.

In short, the answer to this question is yes. That said, there are caveats. This study identified several factors that improve the smoothness and surface translucency of cast glass, such as curved, polished base models, using rubber positives, or a multi-part tension-set investment-mould using 2–4-part mother moulds. Also, using investment materials that resist sticking and firing at low temperatures for short firing durations improves the translucency of the cast surface. That said, none of the cast glass pieces in this study yielded a fully reflective mirror application without post-firing processing.

Objects cast in leaded glass (Reichenbach and Gaffer) achieved reflective mirror coatings through chemical polishing, while harnessing the critical factors outlined in the previous paragraph. The acid's reaction with leaded glass transforms surfaces that would otherwise be prohibitive to cold work by hand.

Artworks that harness good reflective properties, in which a viewer can see their reflection within the object, were the leaded glass components made in *Mirror Palette III*, *Iris Obscura and Persephone*. These pieces had concave or convex cavities for mirroring. Heightened reflective surfaces were also seen in the larger acid-polished prisms comprising *Celeste* and *Roughness Comparator*.

It is important to note that although *Mirror Palette III*, *Iris Obscura, and Persephone* embody reflective surfaces, they do not offer the same crisp definition as commercial mirrors. Even when an investment mould is duplicated from polished glass via a rubber mother mould, the glass counterpart has surface irregularities caused by the translation of a hard, polished material (the base model) to an investment composite.

Simply removing a rubber mould from the investment can extract fine layers of investment from the core's surface, leading to scaring that directly impacts the glass surface and mirror coating. The investment also degrades during firing, leading to surface pitting. This is further amplified when hydrofluoric/sulphuric acids react with the lead component within the glass, resulting in enlarged, exaggerated impressions.

Devitrification can also occur on the glass surface due to interaction with the mould during flow at the top processing temperatures. This results in hazy white lines/striations on the glass surface, which cannot fully polish to a brilliant shine during acid polishing. This again interferes with the mirror's optical properties when light scatters across uneven or opaque surfaces.

5.4.3 What are the potential practical and creative parameters of using three-dimensional mirrored cast glass?

This doctorate offers parameters for processes and themes using three-dimensional mirrored cast glass within the context of the six case studies presented in Chapter 4. Within these pieces, the practical knowledge gained through studio testing, in tandem with the themes resulting from the contextual enquiry, was merged. This enabled a new series of artworks to be established that present how cast mirrors can be used to enhance the visual and thematic aspects of a sculpture(s) for the broader public and the glass art field.

Some of the minutiae of these boundaries are outlined in the previous question, ‘What factors inhibit and enhance the reflective qualities of a mirror coating on a cast glass surface?’, whereby choices in process and material directly influence the reflectivity of mirror coatings on cast glass. The following bullet points address the overarching practical and creative parameters of using three-dimensional mirrored glass within visual practice:

- Cast mirrors can embody a myriad of reflective and non-reflective surface textures and hues that can emulate other materials.
- Acid-polished cast-crystal can achieve mirror coatings that allow a viewer to identify a reflection of themselves.

- Applying hBN coatings to an investment mould can enhance the reflectivity of mirror coatings on cast glass by reducing adhesion between the glass and the investment materials. These, in turn, can produce a painterly ‘mirrored’ effect on the glass, creating a duality between a raw cast surface and the marks made with the hBN-coated side.
- Avoid internal cavities with sharp angles, as they can lead to contamination and mirror staining when aiming for a consistent mirror finish in core-cast glass.
- Increasing the scale and complexity of a core can make it difficult to extract investment materials, leading to contamination/mirror failure. Ensure that the core is made from a soft investment and is accessible by hand/tool for divestment.
- Reflective and non-reflective mirrors used in visual practice can express a range of themes, including, but not limited to, self-perception, optics, superstition, and the dual connotations associated with their use throughout history (as explored in Chapter 4: Cast Studies).

5.4.4 How might the use of mirrors throughout history and within contemporary art practice inform this research?

Reviewing publications, websites, documentary films, and exhibitions that explore the making, use, and symbolism of mirrors for both domestic use and

visual art practice have directly informed the practical and theoretical implications of this research. So too are artworks made before this research, such as *Distilled Portrait I and Demeter's Rose*. An awareness of historical and contemporary ties to mirror-making, their use and symbolism has served as a backbone to the artworks seen in Chapter 4: Case Studies. The following paragraphs provide an overview of these works, both in terms of visual and thematic reasoning.

Iris Obscura II presents four cast glass eye formations, each containing residual concave lenses. The study plays on our visibility and perspective, while embodying the form and symbolic resonance of the mirror being considered as an 'all-seeing eye' (Melchoir-Bonnet, 2001) in histories past. Melchoir-Bonnet (2001) states that God's light, presence and ability to replicate all of nature are embodied in the mirror. As a result, a single highly reflective cast eye was made that reflects all of its surroundings, while integrating a concave lens, a typical form seen in early mirror-making when glass orbs were blown, coated in lead and cut to be used as looking glasses (Gregory, 1998; Melchoir-Bonnet, 2001).

Iris Obscura is a series of individual studies, each conceived using different production methods to realise cast mirrors that point to the optical process and mirror superstitions. The chemically polished lead-glass eye plays with the very notion of seeing. An upturned depiction of the viewer is reflected,

echoing the projection onto the back of most mammals' eyes. In this piece, the mirror inverts the inverted, resulting in true projection at the back of the viewer's eye.

In contrast, a deliberately fractured lens is integrated in this grouping. It plays on the long-observed superstition that breaking a mirror is bad luck. The piece turns the negative connotation of broken mirrors into a physical positive. Only the fracture within the lens can reflect the viewer, while the rest denies reflection. This negation of reflectivity is also seen in an untreated mirrored lens that displays a devitrified horizon line, as well as in a lens externally sandblasted to obscure the mirror within it.

Persephone is a reinterpretation of a church rose window in three dimensions, each containing reflective and non-reflective mirrored cavities of wheat kernels and seed pods. Like *Celeste,* the reflective mirrored surfaces portray humankind as small facets within a complex whole. The ability to reflect the viewer, or to induce mental reflection through mirrored surfaces, adds to the overall vocabulary of these works. We become integral to its meaning.

Persephone speaks of labour for sustenance and of the currency of gold and silver to provide the fundamentals of survival. Within this piece, wheat kernels are reflected in precious metal, silver, thereby observing the link between

labour, sustenance and wealth. *Celeste* pays homage to *Indra's Web*, 2015, a work that sought to embody the ancient Hindu proverb of *Indra's Net*. The proverb represents society as a complex net of reflective jewels, each one reflecting the others. We as humans are jewels within the net. If one is extracted, the net will falter. Consequently, no matter what we do in life, everyone is essential to society existing as one. The use of mirrored prisms in *Celeste* speaks to this proverb, as do the spiritual connotations that mirrors are portals for the human soul (Hammer, no date; Sullivan, 2010).

The works of Esterhazy (Figure 22, p. 92) and Covell (Figure 23, p. 94) speak to introspection, blind spots in the human brain, and imperfect semblances of an environment through unconventional uses of reflective materials. Toch (Figure 21, p. 91) presents a skewed perspective to the viewer by mirror-polishing the cast speculum's rough surface. These artists have influenced works such as *Iris Obscura, Persephone's Rose,* and *Celeste* in their use of semi-reflective mirrors to explore themes surrounding the perception of self and surroundings.

Heavily detailed, blown, and slumped glass forms, seen in works such as *Pollen* by Lemaire (Figure 26, p. 100) and Grade Study by Perez (Figure 27, p. 101), present reflective planes that deny the gaze due to their complex forms and surface textures. This echoes the mirror coatings observed in

Silver Thread (Figure 115, p. 257). The mirrored rope denies a reflection of self yet equally reflects light in its iridescent surfaces.

The works produced in this thesis merge previous art practice (pre-thesis), material testing, and the contextual analysis of visual art and mirror-making history. New understandings have converged to enable the art-practice achieved within this research project. Many of the artworks reviewed in Chapter 3 don't necessarily offer crisp depictions of their environment yet are still valued for their conceptual relevance in engaging with reflection, either physically or metaphorically.

5.5 Contribution to Knowledge

In summary, the PhD contributes new knowledge in the following ways:

- Presents new strategies for controlling the surface texture and translucency of investment cast glasses, such as tension-set mould making and the use of de-ionised water in investment mould-making to produce a range of cast mirror effects. This is demonstrated through studio testing and the production of artwork.
- Provides methods to emulate a variety of colours, reflective and non-reflective mirrors, as well as solid inclusions in mirror-coated, kiln-cast glass that would be materially incompatible due to varying co-efficiencies of expansion.

- Presents new artworks disseminated through exhibitions, publications, lectures, teaching, and this thesis, demonstrating, through critical reflection on their conception, material processes, and reception, how sculptural cast glass mirrors can function both visually and thematically for public and wider art audiences. This contributes to the recognition of the research while serving as inspiration for others to adapt and expand.
- Presents new ways of creating raised, painterly mirrored effects using hand-painted hBN coatings directly onto the surface of investment moulds before the glass casting process.

Before this research project, no published resources or professional art practices were found that had investigated the making and use of core-cast glass mirrors. Very few publications explore the factors that lead to transparent, smooth investment-cast glass surfaces and/or what can improve the reflectivity of mirror coatings applied to cast glass using the chemical silver-deposition process. Resolving these knowledge gaps has expanded my professional practice, while giving other creative practitioners a greater understanding of how to control the transparency of cast glass surfaces and integrate a wide variety of new mirroring effects into their cast glass artwork. These individuals may feel frustrated by the surface finish of their investment cast glass or by the constraints of commercially produced mirrors and wish to incorporate different mirrored surfaces into their work.

This research contributes new knowledge on process-driven solutions such as model selection, mould formulation, investment ingredients, hBN coatings to repel glass adhesion, firing conditions, and post-casting treatments that can dictate translucency and shine in cast glass object making. Studio testing (Chapter 3) highlights the diversity of mirroring effects achievable in open-face and enclosed moulds, while the artworks and jewellery made as case studies (Chapter 4) continue to test these effects, while establishing themes inspired by the history/symbology of mirror making, and their use within contemporary art practice.

Mirrors have historically been applied only to blown and sheet glass without the use of complex mould-making strategies. This research provides technical contributions to glass art and mirror-making by creating reflective and non-reflective three-dimensional glass forms using various investment and graphite moulding techniques. Cast mirrors offer the illusion of solid reflective and non-reflective metal and other materials with a range of textures and hues embedded within the glass, which would otherwise be physically impossible to combine due to differing coefficients of expansion (COE).

Cast glass mirrors are volumetric, precise, and expressive. They offer new pathways for material exploration, conceptual engagement, and technical

refinement within the field. In situating mirrored cast glass within the wider historical, symbolic, and contemporary artistic context, this research not only bridges craft and fine art in the pursuit of technically and thematically driven forms but also adds a new strand to mirror production by combining mirror coatings with unpolished, investment-moulded glass. Its contributions support the continued evolution of glass as a dynamic material in contemporary art practice, moving beyond the notion that it is a purely utilitarian, craft-based medium.

5.6 Areas for Further Research

There is not one solution that 'fits all' for reducing investment adhesion and opacity in investment cast glass. As outlined in the specific technical contributions of this thesis, many factors affect the quality of cast glass surfaces, which in turn affect the reflectivity of mirror coatings. Thesis Chapter 3 is a basic guide for practitioners seeking insights into elements that govern surface adhesion and the opacity of cast glass. Yet it is important to keep in mind that results may shift when a glass model and core are altered in form, detail and scale. Differentials in the glass body, investment, peak firing temperature, and duration may need to be made. For example, longer hold times at higher temperatures to allow large volumes of glass to flow into intricate moulds, or the quality of gypsum-based pottery plaster used in this UK-based research project may differ from that in Australia.

What this practice-based research demonstrates is a strength in the creation and analysis of experimentation, supported by the development of technically demanding artworks. Many of these works can be seen as *meta* in their reference to the use and meaning of mirrors. Careful consideration has been made to create artworks that are relatable to wide public audiences, regardless of specialist knowledge and/or backgrounds. The iterative process of making, observing, and critical evaluation has generated new technical and conceptual knowledge, grounded in both hands-on practice and engagement with broader academic and artistic discussion.

The research outcomes have been effectively communicated through exhibitions, lectures, and workshops to specialist audiences in art and glass practice and non-specialist audiences in gallery and educational contexts. These activities also highlight transferable professional skills, including initiative, project management, and the ability to communicate complex ideas clearly.

