Inner space in sculpture: the use of metal inclusions in glass

Goshka (Małgorzata) Białek

PhD 2017

Inner space in sculpture: the use of metal inclusions in glass

Goshka (Ma³gorzata) Bialek (2017); University of Sunderland

Abstract

The focus of this research was to investigate methods of combining two materials, metal and glass, specifically concentrating on the application of a variety of metals in glass, with different glass techniques, for creative use. Metal inclusions in glass constitute an element in the further development of my artistic practice. However, it was found that the palette of metals used by artists was restricted. This is because the present methods available for artists have demonstrated many limitations and uncertainty of results. Therefore, this research aims to explore the solutions to combining metal and glass in artistic practice.

The study also covers the history of inclusions in glass, and their aesthetic function in craft and art, as well as the perception of inner space occupied by inclusions. The nature of this perception is an important element in understanding why artists are intrigued by inclusions.

Current practice in this field is illustrated through an evaluation of the works of a number of artists who employ glass and inclusions (especially metal). These artists were chosen because they have connections with industry or interests in technology which they apply in their artistic practice. The research also investigated these artists' personal technical procedures and the specific reasons for the development of their procedures. The artists were asked, wherever possible, to provide a statement relating to their technical and creative practice, and the difficulties they encountered. The collected data was partly used to determine directions for research.

Following this, the application of metals in glass as a distinctive method of creating shape and internal structure along with issues relating to transparency, clearness and texture to glass were explored. Studio based experiments to identify creative parameters for combining glass and metal, especially in the hot state, and process routes that allow the combining of these two materials in the hot state were developed and tested. This testing was further extended by compatibility studies and developing applications of metal in glass that would avoid problems arising from incompatibility issues. In particular, experiments were concentrated on nickel, nickel alloys, lead and tin alloys in hot poured glass formed in moulds.

The results of these investigations were explored in the context of the application of metals with glass in various industries, the scientific developments in these fields and the possibility of applying these materials and techniques for creative use by an artist in a studio environment.

The original contribution to knowledge is mainly to be found in the techniques for applying metals, particularly nickel, lead and tin alloys, in glass in a hot stage to creative practice. These techniques especially relate to:

▪ building high temperature resistant moulds with a very fine textured surface

▪ developing a method for the application of nickel (up to 3mm = 118.11mil thickness) and lead/tin (up to 5mm = 196.85mil thickness) alloys with hot pouring glass using the mould method

▪ developing appropriate firing cycles to control the application of inclusions

▪ identifying lubricants and appropriate methods for applying them to prevent reaction and incompatibility problems between different materials.

A further original contribution of this research relates to the assemblage and interpretation of views concerning the perception of inner space in glass sculpture occupied by inclusions.

The subject of this research may be a stimulus to increase cooperation between scientists and artists, as well as promoting understanding of inclusions through a different approach to this subject.

Contents

I. List of practical work:

1. Material tests:
    - Preliminary tests for selection of materials, a total of 45
    - Material and process route testing in the shape of blocks, a total of 25
    - Process route testing in the shape of “head”, a total of 40

2. Artworks:
    - *SelfPsychoanalyses*, a series of sculptures
    - Jewellery: rings, pendants, bracelets and brooches
    - Logo for Hempel Metals Company
    - *Flowing Memory*, ……….
    - *Different point of perspective*, a series of sculptural artworks.
    - *Illusion of space; Perspective in sculpture*,
    - *My way to thinking*, it is assembled from test pieces of research

3. Sketchbooks, journals, notebooks, files and photographs of works:
    - Sketchbooks showing design and visualisation of ideas
    - Notebooks, presentation of technical information collection
    - Collection of photographs of works
    - Journals, recording progress and discussions with advisors, supervisory team, artists and scientists.

II. List of Tables.

III. List of Figures

IV. List of Appendices.

Appendix 1: Firing programs developed during the research.

Appendix 2: List of: interviews, consultations, discussions, workshops with artists, art historians and scientists.

V. 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.

VI. Acknowledgements

I would like to thank:

The University of Sunderland for giving me the opportunity to conduct and complete my PhD research. The specialist facilities and technical advice of the department was one of the main features for basing this research project at the University of Sunderland.

I would especially like to thank: my Directors of Studies Professor Kevin Petrie (PhD), Professor Sylva Petrová (PhD), Dr Jack Dowson, my co-supervisor Colin Rennie, also Professor Brian Thompson and Professor Peter Davis who with their expertise and support have tirelessly directed me throughout my studies. I would also like to thank my technical advisors: Dr Colin Gill, who help me with preliminary selection of materials used in this Doctoral project. Thanks, are also due to the technical support staff of the Department: Tim Betterton, James Maskrey and Robert Winter for their advice and assistance.