The inherent unpredictability of experimental glass casting, which can produce unexpected results can be seen as a limitation. For example, a Hbn coating that repelled glass in one instance, adhered when using the same product from a different batch. Additionally, the research relies on specialised equipment and costly materials, which may limit the accessibility to reproduce or extend the work.

Artwork themes produced as case studies in this thesis (Chapter 4) could have been expanded further to deepen meaning. Many of the pieces, such as *Silver Thread*, *Distilled Portrait I: Series II*, *Celeste*, and *Persephone*, were conceived as refined or “improved” iterations of artworks created before the study. The PhD provided a valuable opportunity to revisit earlier ideas through the lens of new technical and reflective knowledge gained during the study. In contrast, the *Iris Obscura* series, *Roughness Comparator*, and the three stages of studio testing represent original outcomes developed specifically for this investigation. Together, they reveal a trajectory of evolving practice that could, with further development, have more fully articulated the relationships between material process, optical effect, and symbolic associations.

Overall, the research achieves a balance of practical experimentation, critical reflection, and public engagement, contributing to both the technical and conceptual understanding of cast glass mirrors in visual art, while developing skills and insights relevant to professional practice. It is hoped that the hands-on creative parameters of using three-dimensional mirrored cast glass using investment and graphite moulds be expanded beyond this study. Many avenues for further research could build upon what has previously been discussed. Some areas for further research include the following:

- Testing glasses other than Reichenbach 1500 and 1800, Gaffer 210, Bullseye 1401 or Cristallica to see if higher levels of surface translucency leading to reflective mirror coatings can be produced. Other glasses could include, but are not limited to, System 96, Oceanside, Banas and Blackwood Crystal. It was prohibitive in terms of cost and time to investigate the effects of other glasses, some of which are difficult/costly to import.
- Obtaining a lower peak firing temperature and duration for each glass on an individual basis to observe flow and surface transparency. For example, Gaffer crystal may have cast at lower temperatures than those observed in this study, leading to brighter surfaces. However, the other glasses trialled would not have flowed well at temperatures under 797 °C / 1450°F. Investigating the lowest top-firing temperature and duration that allow each glass to flow may yield superior surface results and give practitioners a more in-depth understanding of each glass's possibilities and limitations.

- Trialling investment recipes other than those used in this research, or using different ingredient brands to observe their effects on glass surface performance. For example, pottery plasters vary across countries and may lead to different outcomes. There is also a myriad of other investment recipes that could be trialled but were not examined in this research due to time constraints and limited access to

ingredients that could not be shipped abroad for cost or potential hazard reasons.

- Testing lower percentages of molochite with quartz as a combined investment material with pottery plaster. This would help determine whether a comparable surface glass release can be achieved with a stronger mix. Quartz is known to produce a stronger investment mix but does not release as readily from cast glass as from moulds made using molochite. Initial trials could be conducted with recipe percentages of 40:10, 30:20, 30:20, and 40:10 (molochite: quartz) to assess whether a balance between surface performance and strength can be achieved.

- The use of low-fire, clear, transparent enamels applied to cast surfaces to elevate shine and achieve reflective mirror coatings. As seen in Chapters 3 and 4, cast glass surfaces are often semi-translucent due to interactions between the glass and investment ingredients at high temperatures. This opacity could be lifted by applying a clear enamel to the glass after divestment. Once fired, it can create a glossy surface that enhances the mirror's reflectivity. Applying enamel powders to open-face moulds would be easier. Enclosed-core moulds would pose greater challenges in accessing interior details and achieving an even,

enamelled surface. This new area of enquiry was only realised towards the end of this research project, when time was limited.

- The artworks produced in this study could be developed further through exploration at both macro and micro scales. On a larger scale, the creation of monumental works, either through assembling multiple cast components or producing single, large-scale forms, could significantly advance the evolution of cast mirror practice. Equally, works of a more intimate scale hold considerable potential. This research has only begun to explore how small open-face moulds can be used to create wearable bas-relief mirrors, as demonstrated in the final case study discussed in Chapter 4. However, opportunities remain to investigate even smaller formats or to apply hanging-core processes to produce delicate, small-scale mirrored forms in the round. These future directions highlight how the boundaries of scale, both expansive and miniature, offer rich possibilities for extending the technical and conceptual scope of cast mirror making.

5.7 PhD Learning Outcomes

The University of Sunderland provides seven PhD learning outcomes in its student handbook that researchers should attain upon completion of their studies. The paragraphs below highlight these outcomes and how they have been met in this study:

- **The creation and interpretation of new knowledge, through original research or other advanced scholarship, of a quality to satisfy peer review, extend the forefront of the discipline, and merit publication.**

New knowledge has been created in the form of a broad range of tests to establish the reflective and non-reflective qualities of mirrored cast glass using investment and graphite moulds. These tests have been interpreted visually by eye, through documentary photographs and orally through a journal and this thesis. Tests have been interpreted further to create a series of new artworks that have been exhibited internationally.

Journal contributions to The Glass Arts Society and the Contemporary Glass Arts Society Newsletter have disseminated the research to the glass art field. Selected or invited exhibitions at The British Glass Biennale, Stourbridge, UK; The Pittsburgh Glass Centre, Pittsburgh, USA; The Athenaeum Building; and National Glass Centre, Sunderland, UK are considered equivalent to publication entries.

No published resources or contemporary art practices, other than this research, explore the integration of mirror coatings on cast glass, and very few texts investigate the factors that control surface transparency in cast glass. The originality and timeliness of this research have been evident from

peers' interest in disseminating the study's findings through seminars and lectures. This includes *Mirrors of the Third Dimension,* hosted by Bullseye Glass Company in December 2024. The three-hour seminar highlighted the contents of this thesis in terms of the contextual review, studio testing and case studies, which attracted over 250 global participants.

Farbglashütte Reichenbach GmbH, Bullseye Glass Company, Randsom & Randolph, GoldStar Powders, and Zyp Coatings Inc. have offered concessions in procuring their products to facilitate the practical components of this study. This signals that the research may be of value to glass-art practitioners and suppliers worldwide, both in terms of cast-glass surface control and a new range of mirroring effects for cast glass.

- **A systematic acquisition and understanding of a substantial body of knowledge which is at the forefront of an academic discipline or area of professional practice.**

A rigorous studio practice was maintained to acquire a wide range of tests for mirror-making. Variables such as the kiln, use of distilled water, method of making, firing temperature, and duration were kept consistent within each phase of testing to reduce inconsistencies in results. The outcomes were then systematically numbered, visually assessed, and documented through photographs and note-taking before and after the mirroring process to

observe differentials in surface texture, opacity, hue, and reflection. This enabled a systematic collection of results that could be used to create finished artworks and serve as an example for other practitioners to follow.

The uniqueness of this creative enquiry, community interest in cast surface duplication, and the heightened inclusion of reflective materials in contemporary art practice have led to exhibitions, journal entries, online seminars and conference seminars. These opportunities point to this study being at the forefront of art made with cast glass and mirrors as an academic discipline.

- **The general ability to conceptualise, design and implement a project for the generation of new knowledge, applications or understanding at the forefront of the discipline, and to adjust the project design in the light of unforeseen problems.**

From the outset of this PhD, agendas and goals have been carefully planned to meet deadlines and gain a breadth of knowledge through tests, artworks, and contextual research. Through these endeavours, new insights into cast-glass mirror-making that push the boundaries of how mirrors can look and function have been gained. This includes additive investment ingredients to aid glass mould release, unconsidered fabrication techniques to assist in

core-cast glass production, and the creation of artworks that intertwine themes associated with the history and symbolism of reflective surfaces.

Glass can be a challenging, unpredictable material. Results can shift during the making process, or fail due to an unexpected occurrence within the firing, for example, air entrapment or devitrification, which can inhibit visual access to a mirrored surface. Previous experience in glassmaking has helped to alleviate pressure from finishing tasks when deviations occur. Unexpected results, such as surface contamination resulting in black, tarnished mirror coatings, have often been embraced within the project and utilised to create clear distinctions between fully reflective and unreflective surfaces when using a variety of cast glass mirrors in a single art piece, for example, *Persephone,* 2025.

- **A detailed understanding of applicable techniques for research and advanced academic enquiry.**

This research demonstrates a detailed understanding of techniques applicable to practice-based enquiry in visual art. The studio-based methods were grounded in the iterative cycle of making and reflection, in which hands-on glass-casting processes are integrated with critical self-evaluation at each stage of production. This dual emphasis on practice and reflection is informed by established approaches to creative practice research, which recognise artistic processes themselves as valid sites of knowledge generation.

The research situates these methods within their historical and theoretical contexts, drawing on key texts that define and debate practice-based methodologies. Through this engagement, the study demonstrates an advanced awareness of how such approaches both align with and diverge from more traditional academic research methods. Parallels and contrasts with other practice-based researchers are identified, highlighting both the shared strategies of reflective making and the specificities of working with cast glass as a conceptual medium.

A critical evaluation of the strengths and limitations of practice-based research supports this understanding. The potential challenges of subjectivity, documentation, and the translation of tacit knowledge are articulated, along with strategies to address them, such as systematic process documentation, cross-referencing with theoretical literature, and situating the work within wider artistic and scholarly discourses.

Through this combination of material experimentation, reflective practice, and critical contextualisation, the research not only employs but also interrogates advanced techniques of practice-based enquiry. This demonstrates a detailed

and critical understanding of methodologies appropriate for generating new knowledge in the field of visual art practice.

- **The ability to make informed judgements on complex issues in specialist fields, often in the absence of complete data, and be able to communicate their ideas and conclusions clearly and effectively to specialist and non-specialist audiences.**

This research demonstrates the ability to make informed judgments about complex issues within the field of practice-based visual art, particularly regarding the experimental processes of glass casting and the thematic implications of mirrors in contemporary practice. These judgements have often been made in the absence of complete data, with uncertain outcomes, requiring critical evaluation and adaptive decision-making. For example, using Cristalica batch for investment-cast pieces did not flow adequately at lower processing temperatures during testing phases 1 and 2. The glass was reintroduced into the research within phase 3 due to its sufficient flow in preheated moulds using the hot-billet method. This demonstrates how processes can be adapted to work in favour of the task at hand.

The findings and creative works have been communicated clearly and effectively through the written thesis and public exhibitions. Presentations and

discussions concerning research for The Glass Arts Society Conference and Bullseye Glass Company, for example, have engaged specialist audiences, such as academics and practitioners in art and glass. Public exhibitions such as *Three Artists* (National Glass Centre, Sunderland, UK), Iris Obscura (The Athenaeum Building, Sunderland, UK), and the British Glass Biennale (Ruskin Glass Centre - Stourbridge, UK) have engaged non-specialist audiences. This dual communication demonstrates the ability to articulate complex ideas across different contexts, ensuring that the knowledge generated is meaningful and relevant to both expert and general audiences.

- **The ability to undertake pure and/or applied research and development at an advanced level, contributing substantially to the development of new techniques, ideas or approaches.**

This research demonstrates the ability to make informed judgments on complex issues in practice-based visual art, particularly regarding the experimental processes of glass casting and the thematic use of mirrors. Such judgements were often required in the absence of fully resolved outcomes, where material behaviour and artistic direction remained open-ended and unpredictable.

The work has been communicated effectively through both the written thesis, public exhibitions and lectures. By presenting and discussing the research in these different contexts, the project demonstrates the capacity to convey complex ideas with clarity and relevance across diverse audiences.

- **The qualities and transferable skills necessary for employment requiring the exercise of personal responsibility and largely autonomous initiative in complex and unpredictable situations, in professional or equivalent environments.**

This research has required the exercise of self-direction, initiative, and personal responsibility in navigating complex tasks inherent in material experimentation, artistic practice, academic writing and teaching. The technical challenges of casting multiple glasses from different materials at different temperatures, alongside the development of positioning cast mirrors in contemporary visual art, have necessitated problem-solving, adaptability, and independent decision-making.

Beyond the studio, these qualities have been extended through the organisation and delivery of public exhibitions, as well as through teaching

and facilitation. Lectures and freelance workshops at universities such as The Birmingham School of Jewellery, through Birmingham City University, UK, and private institutions such as Pilchuck Glass School, Stanwood, WA, USA, have developed and demonstrated a range of transferable skills, including clear communication, curriculum planning, leadership, demonstrations, and the ability to engage diverse audiences. Together, these experiences evidence the professional competencies necessary for employment in environments where communication, initiative, responsibility, adaptability and patience are critical.

5.8 Closing Remarks

It has been deeply rewarding to share the journey of this research through publications, lectures, seminars, and exhibitions, and to receive genuine interest, encouragement, and support in return. This enthusiasm has come from artist and student communities working with glass, from companies developing glass products, and from institutions committed to advancing glass art. Such engagement feels especially significant at a time when, over the past five years, several UK university glass programmes have closed, including the National Glass Centre, where this research was carried out. It is hoped that glass art, together with the rigorous research that continues to expand its possibilities as a medium of artistic expression, will endure and thrive.

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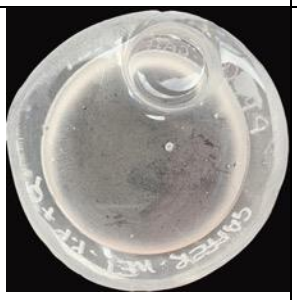
7 Appendices

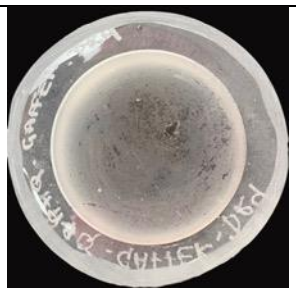
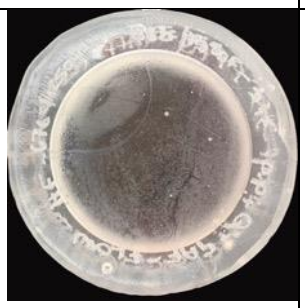
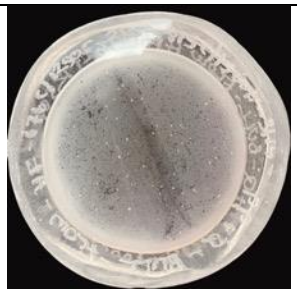
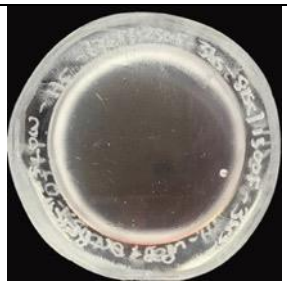
The appendices provide additional details, presented through images and text, to support and expand upon the contents of this thesis. They are divided into four sections: A – Plates, B – Material Testing, C – Health and Safety, and D – Research Dissemination. Appendix A provides detailed documentation of the individual tests discussed in Chapter 3, covering both pre- and post-mirroring stages, and is supported by descriptive notes that reinforce the main body of the text. This section also includes an overview of material sources, firing schedules, and annealing charts. Appendix C contains a brief health and safety disclaimer, and Appendix D presents research dissemination through published journal articles authored by the researcher, along with images of artworks displayed within exhibitions.

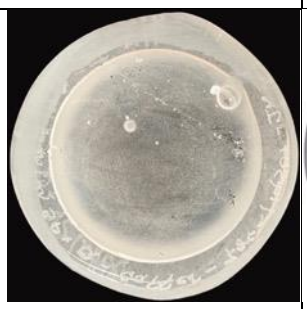
7.1 Appendix A: Images of Studio Tests

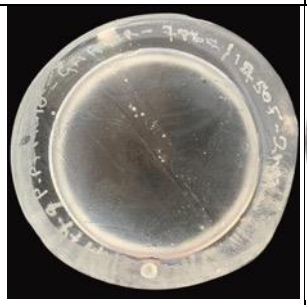
This section presents images of the most distinctive and diverse effects created within phases I and II of testing, along with notes describing the appearance of each cast glass surface before and after mirroring.

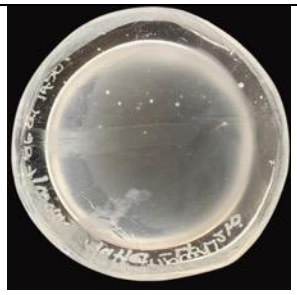
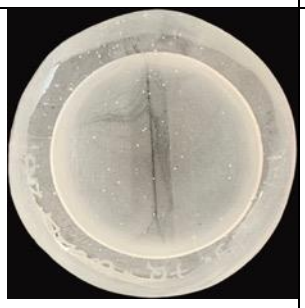
7.1.1 Open-Face Tests (Phase I)

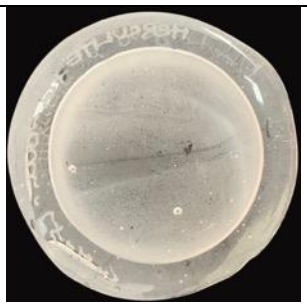
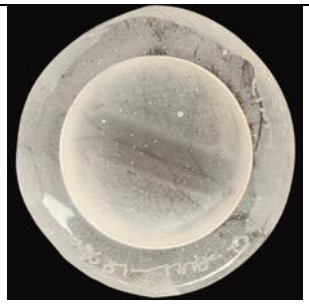
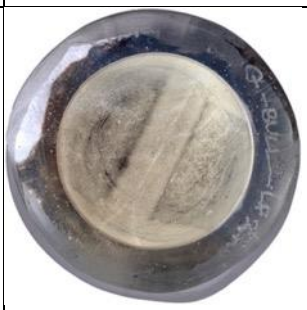
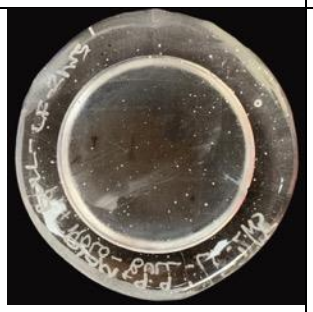
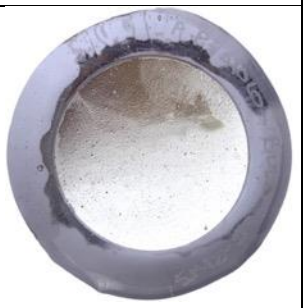
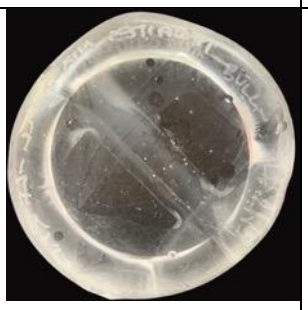
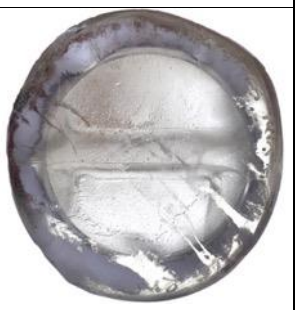
	Glass / Investment	Un-Mirrored	Mirrored
1.	**Gaffer = 50:50 = Pottery Plaster / Quartz = 2hrs top temp = Wet mould test**		

2.	**Gaffer = 50:50 = Pottery Plaster / Quartz = 2hrs top temp = Dry mould test**		
3.	**Gaffer = 50:50 = Pottery Plaster / Quartz = 2hrs top temp = High-fire flow test**		
4.	**Bullseye = 50:50 = Pottery Plaster / Quartz = 2hrs top temp = High-fire flow test**		
5.	**Reich 1500 = 50:50 = Pottery Plaster / Quartz = 2hrs top temp = High-fire flow test**		
6.	**Cristalica = 50:50 = Pottery Plaster / Quartz = 2hrs top temp = High-fire flow test**		

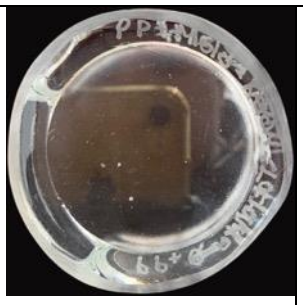
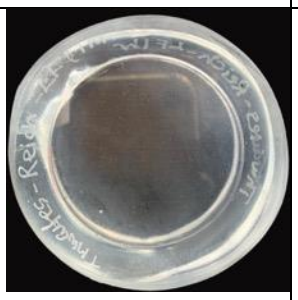
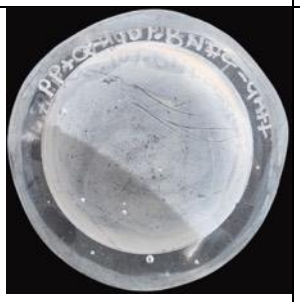
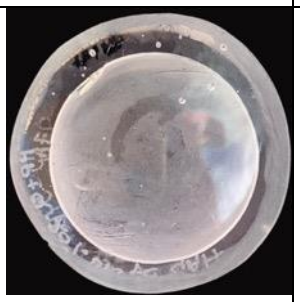
7.	**Cristalica = 50:50 = Pottery Plaster / Quartz = 2hrs top temp = Low-fire flow test**		
8.	**Gaffer = 50:50 = Dental SP / Quartz =787C / 2hrs**		

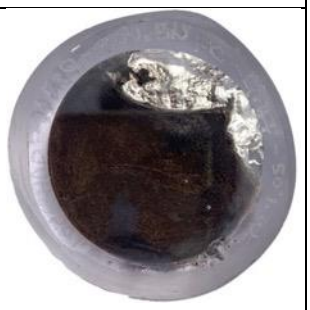
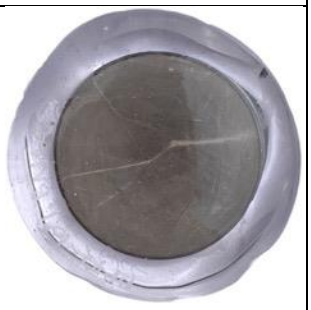
11.	**Gaffer = 50:50 = Crystacal R / Quartz =787C / 2hrs**		
12.	**Gaffer = 50:50 = Pottery Plaster / Molochite =787C / 2hrs**		

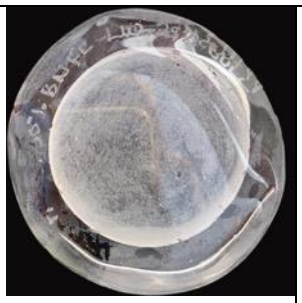
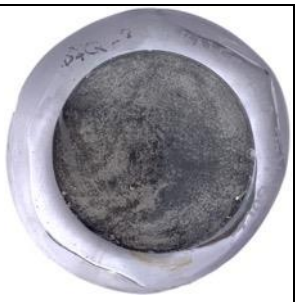
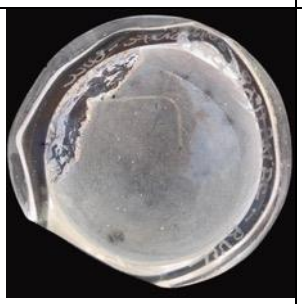
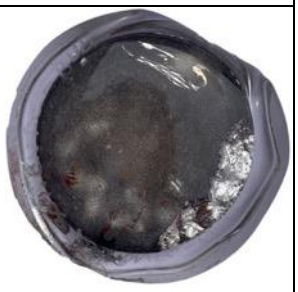
13.	**Gaffer = Thwaites Mix =787C / 2hrs**		
14.	**Bullseye = 50:50 = Pottery Plaster / Quartz =787C / 2hrs**		
15.	**Bullseye = 50:50 = Dental SP / Quartz =787C / 2hrs**		
16.	**Bullseye = Crystalcast =787C / 2hrs**		

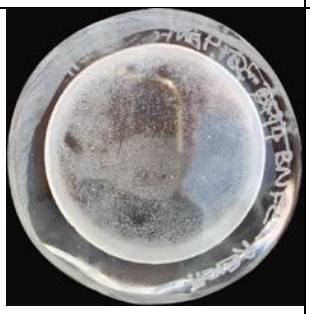
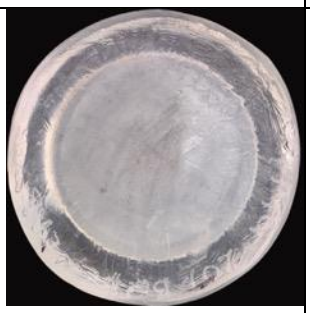
17.	**Bullseye = 50:50 = Herculite / Quartz =787C / 2hrs**		
18.	**Bullseye = 50:50 = Crystacal R / Quartz =787C / 2hrs**		
19.	**Bullseye = 50:50 = Pottery Plaster / Molochite =787C / 2hrs**		
20.	**Bullseye = Thwaites Mix =787C / 2hrs**		