Durham University – Professor Chris Greenwell and his assistant Leon Bowen, Professor David Wood and his assistant Dr Linzi Dott, Dr Richard McWilliam and Dr Florian Bryce Soulard for their expertise, introduction to the innovative technological processes (as programed holograms, deposition of metals, modern instruments for chemical analysis) and conduct analysis of materials used in my research.

Society of Glass Technology – Professor Russell Hand, President of SGT; David Moore, Managing Editor SGT; Dr David Martlew, Dr Doug Crozier and Bill Brookes for their expertise, technical support and access to the SGT publications.

Academy of Technology in Krakow in Poland - Professor Jozef Zasadzinski whose expertise includes properties of non-iron metals, Professor Stanislaw Rzadkosz from the Department of casting metals and with Dr. Elzbieta Greiner-Wrona from the Department of Glass, they have international reputations and their publications appear in most international Journals. Therefore, I thank them for their expertise and access to the extended range of the publications of necessary information for some technological solutions in this work.

Newcastle University – Professor Phil Taylor, Dr Oana Bretcanu (specialist in material engineering) for their expertise.

National Glass Centre – making it possible for me to use the workshop and equipment.

I would like to express thanks to Dr John Metson and Professor Linda Thompson for linguistic help.

I am very thankful to artists, curators, owners of galleries, historians of art and glass instructors, who took part in this research project in particular: Serge Lechaczynski (owner of *La Verrerie de Biot*), John Kaplan, Bertil Vallien, Antoine Leperier, Mary Shafer, Janusz Walentynowicz, Beth Hylen (Librarian, Rakow Research Library, The Corning Museum of Glass), Colin Reid, De La Torre Brothers, Anna Eremeeva (The Hermitage Museum, St. Petersburg, Russia), Sally Resnik Rickriver, Michael Glancy, Paul Stankard, Uta Majmudar, Anna Chrysopoulo and many, many others.

I am very grateful for the help and support that I have received throughout this research project.

1. Introduction

This chapter introduces the initial background of the thesis; it outlines the research field; accordingly, it describes and examines the problems occurring during the application of metal inclusions in glass. The chapter defines the aims and objectives established for this project, as well as the methodology used during the research.

1.1. Background of this research project

This research deals with inclusions in glass, predominantly metal inclusions for creative use. The investigation concentrates on the existing technology developed by artists, the adaptation of available industrial technology and the development of new technology in the possibilities of immersing different kinds of metals into glass sculptures. Inclusions are very important for glass artists in their studio practice. They employ inclusions, such as air bubbles (Figure 1, p.21), metals (Figure 2, p.22), ceramic (Figure 3, p.22), coloured glass, fabrics, images (Figure 4, p.23), enamels and organic materials for decorative and narrative effects by using internal space in the object.

Figure 1. Jo Mitchell; *Legion*; 2015;

Pilkington's tinted float glass, kiln-controlled air entrapment.

H150cm x W500cm x D 100cm; Photographed by Colin Rennie.