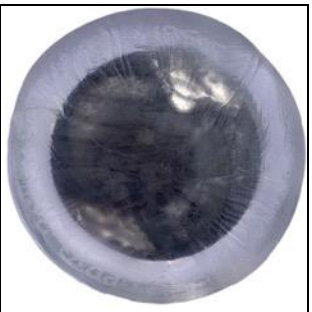
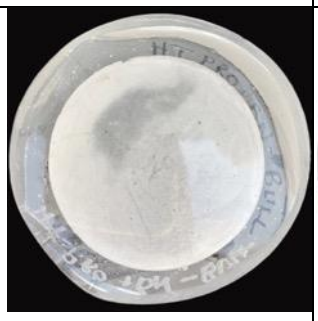
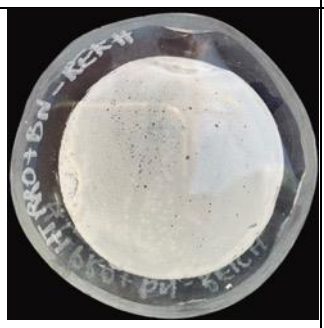
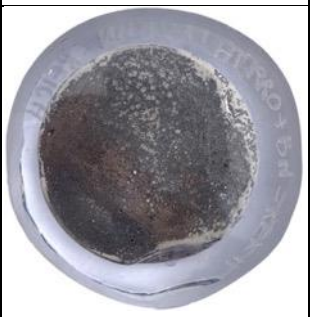
21.	**Reichenbach 1500 = 50:50 = Pottery Plaster / Quartz =787C / 2hrs**		
22.	**Reichenbach 1500 = 50:50 = Dental SP / Quartz =787C / 2hrs**		
23.	**Reichenbach 1500 Crystalcast =787C / 2hrs**		
24.	**Reichenbach 1500 = 50:50 = Herculite / Quartz =787C / 2hrs**		

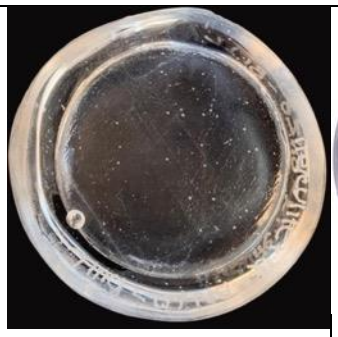
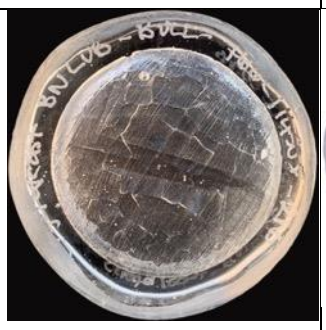
25.	**Reichenbach 1500 = 50:50 = Pottery Plaster / Molochite =787C / 2hrs**		
26.	**Reichenbach 1500 Thwaites Mix =787C / 2hrs**		
27.	**Gaffer = 45:45:10 = Pottery Plaster / Quartz / HbN Powder =787C / 2hrs**		
28.	**Gaffer = 40:40:20 = Pottery Plaster / Quartz / HbN Powder =787C / 2hrs**		

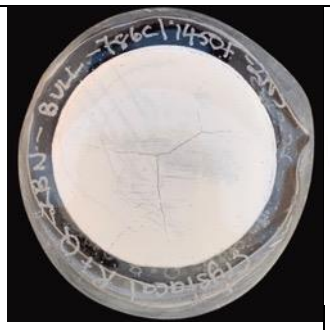
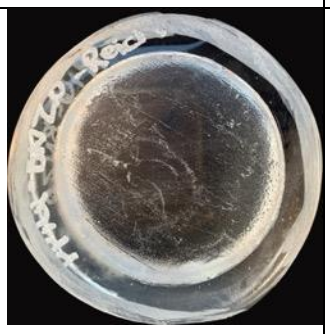
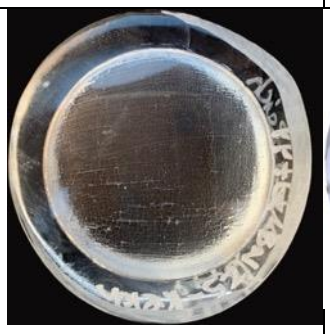
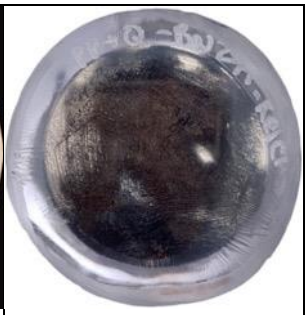
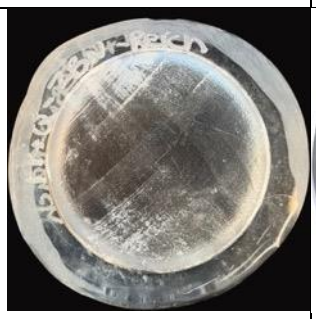
29.	**Gaffer = 35:35:30 = Pottery Plaster / Quartz / HbN Powder (extra 25% water =787C / 2hrs**		
30.	**Gaffer = 35:35:30 = Pottery Plaster / Quartz / HbN Powder (extra 50% water =787C / 2hrs**		
31.	**Bullseye = 45:45:10 = Pottery Plaster / Quartz / HbN Powder =787C / 2hrs**		
32.	**Bullseye = 40:40:20 = Pottery Plaster / Quartz / HbN Powder =787C / 2hrs**		

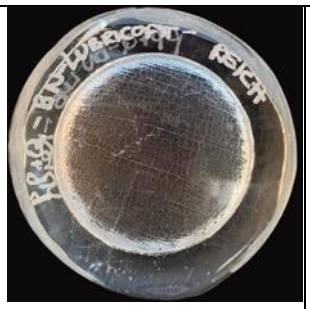
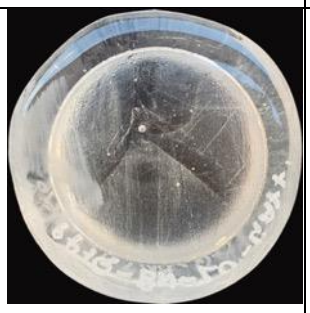
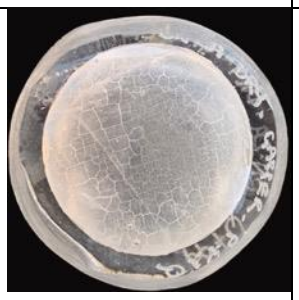
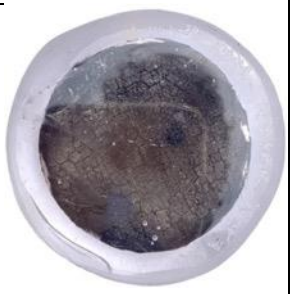
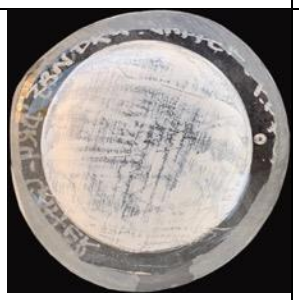
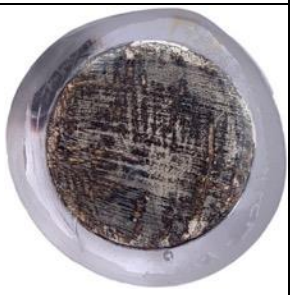
33.	**Bullseye = 35:35:30 = Pottery Plaster / Quartz / HbN Powder / 25% extra water =787C / 2hrs**		
34.	**Bullseye = 35:35:30 = Pottery Plaster / Quartz / HbN Powder / 50% extra water =787C / 2hrs**		
35.	**Reich 1500 = 45:45:10 = Pottery Plaster / Quartz / HbN Powder =787C / 2hrs**		
36.	**Reich 1500 = 40:40:20 = Pottery Plaster / Quartz / HbN Powder =787C / 2hrs**		

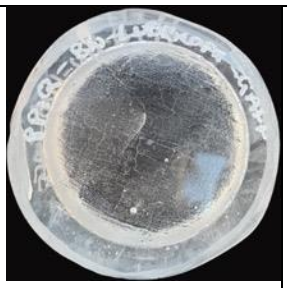
37.	**Reich 1500 = 35:35:30 = Pottery Plaster / Quartz / HbN Powder / 25% extra water =787C / 2hrs**		
38.	**Reich 1500 = 35:35:30 = Pottery Plaster / Quartz / HbN Powder / 50% extra water =787C / 2hrs**		
39.	**Cristalica = 45:45:10 = Pottery Plaster / Quartz / HbN Powder =850C / 2hrs**		
40.	**Cristalica = 40:40:20 = Pottery Plaster / Quartz / HbN Powder =850C / 2hrs**		

41.	**Cristalica = 35:35:30 = Pottery Plaster / Quartz / HbN Powder =850C / 2hrs**		
42.	**Gaffer = ProHT - BN =787C / 2hrs**		
43.	**Bullseye = ProHT - BN =787C / 2hrs**		
44.	**Reich 1500 = ProHT - BN =787C / 2hrs**		
45.	**Cristalica = ProHT - BN =787C / 2hrs**		

46.	**Bullseye = 50:50 = Pottery Plaster / Molochite Zyp BNZO =787C / 2hrs**		
47.	**Bullseye = 50:50 = Pottery Plaster / Molochite Zyp BNZA =787C / 2hrs**		
48.	**Bullseye = 50:50 = Pottery Plaster / Molochite Zyp BNLubricoat =787C / 2hrs**		
49.	**Bullseye = 50:50 = Pottery Plaster / Molochite Zyp BNZS =787C / 2hrs**		

50.	**Bullseye = 50:50 = Pottery Plaster / Molochite Zyp BNZBN =787C / 2hrs**		
51.	**Reich 1500 = 50:50 = Pottery Plaster / Molochite Zyp BNZO =787C / 2hrs**		
52.	**Reich 1500 = 50:50 = Pottery Plaster / Molochite Zyp BNZS =787C / 2hrs**		
53.	**Reich 1500 = 50:50 = Pottery Plaster / Molochite Zyp BNZA =787C / 2hrs**		
54.	**Reich 1500 = 50:50 = Pottery Plaster / Molochite Zyp BNZBN =787C / 2hrs**		

55.	**Reich 1500 = 50:50 = Pottery Plaster / Molochite Zyp BNLubricoat =787C / 2hrs**		
56.	**Gaffer = 50:50 = Pottery Plaster / Molochite Zyp BNZO =787C / 2hrs**		
57.	**Gaffer = 50:50 = Pottery Plaster / Molochite Zyp BNZs =787C / 2hrs**		
58.	**Gaffer = 50:50 = Pottery Plaster / Molochite Zyp BNZA =787C / 2hrs**		
59.	**Gaffer = 50:50 = Pottery Plaster / Molochite Zyp BNZBN =787C / 2hrs**		

60.	**Gaffer = 50:50 = Pottery Plaster / Molochite Zyp BNLubricoat =787C / 2hrs**		

7.1.2 Enclosed Tests (Phase II)

	Glass / Investment	Un-Mirrored	Mirrored
1.	**= Bullseye = 50:50 = Dental SP / Quartz = 4hrs top temp**		
2.	**Bullseye = 50:50 = Pottery P / Molochite = 6hrs top temp**		
3.	**Bullseye = 50:50 = Pottery P / Molochite = 2hrs top temp**		

4.	**Bullseye = 50:50 = Dental SP / Quartz = 2hrs top temp**		
5.	**Bullseye = 50:50 = Crystacal R / Quartz = 2hrs top temp**		
6.	**Bullseye = 50:50 = Pottery P / Molochite Zyp BNZS (4 coats) = 2hrs top temp**		
7.	**Bullseye = 50:50 = Pottery P / Molochite Zyp BZO (4 coats) = 2hrs top temp**		

8.	**Bullseye = 50:50 = Pottery P / Molochite Zyp BNLub Spray = 2hrs top temp**		
9.	**Bullseye = 50:50 = Pottery P / Molochite Zyp BNLub (1 Coat) = 2hrs top temp**		
10.	**Bullseye = 50:50 = Pottery P / Quartz Zyp BNZO (Hand-painted) = 2hrs top temp**		
11.	**Reich 1500 = 50:50 = Pottery P / Quartz = 2hrs top temp**		
12.	**Reich 1500 = 50:50 = Pottery P / Quartz = 2hrs top temp**		

13.	**Reich 1500 = 50:50 = Dental SP / Quartz = 2hrs top temp**		
14.	**Reich 1500 = 50:50 = Crystacal R / Quartz = 2hrs top temp**		
15.	**Reich 1500 = 50:50 = Pottery P / Quartz =Zyp BNLub (4 Coats) = 2hrs top temp**		
16.	**Reich 1500 = 50:50 = Pottery P / Quartz =Zyp BNLub (Hand Painted) = 2hrs top temp**		

17.	**Reich 1800 = 50:50 = Pottery Plaster / Quartz = 2hrs top temp**		
18.	**Reich 1800 = 50:50 = Dental SP / Quartz = 2hrs top temp**		
19.	**Reich 1800 = 50:50 = Thwaites Mix = 2hrs top temp**		
20.	**Reich 1800 = 50:50 = Pottery Plaster / Quartz =Zyp BNLub (3 coats) = 2hrs top temp**		
21.	**Reich 1800 = 50:50 = Crystacal R / Quartz = 2hrs top temp**		

23.	**Gaffer = 50:50 = Pottery Plaster / Quartz = 2hrs top temp**		
24.	**Gaffer = 50:50 = Pottery Plaster / Quartz =Zyp ZBN (3 Coats) = 2hrs top temp**		

7.2 Materials

The raw and commercially purchased materials used to produce the tests and finished artworks presented in Chapter 3: Material Testing and Chapter 4: Case Studies are documented in this section, along with their distributors.

7.2.1 Glass bodies

The following list shows the glass bodies used within this research, along with their suppliers:

Cristalica (soda-lime) ‘Pre-Melted’ Cullet – COE: 96.5

BMRC Group s.r.o.
Pod Dráhou 1638/7, 170 00 Praha 7
Czechia

info@bomma-glassworks.com

Bullseye (soda-lime) ‘Crystal Clear’ – 1401 Billet – COE: 90

3610 SE 21st Ave,
Portland, OR 97202,
United States

sales@bullseyeglass.com

Reichenbach (40% Lead Crystal) Clear – 1500 Billet – COE: 96
Gaffer (40% Lead Crystal) Clear – G210 Billet – COE: 92

Farbglashütte Reichenbach GmbH
Sohländer Str. 3,
02894 Reichenbach,
Germany

info@farbglas.de

7.2.2 Raw Materials

The following list shows the raw materials used to create the investment recipes in this research, along with their suppliers.

Pottery Plaster (Sedgefield Pottery, UK)

Quartz (Sedgefield Pottery, UK)

Herculite No. 2: Plaster (Special Plasters, UK)

Crystacal R Plaster (Special Plasters, UK)

Dental SP Plaster (Special Plasters, UK)

Molochite (Sedgefield Pottery, UK)

Kaolin (Sedgefield Pottery, UK)

HbN Powder (ZYP Coatings Inc, USA)

Sedgfield Pottery Supplies

Business Park, Unit 28
Flexspace
Lingfield Way
Darlington
DL1 4QZ
UK

sales@sedgefiledpottery.co.uk

Special Plasters

Unit 2 Benson Rd
Hockley
Birmingham
B18 5TD
UK

info@specialplasters.co.uk

ZYP Coatings INC

120 Valley Court
Oak Ridge, TN 37830
USA

info@zypcoatings.com

7.2.3 Commercial Investment Materials / Release Agents

GRS Crystalcast Investment (Special Plasters, UK)

R&R 910 Investment (Randsom and Randolph, USA)

R&R 50/50 Investment (Randsom and Randolph, USA)

R&R Multivest Investment (Randsom and Randolph, USA)

HbN Coating: Type ZO (ZYP Coatings Inc, USA)

HbN Coating: BN Lubricoat ZA Paste (ZYP Coatings Inc, USA)

HbN Coating: BN Lubricoat Paste (ZYP Coatings Inc, USA)

HbN Coating: BN Lubricoat ZS (ZYP Coatings Inc, USA)

HbN Coating: ZBN Release(ZYP Coatings Inc, USA)

HbN Coating: DMX Powder (ZYP Coatings Inc, USA)

HbN Coating: Spray Release (ZYP Coatings Inc, USA)

7.2.4 Coldworking Consumables

HIS Glassworks, USA

2000 Riverside Dr #19
Asheville, NC 28804
USA

support@hisglassworks.com

Bohle Ltd

Fifth Avenue
Tameside Park
Dukinfield
Cheshire
SK16 4PP
UK

info@bohle.ltd.uk

7.2.5 Mirroring Chemicals and Waste Treatment

Angel Gilding, USA

1945 Gardner Rd
Broadview, IL 60155
USA

cust.service@angelgilding.com

7.2.6 Mirror Backing Paints

AP Non-Weiler, USA

3321 County Rd A
Oshkosh, WI 54901
USA

orders@CrescentBronze.com

7.2.7 Silicone and Polyurethane Rubbers

Mould Life, UK

Unit D, Anglian Ln
Bury
Saint Edmunds
IP32 6SR
UK

info@mouldlife.co.uk

Notcutt, UK

Homewood Farm
Newark Lane
Ripley
Surrey
GU23 6DJ

sales@notcutt.co.uk

Polytek Inc

55 Hilton Street
Easton
PA 18042
United States

sales@polytek.com

7.2.8 Tools

Forged Metal Tools: Top Pot Supply

15 Lodge Road, Locks Heath
Southampton
SO31 6QY
UK

robin@toppot.co.uk

Clay Tools: Mud Tools

PO Box 111
Bat Cave, NC 28710
USA

sales@mudtools.com

7.3 Firing Schedules

The firing cycles used to cast investment moulds within this project are documented here. This includes the pre-firing (ramp-up) cycle used to remove water content from investment, along with the firing temperatures and durations used for studio tests and finished artworks. The annealing / cooling cycles differ depending on the glass body and casting thickness. The schedules used for annealing are documented in the following section.

7.3.1 General Pre-Fire Cycle

(to remove water content from mould prior to firing with glass)

37C/hr – 98C – HOLD 5hrs

37C/hr – 149C – HOLD 5hrs

93C/hr – 593C – HOLD 1hr

93C/hr – 100C – OFF

7.3.2 Firing Cycle for Phases I + II of Testing

98C/hr – 662C – HOLD 4hrs

300C/hr – 787C – HOLD 2hrs

300C/hr – Annealing (based on glass body and thickness)

7.3.3 Firing Cycle's for Distilled Portrait I (First Firing)

First firing using Gaffer Crystal in pre-fired mould. Result's showed debris clouding.

Pre-fire

37C/hr – 98C – HOLD 7hrs

37C/hr – 149C – HOLD 7hrs

40C/hr – 593C – HOLD 2hr

40C/hr – 100C – OFF

Firing

93C/hr – 593C – HOLD 2hrs

9999 – 815C – HOLD 3hrs

9999 – Annealing

7.3.4 Firing Cycle for Distilled Portrait I (Subsequent Firings)

(includes pre-fire with glass loaded)

37C/hr – 98C – HOLD 5hrs

37C/hr – 149C – HOLD 5hrs

93C/hr – 676C – HOLD 2hrs

9999/hr – 815C – HOLD 2hrs

50C/hr – 600C – HOLD 3hrs

100C/hr - Annealing

7.3.5 Firing Cycle for Distilled Portrait I and Cast Prisms using Hot Billets (Cristalica Batch)

Firing Cycle for Hot Billet Cast Prism (4” / 10cm thickness)

93C/hr – 104C – HOLD 5hrs

93C/hr – 148C – HOLD 5hrs

93C/hr – 593C – HOLD 2hrs

200C/hr – 800C – HOLD 1hr (Load Billet)

9999/hr – 860C – HOLD 2.5hrs

9999/hr – 520 C / HOLD 8hrs

4C/hr – 380C / HOLD 0hrs

7C/hr – 280C / HOLD 0hrs

22C/hr – 100C / OFF

7.3.6 Investment Cast Large Prisms (in pre-fired moulds)

97C/hr – 676C – HOLD 3hrs

9999C/hr – 815C – HOLD 2.5hrs

9999C/hr – Annealing

7.3.7 Bird Dome using Hot Billets (including pre-fire)

93C/hr – 98C – HOLD 5hrs

93C/hr – 148C – HOLD 5hrs

93C/hr – 598C – HOLD 2hrs

200C/hr – 676 – HOLD (until ready to load glass)

9999C/hr – 800C – HOLD (load glass)

9999C/hr – 840C – HOLD 3hrs

9999C/hr – 520C – HOLD 20hrs

2C/hr – 380C

3C/hr – 280C

7C/hr – 100C

7.4 Annealing Schedules

7.4.1 Gaffer Crystal

GAFFER® CASTING CRYSTAL ANNEALING SCHEDULES. SEMI-OPEN AND OPEN FORMS *

Thickness inches / mm	Anneal Soak Time @ 806°F @ 430°C	Initial Cooling Rate °F/Hr °C/Hr	Initial Cooling Range °F °C	Second Cooling Rate °F/Hr °C/Hr	Second Cooling Range °F °C	Final Cooling Rate** °F/Hr °C/Hr	Final Cooling Range °F °C	Total Elapsed Time
0.5 in 12 mm	2 hr	120 67	806 - 680 430 - 360	240 133	680 - 590 360 - 310	720 402	590 - 70 310 - 21	4 hours 10 mins
0.75 in 19 mm	3 hr	52 29	806 - 680 430 - 360	104 58	680 - 590 360 - 310	312 174	590 - 70 310 - 21	8 hours
1.0 in 25 mm	4 hr	29 16	806 - 680 430 - 360	58 32	680 - 590 360 - 310	174 96	590 - 70 310 - 21	13 hours
1.5 in 38 mm	6 hr	13 7.2	806 - 680 430 - 360	26 14.4	680 - 590 360 - 310	78 43	590 - 70 310 - 21	26 hours
2.0 in 50 mm	8 hr	7.8 4.3	806 - 680 430 - 360	15.6 8.6	680 - 590 360 - 310	46.8 25.8	590 - 70 310 - 21	41 hours 30 mins
2.5 in 60 mm	10 hr	5.2 2.9	806 - 644 430 - 340	10.4 5.8	644 - 554 340 - 290	31.2 17.4	554 - 70 290 - 21	2 days 17 hours
3.0 in 75 mm	12 hr	3.3 1.8	806 - 644 430 - 340	6.6 3.6	644 - 554 340 - 290	19.8 10.8	554 - 70 290 - 21	4 days 5 hours
3.5 in 88 mm	14 hr	2.5 1.4	806 - 644 430 - 340	5.0 2.8	644 - 554 340 - 290	15 8.4	554 - 70 290 - 21	5 days 12 hours
4.0 in 100 mm	16 hr	1.8 1.0	806 - 644 430 - 340	3.6 2.0	644 - 554 340 - 290	10.8 6	554 - 70 290 - 21	7 days 8 hours
4.5 in 113 mm	18 hr	1.6 0.9	806 - 644 430 - 340	3.2 1.8	644 - 554 340 - 290	9.6 5.4	554 - 70 290 - 21	8 days 5 hours
5.0 in 125 mm	20 hr	1.3 0.7	806 - 644 430 - 340	2.6 1.4	644 - 554 340 - 290	7.8 4.2	554 - 70 290 - 21	10 days 9 hours
5.5 in 138 mm	22 hr	1.1 0.6	806 - 644 430 - 340	2.2 1.2	644 - 554 340 - 290	6.6 3.6	554 - 70 290 - 21	11 days 20 hours
6.0 in 150 mm	24 hr	0.9 0.5	806 - 608 430 - 320	1.8 1.0	608 - 518 320 - 270	5.4 3	518 - 70 270 - 21	16 days
6.5 in 165 mm	26 hr	0.7 0.4	806 - 608 430 - 320	1.4 0.8	608 - 518 320 - 270	4.2 2.4	518 - 70 270 - 21	19 days 20 hours
7.0 in 175 mm	28 hr	0.6 0.33	806 – 608 430 - 320	1.2 0.66	608 - 518 320 - 270	3.6 2	518 - 70 270 - 21	23 days 19 hours
7.5 in 190 mm	30 hr	0.5 0.3	806 - 608 430 - 320	1.0 0.6	608 - 518 320 - 270	3 1.8	518 - 70 270 - 21	26 days 6 hours
8.0 in 200 mm	32 hr	0.47 0.26	806 - 608 430 - 320	0.94 0.52	608 - 518 320 - 270	2.8 1.56	518 - 70 270 - 21	30 days 4 hours
8.5 in 215 mm	34 hr	0.41 0.23	806 - 608 430 - 320	0.8 0.46	608 - 518 320 - 270	2.4 1.4	518 - 70 270 - 21	33 days 21 hours
9.0 in 225 mm	36 hr	0.35 0.2	806 - 608 430 - 320	0.7 0.4	608 - 518 320 - 270	2.1 1.2	518 - 70 270 - 21	38 days 22 hours
9.5 in 242 mm	38 hr	0.32 0.18	806 - 608 430 - 320	0.64 0.36	608 - 518 320 - 270	1.9 1.1	518 - 70 270 - 21	42 days 6 hours
10.0 in 254 mm	40 hr	0.29 0.16	806 - 608 430 - 320	0.58 0.32	608 - 518 320 - 270	1.74 0.96	518 - 70 270 - 21	47 days 15 hours

* Based on: *Schedules for commercial annealing of ordinary ware.* Corning Glassworks. Corning N.Y. 1950. **For forms that are able to cool reasonably equally on all sides.**

** Obviously cooling rates of thinner pieces are faster than ordinary kilns lose heat. In those cases the kiln can be allowed to cool at its natural rate.

Revised schedules August 2010

STUDIO TIPS

Annealing Thick Slabs: Celsius, rates in degrees-per-hour

Annealing Pieces of Uniform Thickness

THICKNESS	RATE	TEMP	ANNEAL HOLD h:min	1ST COOLING RATE	TEMP	HOLD	2ND COOLING RATE	TEMP	HOLD	FINAL COOLING RATE †	TEMP	HOLD	TOTAL
0.25″/ 6 mm	AFAP*	482	1:00	83	427	0:00	150	371	0:00	500	21	0:00	≈3:00
0.5″/ 12 mm	AFAP	482	2:00	55	427	0:00	99	371	0:00	330	21	0:00	≈5:00
0.75″/ 19 mm	AFAP	482	3:00	25	427	0:00	45	371	0:00	150	21	0:00	≈9:00
1″/ 25 mm	AFAP	482	4:00	15	427	0:00	27	371	0:00	90	21	0:00	≈14:00
1.5″/ 38 mm	AFAP	482	6:00	6.7	427	0:00	12	371	0:00	40	21	0:00	≈28:00
2″/ 50 mm	AFAP	482	8:00	3.8	427	0:00	6.7	371	0:00	22	21	0:00	≈47:00
2.5″/ 62 mm	AFAP	482	10:00	2.4	427	0:00	4.3	371	0:00	14.4	21	0:00	≈70:00
3″/ 75 mm	AFAP	482	12:00	1.7	427	0:00	3.1	371	0:00	10	21	0:00	≈99:00
4″/ 100 mm	AFAP	482	16:00	0.94	427	0:00	1.7	371	0:00	5.6	21	0:00	≈170:00
6″/ 150 mm	AFAP	482	24:00	0.42	427	0:00	0.76	371	0:00	2.5	21	0:00	≈375:00
8″/ 200 mm	AFAP	482	32:00	0.23	427	0:00	0.42	371	0:00	1.4	21	0:00	≈654:00

This annealing chart has been formulated for use with Bullseye clear glass.**

- It only applies to flat slabs of uniform thickness positioned to cool evenly from top and bottom.
- If your work is not positioned to cool evenly from top and bottom or is anything besides a flat slab of uniform thickness, select the annealing cycle listed for pieces that are at least twice the thickness of your work's thickest area.
- Please Note: Even the most conservative annealing cycle may fail if the kiln cannot cool the work uniformly. For more information, see *TechNotes 7: Monitoring Kiln Temperatures for Successful Annealing* at bullseyeglass.com.

How to read this chart in 4 steps

1. Calculate the final post-fired thickness of your slab.
2. Match that thickness with the size options listed in the chart's far left column.
3. Focus on the row to the right of your piece's listed thickness. This is now your focal row; it contains all information necessary to successfully anneal your slab.
4. Notice the chart's top row. The boxes in the top row explain the information in the columns below them. Intersect your focal row with the top row to interpret the chart.

As an example expressed in Bullseye's standard chart style, a 25 mm slab of uniform thickness would follow this annealing cycle.

RATE	TEMPERATURE	HOLD
AFAP*	482 °C	4:00
15	427 °C	0:00
27	371 °C	0:00
90	21 °C	0:00

* AFAP=As fast as possiible.

** This chart is derived from Corning's method as shown in McLellan and Shand (1984), Glass Engineering Handbook, 3rd Edition, New York, McGraw Hill.

† Your kiln may cool more slowly than this rate, and if so it may display an FTC (Failed To Cool) or FTL (Firing Too Long) error message. These messages do not affect the firing.

BULLSEYE glass

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7.4.3 Cristalica Batch (Distributed by Bomma)

Technical Information			
Alfa:	9,6 (20 - 300 °C)	Melting temperature:	1250 – 1280 °C (2282 - 2336 °F)
Specific weight:	2.5455 g/cm3	Working temperature	1150 - 1250 °C (2102 - 2282 °F)
Index of refraction:	1.5211	Flow point	898 °C (1648 °F)
Yield rate:	100 %	Softening point	702 °C (1297 °F)
		Annealing points:	518 °C (964 °F)
		Transformation temperature	511 °C (952 °F)
		Strain point:	488 °C (910 °F)

Compatibility:	
Basic compatibility:	Glasshütte Reichenbach, Gaffer Colours, Kugler glass
Advanced compatibility:	The compatibility is generally based on Alfa with a limited tolerances (+/- 0.2 based on experience with Reichenbach and Gaffer Colors). It is always highly recommended to test your specific application before launching into full production with any design or color application or combination. Cadmium colors, Cadmium-Selenium colors, should be tested based on application.

Melting:
Before first melting Bomma Cullet, we recommend cleaning your furnace to avoid contamination from any old material. When using Bomma Cullet continuously, it is recommended to charge again when there is a minimum of 1/3 of the furnace capacity remaining.
Start melting a single layer of the Bomma Cullet at a temperature between 1250 - 1280 °C (2282 - 2336 °F) (depending on the type of furnace).
When the charge is melted, add another layer of the Cullet. Repeat until the requested amount of melted glass is ready.
To start working, adjust the temperature for the product that you are going to create.
Enjoy the longworking Glass.

Cooling down			
The annealing oven should start at 525°C (977 °F)			
Pieces under 10 mm of thickness			
15 min 525°C (977 °F)	90 min until 410 °C (770 °F)	90 min until 200°C (392 °F)	
Pieces 10-40 mm of thickness			
30 min 525°C (977 °F)	200 min until 410 °C (770 °F)	200 min until 200°C (392 °F)	
Pieces 4 - 9 cm of thickness			
45 min 525°C (977 °F)	330 min until 410 °C (770 °F)	330 min until 200°C (392 °F)	110 min down to 30°C (86 °F)
Pieces 9-15 cm of thickness			
60 min 525°C (977 °F)	540 min down to 410 °C (770 °F)	540 min down to 200°C (392 °F)	180 min down to 30°C (86 °F)

www.bomma.cz/cullet

bomma

7.4.4 Reichenbach Crystal

Annealing programm casting glass — **Farbglashütte Reichenbach GmbH**

1. phase 0 irregular annealing until above the upper annealing point
2. phase 1 bring the glass on a uniform temperature of 480 °C
3. phase 2 / 3 regular linear annealing of the glass
4. phase 4 annealing up to room-temperature

material	phase 1	phase 2			phase 3			phase 4			whole annealing time
thickness	dwell on 480 °C	temp.-range	rate	total	temp.-range	rate	total	temp.-range	rate	total	
(mm)	(min)	(°C)	°C/h	(min)	(°C)	°C/h	(min)	(°C)	°C/h	(min)	(min)
10	60	480 - 400	67	72	400 - 320	135	36	320 - 20	650	28	195	3h 16min
20	90	480 - 400	29	166	400 - 320	57	84	320 - 20	290	62	402	6h 42min
30	150	480 - 400	15	320	400 - 320	21	229	320 - 20	125	144	843	14h 03min
40	190	480 - 400	7,4	649	400 - 320	15,5	310	320 - 20	70	257	1405	23h 25min
50	240	480 - 400	4,3	1116	400 - 320	9	533	320 - 20	44	409	2299	1d 14h 19min
60	300	480 - 400	2,9	1655	400 - 320	6	800	320 - 20	30	600	3355	2d 07h 55min
70	350	480 - 400	2,3	2087	400 - 270	4,8	1625	270 - 20	22	682	4744	3d 07h 04min
80	380	480 - 400	1,65	2909	400 - 270	3,6	2167	270 - 20	17	882	6338	4d 09h 38min
90	420	480 - 400	1,4	3429	400 - 270	2,7	2889	270 - 20	13	1154	7891	5d 11h 31min
100	480	480 - 400	1	4800	400 - 270	2,1	3714	270 - 20	10	1500	10494	7d 06h 54min
125	600	480 - 400	0,7	6857	400 - 270	1,5	5200	270 - 20	8	1875	14532	10d 02h 12min
150	720	480 - 400	0,5	9600	400 - 270	1,1	7091	270 - 20	5	3000	20411	14d 04h 11min
200	960	480 - 400	0,26	18462	400 - 270	0,53	14717	270 - 20	3	5000	39139	27d 04h 19min

The specified annealing times and temperatures are theoretical values only.
The actual annealing times and temperatures have to be adapted to the respective used hardware and glass mold.

7.5 Appendix B: Health and Safety

Anyone following the processes shared within this research are accountable for their own health and safety. The author of this thesis takes no responsibility for the actions of other individuals. The following bullet points outline measures to take when working with glass and toxic particulates.

- Safety glasses must always be worn when working with glass and airborne particulate dust.
- Respiratory protective equipment (RPE) with cartridges of at least factor 20 should be worn when working with particulates such as those used in mould making processes (plaster, quartz, molochite etc). Guidance for health and safety using toxic materials is provided at http://www.hse.gov.uk/pubns/guidance/crseries.htm.
- Use a respirator with organic vapour cartridges when working with polyurethane rubber.
- Use protective gloves when working with silicone or polyurethane rubber, and catalysts in a liquid state.
- Use an extraction unit directly over a work area when using particulates for mould-making.
- Vacuum and mop floors after working with particulates to remove settled dust.
- Change and wash work clothing after mould-making. Shower after a workday to remove particulates from hair/body.

- Use kilns in a well-ventilated area. An extraction system is recommended for the kiln when firing.
- Heat-resistant gloves and a face shield should be worn when opening the kiln at its top temperature.
- Safety glasses, protective footwear and an apron must be worn when cold working. Long hair should be tied back.
- Wear a particulate respirator when cold working with loose silicon carbide grits.

7.6 Appendix C : Research Dissemination

The range of outcomes from this research includes artworks, publications, presentations, exhibitions, documentation, workshops, and masterclasses presented domestically and internationally across a range of academic and public contexts. Over the period of this study (2021-25), participation in four public exhibitions was carried out in a variety of locations across the UK and the USA. These opportunities are documented in Appendix D: Portfolio.

The research was disseminated through a lec-mo (lecture/demonstration) called *Mirrors of the Third Dimension* at The Glass Arts Society Conference in Tacoma, WA, USA, in May 2023. This gave the opportunity to share the research to date to a large audience of international glass artists and enthusiasts. Many participants expressed their appreciation for the study, as they had been struggling to find a ‘happy medium’ for improving their cast

glass surfaces, and they looked forward to reviewing the published thesis. A journal article documenting the lec-mo was later published in the *2023 Glass Arts Society Journal*.

Following this, the lecture was extended into a three-hour seminar, shared virtually through Bullseye Glass Company to an international audience of 250 viewers. Feedback was encouraging, with many participants stating that they had learned a wide scope of technical knowledge from the research and were inspired by the results. The seminar is scheduled again in September 2026 due to its popularity within the community. A shortened 1-hour presentation was shared at the first Pilchuck Glass School Casting Conference in August 2025. I was invited as a committee member to aid in the programming of the event with Michael Endo, Raya Friday, Alicia Lomne, Max Stewart and Tone Ørvik.

Some of the casting methods used in this research have been shared in workshops, both in person and virtually. These include several online classes called Part A: Open-Face Moulds and Part B: Enclosed Moulds through Warm Glass UK. One and two-week teaching sessions in lost wax casting and core-casting at The Corning Museum of Glass, USA, Penland Mountain School of Craft, USA and Bild-Werk in Germany, along with a focused project incorporating miniature core-cast mirrors through The Birmingham School of Jewellery from October – December 2025 (see Chapter 5: Case Studies)

LECTURE

Mirrors of the Third Dimension

By Joanna Manousis

There are certain qualities in objects and entities in life that attract our attention. Light paves the way to discovery, which is amplified when light is reflected to us from shiny surfaces. Water, polished obsidian, metal, and glass all do this, however arguably, no other human-made entity has captured our gaze more so than the mirror. It has allowed us to perceive what we cannot by eye – ourselves, while setting up a range of polarized dualities, vanity in beauty, truth in fiction, good and evil.

It was a glass sculpture that paved an ambition to pursue a PhD focusing on three dimensional cast glass mirrors. Created in 2012, a series of cast lead-crystal distillery jars entitled, 'Distilled Portraits' (Fig. 1), were made that contained the residual voids of objects representing individuals. Using 'core-casting', a process whereby investment 'positive(s)' are embedded within a mould and extracted from the glass after annealing to create negative space, the hollows of pig's feet, oysters, spools of yarn and a magpie resting on a pomegranate were encapsulated in solid, hand-polished glass. Satin surfaces of interior silhouettes trapped light, creating ambient glow, and an internalized energy reminiscent of the souls the objects referenced.

A coating of silver nitrate mirror was applied to the magpie (Fig. 2), with an intention that it would become a reflection of itself, its audience, and the jar; a vessel used for the containment of objects. However, rather than enlivening the surface to encapsulate its environment, the bird transformed into a brushed silver statuette that denied the reflected gaze.

Mirror coatings only look fully reflective on blemish free, shiny surfaces that are best viewed optically through clear glass . For these reasons, mirroring to this day has been performed almost exclusively on blown and sheet glass applications, whereby the surface is pristinely polished, thus rendering a reflective mirror. This may be the reason why refractory cast glass has not been considered as a valid choice in the production of mirrors. Striving to obtain a pristine, clear glass surface cast directly from an investment material is challenging, particularly when creating moulds and glass forms by hand without mechanized equipment.

'Distilled Portrait I' became emblematic of a decade-long pursuit to create reflective cast mirrors. As years passed, consecutive pieces shed light on factors that affect reflectivity, however variables were never controlled, constant and systematically catalogued. For these reasons, empirical research was undertaken to ascertain if reflectivity could be achieved on un-polished, investment cast glass.



Top: Fig 1, Distilled Portraits, 2012. Core-cast crystal / stainless. (x3) 16" x 6" x 6". Bottom: Fig 3, Phase 1 Mirror Tests, 2021. Cast glass / crystal / mirror.

Preliminary studio testing started in February 2021 within the Glass and Ceramics Department at the University of Sunderland, a complex of material specific studios housed at The National Glass Centre, UK. Over 100 samples were carried out in 'Phase 1' of studio testing, some of which can be seen in Fig. 3. An optical flat lens was used as a base model to create silicone inserts for the duplication of open-face investment moulds for casting.

It had been determined through previous studio practice and other documented findings that steaming wax from a mould when utilizing the 'lost-wax-casting' technique causes mould weakness and surface erosion due to the introduction of excess water and heat. To negate these adversary effects wax was avoided wherever possible within this research.

For the research to be relevant and have a higher impact, four of the most utilised clear commercial glasses within the international studio glass-art community (Gaffer (Lead-Crystal), Bullseye (Soda-Lime), Reichenbach 1500 (Lead-Crystal) and Cristalica



Fig 4, Phase 2 Mirror Tests, 2021. Cast glass / crystal / mirror (Enclosed Zyp Coating (thick application) test with open-face counterpart).

(Soda-Lime) were used in combination with a range of commercial and hand-made investment mixes.

To keep variables constant, the same Kiln Care GTA 80 / 12 KW kiln made in 05/07 was used for all firings. Preliminary samples were subjected to flow tests to find a temperature range that would allow all glasses to melt and fill the mould within a given time. Moulds were also pre-fired before loading glass to prevent devitrification on the glass surface. It was observed that higher temperatures and longer peak firing durations (even at low temperature ranges) lead to greater surface opacity which reduces the reflectivity of an applied mirror coating.

Cristalica was omitted from testing due to its viscosity and resistance to flow, followed by Gaffer crystal due to its higher surface opacity in comparison to Reichenbach crystal (40% lead) when cast. Although many of the Bullseye samples had a high level of opacity, this glass was retained for further testing due to its promising results using Boron Nitride (B4N) coatings (ZYP Coatings) and molochite within the investment mix (noting that molochite lacks strength within an investment mix compared to quartz (silica)).

Boron Nitride (B4N) was used as both an investment modifying ingredient and as a surface coating using ZYP Coatings products. Tests using B4N as a modifying ingredient were poor, with severe surface contamination causing a black mirror. However, several B4N coatings created iridescent, non-reflective silver mirrors with Bullseye and Reichenbach.

Further tests with controlled applications of B4N - ZYP Coatings using a soft brush and spray gun were carried out. These samples assessed the thickness of paint causing surface cracking in fired tests and whether a spray method of application would help to alleviate the linear marks created by a brush.

The glass, investment, and firing for 25 of the most promising and visually diverse samples from 'Phase 1' testing were applied to enclosed investment moulds, 'Phase 2', to observe if the properties of the cast surface and mirror quality remained consistent with a completely different mould set up.

The recessed detail of a three-dimensional 'bullet' shape enclosed in a cylindrical dome of solid glass utilizing refractory core-forming techniques was used as a sample. This form was created by making rubber 'mother-moulds' to create the investment mould for the dome in two halves. This two-part investment mould 'tension set' the investment core of the bullet shape in place. A final coating of investment material was then applied to set the two halves permanently for the duration of the firing.

This process was tedious and time consuming, however it was the only way to create a core-formed mould without the need of lost wax. A greater volume of glass was used to fill the enclosed moulds, which were subjected to a slightly longer pre-firing cycle to ensure that the glass would flow. After annealing and divestment, enclosed samples were then cold worked to a full polish by hand, in order visually assess the interior surface left from the investment core with clarity.

Once mirrored, the cold worked samples made in 'Phase 2' highlighted very similar mirrored surface effects when comparing them to their 'Phase 1' counterparts, however the curved surface of the bullet shape recess led to higher levels of reflectivity in some instances when compared to the flat open-face tests.

Although the initial ambition for this research was to create full reflection in cast glass, a broad palette of visual 'effects' for cast glass mirrors were unveiled during preliminary testing. These effects offer a range of aesthetic options, for example, the mirror can take on the appearance of iridescent 'tin foil', brushed silver 'peach fuzz' or mottled 'moon rock' (to name a few).

Ultimately, these tests present new ways in which the mirror can function visually when applied to cast glass. Within the realm of art making, silvered glass does not necessarily need to be a perfect reflective surface but can be used to emulate a range of materials, textures, hues, and surface patterns. This palette of silvering effects gives the artist / maker multiple choices in the aesthetic outcome of a cast mirror application. This sets up a new and extended vocabulary in how the mirror can look and function. The glass form, its interior surface, and the visual effect achieved in the mirror can all play a part in the narrative of the artwork.

Now that a breadth of material testing is complete, a series of artworks are currently in progress that entwine the rich metaphors and cultural associations of the mirror through time while harnessing a new palette of mirroring effects. For information and insights on Joanna Manousis' creative practice, research, and publication dates, please follow @joannamanousis / www.joannamanousis.com for more information.

7.6.2 Publication: The Contemporary Glass Arts Society Newsletter, *Fruits of Labour: A Glass Education* (October 2024)

Education has cultivated generations of glass artists, allowing them to transform imagination into exquisite, tangible art forms that few thought possible. Each generation builds on the academic work and instruction of the last generation. The reality is that mastering the technical intricacies of glass demands expert instruction, patience, and access to expensive specialised equipment and raw materials - resources that universities are uniquely positioned to offer. Yet, as financial pressures intensify on UK universities, the dwindling number of glassmaking programs are at significant risk, leaving the community of makers deeply worried about the future of glass in academia, and, by extension, the art form's ability to evolve and thrive.
For many aspiring glass artists, particularly those without financial means, this raises pressing questions: How can they gain access to this demanding craft, and how can they sustain a lifetime of dedication to glass?

Looking back, my journey as a glass artist would not have been possible without access to higher education in the arts and the resources that came with it. Graduating from the University of Wolverhampton's BFA Glass program in 2007 was just the beginning. I spent a year of my undergraduate studies at The New York College of Ceramics at Alfred University in the USA, where I also earned my MFA. This period, which included a year of teaching

as an adjunct professor in the glass department and the institution's cross-disciplinary approach, was personally and professionally transformative. During my Master's studies, I was determined to move beyond traditional pedestal-based objects and explore larger-scale installations. I delved into various techniques, including hot-blow moulds and core-casting, and being largely self-taught, I dedicated countless hours to experimentation. I aimed to create a trompe l'oeil pomegranate for my thesis - a three-dimensional interpretation of a Dutch-Flemish still life. The project demanded mastery of diverse techniques to replicate the texture and hue of the fruit's skin, the glossy seeds, and the mirrored flesh, alluding to themes of vanity and desire.

After eight arduous months, endless self-questioning, and countless discarded attempts, the remnants scattered around the studio, I finally crafted an art-worthy pomegranate. Such a project would have been unimaginable without the extended access to university equipment, resources, and the encouragement I received. The connections I made with educators, professionals, and fellow artists were invaluable -, relationships that have profoundly influenced my artistic journey, marked by the same uncertainty and challenges many artists face. The skills and ambitions cultivated in these academic environments are indispensable, as institutions like these foster cross-disciplinary approaches essential to the evolution of art.

After graduating from Alfred University, I eagerly launched my professional career as a glass artist. Predominantly US-based, I earned a living as a

freelance instructor in the public and private sectors while maintaining a studio practice centred on cast glass sculptures. However, my ability to earn a living by selling my artwork largely depended on access to studio spaces provided by university and museum residencies. Imagine the immense personal resources needed to create intricate glass artwork at scale without access to these essential facilities.

In 2021, I earned an opportunity to pursue a practice-based PhD at The National Glass Centre (NGC) through the University of Sunderland. My family relocated to NE England, including my husband, a glass artist, and our two young children. For over a decade, I have been obsessed with the potential of dimensional mirrors within solid glass sculptures. My PhD program would allow me to delve deeply into the subtleties affecting the reflective capabilities of cast glass.

The National Glass Centre is home to arguably the country's most comprehensive academic glassmaking facilities and plays a crucial role in public education through daily demonstrations, classes, and exhibitions. The NGC is one of the few rentable facilities for glass artists, offering specialised equipment and resources rarely available elsewhere. It is also a vital institution for educating the next generation and preserving the region's rich glassmaking legacy. Equally important, institutions like NGC played a crucial role in elevating glass to an art form while influencing various industrial

applications, including innovations in materials, optics, architecture, and coatings.

Unfortunately, the University of Sunderland recently announced its decision to close the NGC due to building maintenance costs, a decision that is devastating for the UK glass community. While I am grateful to be completing my PhD at the NGC, it saddens me to know I'll be among its last graduates. The closure means the loss of a great facility and academic glass centre, along with the potential innovations that could have emerged from it.

Some suggest that the private sector will step in to fill the void. However, in my experience, the demographic of those who enrol in private glassmaking classes and rent studio equipment often hobbyists or retirees with the financial means to afford small kilns and supplies differs significantly from those in academic settings. This market is a far cry from university programs, which attract younger adults, conduct essential research, and invest in the advanced equipment needed to push the boundaries of glassmaking. University programs offer a unique opportunity for young people to dedicate their lives to the craft, ensuring that the knowledge is advanced, and the tradition is kept alive for future generations.

There are broader implications as well. As university glass programs dwindle, so does public awareness of contemporary glass and the knowledgeable

collector base that supports it. Public access to art glass - its rich history and its transformative ability to serve both functional and artistic purposes - is vital for sustaining the artists who work with this medium. Education and awareness go beyond preserving an art form; they are essential for fostering an economy where glass artists can thrive.

University programs have honed my skills and shaped my studio practice. They have provided the focus, risk-taking opportunities, and time necessary to create complex, labour-intensive works that would be impossible in a private studio, where financial pressures often dictate creative decisions. Moreover, these programs have allowed me to share my knowledge with others, teaching in a communal environment that fosters collaboration and innovation.

Looking to the future, I aspire to create a living/working space to continue honing my craft and passing it on to others. Perhaps my students, or even their students, will push the boundaries of glass art in ways I can't yet imagine. Where and when this will happen remains uncertain, but one thing is clear: it takes a village supported by higher education glass programs.

7.7 Appendix D: Portfolio

This appendix shows photographs from exhibitions featuring studio tests and finished artworks. Some of these images show spectators during opening receptions to give an understanding of attendance and/or the scale of the works themselves.

7.7.1 Collect 2023, Somerset House, London

In March 2023, The Queen Elizabeth Trust (Qest) showcased a configuration of mirrored prisms titled *Indra* at *Collect*, an art, design and craft fair held annually at Somerset House, London. Qest is a charity promoting the longevity of British craft skills. The organisation sponsored this PhD in tandem with The Northern Bridge Consortium and held a booth displaying select works from their scholars to show the breadth and excellence of makers residing in the UK.

In addition to exhibiting with Qest, *Iris Obscura* I and *Silver Thread* were showcased with Bullseye Projects. This was the first public debut of all three sculptures, and an image featuring *Silver Thread* was used to publicise the fair through Crafts Council England. Iris Obscura was then showcased in the *Transitions in the Kiln* exhibition with Bullseye Projects at the Bellevue Arts Museum in WA, USA, winning third place in the student category.



Figure 159. *Silver Thread* in Bullseye Projects Booth at Collect 2023. Image Credit: Michael Endo



Figure 160. *Iris Obscura I* in Bullseye Projects Booth at Collect 2023. Image Credit: Michael Endo



Figure 162. *Iris Obscura I* with Bullseye Projects at Collect, London. Image courtesy of Michael Endo



Figure 161. Queen Elizabeth Scholarship Trust at Collect, Somerset House, London. Image courtesy of Qest



Figure 163. *Indra* in Qest Booth at Collect 2023. Image Credit: Joanna Manousis

7.7.2 This is Becoming a Pattern, *Pittsburgh Glass Center, USA*

This is Becoming a Pattern was a group exhibition curated by Jason Forck at The Pittsburgh Glass Center in Pittsburgh, PA, USA. The show incorporated works made by Joanna Manousis, Mel Douglas, Nancy Callan, Corey Pemberton, Amanda Simmonds and Nathan Sandberg, running from October 2023 to January 2024.



Figure 164. *This Is Becoming a Pattern* at The Pittsburgh Glass Centre Gallery, USA. Image Credit: Joanna Manousis



Figure 165. *This Is Becoming a Pattern* at The Pittsburgh Glass Centre Gallery, USA. Image Credit: Joanna Manousis



Figure 166. *Silver Tread* and *Mirror Palette II* at *This Is Becoming a Pattern* at The Pittsburgh Glass Centre Gallery, USA. Image Credit: Joanna Manousis



Figure 167. *Silver Tread* at *This Is Becoming a Pattern* at The Pittsburgh Glass Centre Gallery, USA. Image Credit: Joanna Manousis



Figure 168. Detail of Indra at This Is Becoming a Pattern at The Pittsburgh Glass Centre Gallery, USA. Image Credit: Joanna Manousis



Figure 169. *Electri* and at *This Is Becoming a Pattern* at The Pittsburgh Glass Centre Gallery, USA. Image Credit: Joanna Manousis



Figure 170. *Chrysalis* at *This Is Becoming* a Pattern at The Pittsburgh Glass Centre Gallery, USA. Image Credit: Joanna Manousis

7.7.3 Iris Obscura

Iris Obscura was the first solo exhibition documenting studio tests and finished artworks side by side. Held at The Athenaeum Building in downtown Sunderland, England, from May – July 2024, the show would not have been made possible without the generous support of Breeze Creatives.



Figure 171. *Iris Obscura* at The Athenaeum Building, Sunderland, UK Image Credit: Colin Davison



Figure 172. *Celeste* in *Iris Obscura* at The Athenaeum Building, Sunderland, UK Image Credit: Colin Davison



Figure 173. *Mirror Palette III in Iris Obscura* at The Athenaeum Building, Sunderland, UK Image Credit: Colin Davison]



Figure 174. *Celeste* in *Iris Obscura* at The Athenaeum Building, Sunderland, UK Image Credit: Colin Davison



Figure 176. *Distilled Portrait I: Series II* in *Iris Obscura* at The Athenaeum Building, Sunderland, UK Image Credit: Colin Davison



Figure 175. Opening Reception at *Iris Obscura* at The Athenaeum Building, Sunderland, UK Image Credit: Michael McGuire



Figure 178. Figure 172. Opening Reception at Iris Obscura at The Athenaeum Building, Sunderland, UK Image Credit: Michael McGuire



Figure 177. Opening Reception at *Iris Obscura* at The Athenaeum Building, Sunderland, UK Image Credit: Michael McGuire



Figure 179. Opening Reception at Iris Obscura at The Athenaeum Building, Sunderland, UK Image Credit: Michael McGuire



Figure 180. Opening Reception at *Iris Obscura* at The Athenaeum Building, Sunderland, UK Image Credit: Michael McGuire



Figure 182 Student Group Talk at Iris Obscura at The Athenaeum Building, Sunderland, UK



Figure 181. Student Group Talk at Iris Obscura at The Athenaeum Building, Sunderland, UK

7.7.4 *British Glass Biennale* at the Ruskin Glass Centre

A select group of tests made in Phase 2 of testing was chosen for the British Glass Biennale from August to September 2023 at the Ruskin Glass Centre, UK. The following images were taken during this event.



Figure 183. *British Glass Biennale 2023* at The Ruskin Glass Centre, UK Image Credit: Joanna Manousis



Figure 184. *Mirror Palette II* at the British Glass Biennale 2023, The Ruskin Glass Centre, UK
Image Credit: Joanna Manousis



Figure 185. Panel Discussion at the British Glass Biennale 2023, The Red House Cone, UK
Image Credit: Effie Burns

7.7.5 *Three Artists* at the National Glass Centre

Three Artists was the penultimate exhibition held at the National Glass Centre in Sunderland, UK from June 2025 – January 2026. Featuring the works of Zac Weinberg, Anthony Amoak-Attar and Joanna Manousis, the show draws together all tests and artworks made during this PhD study.



Figure 186. *Persephone* in *Three Artists Exhibition*, National Glass Centre, UK. Photo Credit: Colin Davison



Figure 188. Three Artists Exhibition, National Glass Centre, UK. Photo Credit: Colin Davison



Figure 187. *Three Artists* Exhibition, National Glass Centre, UK. Photo Credit: Colin Davison



Figure 189. Distilled Portrait I: Series II in *Three Artists* Exhibition, National Glass Centre, UK. Photo Credit: Colin Davison



Figure 190. *Mirror Palette I + II* in Three Artists Exhibition, National Glass Centre, UK. Photo Credit: Colin Davison



Figure 191. *Mirror Palette I + II* in *Three Artists* Exhibition, National Glass Centre, UK. Photo Credit: Colin Davison



Figure 192. *Three Artists* Exhibition, National Glass Centre, UK. Photo Credit: Colin Davison

8 Glossary of Terms

Abrasives

A substance or material used to cut, grind or polish a surface, such as silicon carbide grit used to refine glass.

Annealing

A process whereby a material (glass) is cooled slowly to remove thermal stress, which can lead to cracking.

Bas-relief

A method of moulding or carving whereby shallow details protrude from a surface.

Casting

A method of making an object by pouring a molten material into a mould.

Cerium Oxide

A white or orange water-insoluble rare earth powder, often used in the final stages of polishing glass using a felt wheel on a lathe.

Chemical Silvering

The process of applying a thin, reflective coating of silver to a surface, typically glass, to create mirrors.

Cold Working

The process of cutting and polishing glass using abrasive materials and equipment.

Contamination

When an impurity is in or on the surface of something, giving undesirable characteristics. In the context of this thesis, residual investment particles embedded on the surface of cast glass can cause mirror staining.

Core-cast

A mould-making process whereby a solid form (core) is placed into a mould to create a negative impression. In glass casting, a core is made of investment (heat-resistant) materials.

Cullet

Pieces of glass, which are often melted or recycled in a furnace.

Devitrification

When non-crystalline glass turns into a crystalline structure due to slow cooling, chemical interaction or exposure to high temperatures. This can cause a white haze, roughness, or brittleness.

Divested

When something is removed from another, for example, an investment mould being removed from a glass casting.

Enclosed-Mould

A mother mould or investment mould that encircles an object in the round.

Firing

The process of heating and cooling a kiln.

Flask Mould

A mould made by pouring material over an object/form that is surrounded by a barrier, such as wooden coddle boards, clay or a flexible vinyl sheet, for example.

Formulas

A mixture of ingredients, for example, an investment recipe.

Gypsum

A soft white sulphate mineral that hardens when mixed with water to make materials such as pottery, plaster, and cement.

Hand-built

Something that is built by hand, for example, a mould made by applying and manipulating layers of material, rather than pouring them.

Hand-lapping

The process of grinding glass by hand using loose silicon carbide grit mixed with water on a piece of sheet glass.

Hand-polishing

Polishing a material by hand.

hBN

An abbreviation for *hexagonal boron nitride*. A synthetic, white, lubricious ceramic material composed of boron and nitrogen atoms arranged in a 2D layered, graphite-like honeycomb structure.

Hot Billet

A glass billet at a high temperature that remains solid.

Hot billet Casting

The process of adding hot billets of glass to a pre-heated mould in a kiln.

Hydrocal

A high-strength, low-expansion hydraulic gypsum cement used primarily for casting, moulding, and art, offering roughly twice the compressive strength of standard moulding plaster.

Investment

A refractory ceramic, plaster, or slurry material, which is often used for moulds subjected to high heat.

Investment-cast
A material moulded in a refractory mould.

Kaolin
A fine soft white clay, resulting from the natural decomposition of other clays or feldspar.

Kiln-Casting

Casting glass in a kiln using moulds.

Molochite

A high-temperature calcined kaolin (China Clay) that is used primarily as a white, low-iron, refractory aggregate or grog in ceramics and investment casting.

Modifier

A material that changes the structure of a mixture to give it certain properties, such as strength or permeability in mould making.

Mother Mould

A mould that can create duplicate cast forms. Sometimes referred to as a rubber mould when made of a flexible material such as silicone or polyurethane. It is used for lost wax or investment casting.

Mylar

A form of polyester resin used to make heat-resistant plastic films and sheets. Often used for helium balloon manufacture.

Obsidian

A hard, dark, glasslike volcanic rock formed by the rapid solidification of lava.

Opacity

Lacking transparency/

Open-Face Mould

A single-sided mould that often looks like a tray in cast glass processes.

Peak Temperature

The highest temperature within a firing schedule.

Polished

A refined, shiny surface.

Polyurethane

A versatile, durable, and flexible synthetic polymer material.

Pontil mark

The mark of a metal rod ‘punty or pontil’, used to transfer a piece of glass for manipulation at high temperatures.

Pre-fired

A material that has been heated previously. In the context of this thesis, a mould that has been fired in a kiln to remove water content and impurities.

Punty

A punty or ‘pontil’ is a metal rod used to hold or shape soft glass

Quartz

A mineral consisting of silica.

Ramping

An increase or decrease in voltage, i.e heat in a kiln firing.

Sprue

A reservoir or channel used to contain material. For example, an area of a mould that holds solid glass ready to heat and flow into a mould cavity.

Rondelles

A round plate of glass made by spinning a bubble of glass out into a flat plate in glassblowing.

Separator

A material that helps prevent a material from sticking.

Silicon-carbide grit

A synthetic, high-performance abrasive material composed of silicon and carbon, known for being extremely hard (second only to diamond) and sharp.

Silicone or polyurethane positives

A shape made of rubber that allows impressions to be made in a mould. Within this research, silicone positives are used to create bas-relief moulds.

Silvering

Applying a thin layer of silver to a surface using the chemical deposition technique.

Soda-lime

A mixture of calcium oxide and sodium hydroxide.

Striations

A long, thin streak on or in a material.

Sucker

A depression on a surface.

Talc

A white, soft mineral made of hydrated magnesium silicate

Tension-set

Something that is held under pressure without a mechanical joint. For example, a tension set mould is made in two halves that, in some instances, hold a core in place.

Tension-set Investment Mould

A heat-resistant mould made of multiple parts that holds an investment core in place.

Thermal Shock

When a material cracks due to rapid heating or cooling.

Thermal Strain

The change in dimension of a material due to temperature variations.

Tin-Mercury Amalgam

An alloy formed by mixing tin with liquid mercury, historically used as a reflective coating for mirrors

Undercuts

An indentation, protrusion, or feature on a part that prevents it from being directly removed from another piece/mould.

Veil

A white mark, often caused by contamination or crystallisation in cast glass.

Viscosities

The thickness of a liquid.

Voids

A negative/residual space.

Zircon

A zirconium silicate mineral.