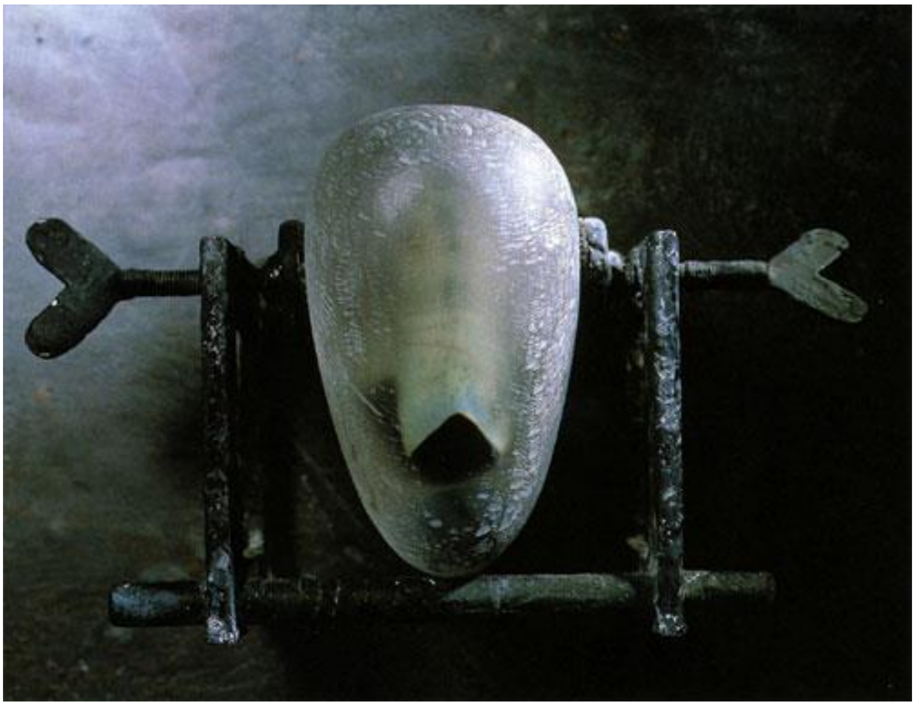

Figure 2. Bertil Vallien; *The Bar*; 1999;

Sandcast glass with metal, colour glass powders inclusions

H 25 cm x W 43 cm. x D23 cm; Photographed by: G. Ortegren.

Figure 3. Jessamy Kelly, *Spliced*; 2009;

Copper Cobalt Blue, kiln cast glass sculpture with a pâte de verre & bone china core;

Size: 60cm x 20cm x 18cm; Photographed by David Ward.

Figure 4. Jeffrey Sarmiento, *Race/March*; 2013;

Screen-printed inclusion in glass blocks; Size: 176cm x 85 cm x 20cm; Courtesy of Jeffrey Sarmiento.

The starting point for this research developed from experience gained during my study towards a first degree in sculpture, and from further experience gained during my MA degree study in glass. The research is informed by, and builds on, my earlier experiments using metals (Figure 6, p.26) and the immersion of prints in glass (Figure 5, p.24 & Figure 9, p.29).

Using experience gained in the sculpture and crafts field (BA Fine Arts and MA Glass and Ceramics, University of Sunderland), it was intended, firstly, to develop techniques for the expansion of other sculptors' creative potential of combining glass in their studio practice. Secondly, the aim was to equip other glass artists with a wider 'palette' of inclusions for utilisation of the 'positive space' (internal space) in sculptures. 'Positive space' is the space taken by an object, but the management of the internal space is possible only if the materials employed are transparent or semi-transparent, for example glass (Figure 5, p.24).

Figure 5. Goshka Bialek; *Newspaper*; 2002

Inclusion of screen printing images on transfer paper in glass;

H180cm x W50cm x D30cm; Photographed by Tim Adams.

This investigation also gave attention to the needs of sculptors who have employed or started to use glass as a new medium in their artistic practice. It was noticed that in most universities (also in the University of Sunderland) the application of glass is taught in Applied Art departments and students who study Sculpture (which is usually taught in Fine Art departments) have very limited access to glass as a medium. Generally, first year sculpture programmes contain an introduction to metal, wood, stone and digital technology only. It is very rare that students have opportunities to work with glass and they do not have the confidence to accommodate glass in a professional manner in their artistic practice. This research will show the potential of using glass and metal insertions by making the technical methods more accessible to artists.

Also, it has been observed in glass studios and universities, in the preparation for this research, that glass artists, students and their teachers are limited in using the potentially wide palette of metal inclusions owing to the incompatibility issues of combining metal and glass, particularly in a hot state. Interviews that have been conducted as part of this study with glass artists showed that many of them experienced some technological problems and often gave up the further development of their preliminary ideas and further use of the combination of metals with glass because of a lack of access to suitable technology to achieve the intended initial objectives (Reid, 2014) and (Vallien, 2013).

Some of these technological processes were previously thought impossible or unlikely to produce the desired effects. The review of literature and questionnaires sent out to artists also showed that the thickness of the metal inclusion has an effect during annealing, with the belief that any metal thicker than a foil 2-5 mil (= 0.0508-0.127mm) would cause the glass to crack (Walker 2010). However, having started experiments with metals of greater thickness than foil (up to 3mm = 118.11mil), it was established that thicker inclusions could be regularly produced effectively.

All inclusions in glass require knowledge and practice in applying them, as well as an understanding of the existing technology. It is difficult to obtain this information from the publications accessible for artists. In order for artists to realise their artistic ideas, they often need to solve technical problems themselves. To be able to achieve my artistic ideas, a number of technological problems have had to be overcome.

Transparent and semitransparent materials and the use of inclusions are a very important element in my sculptural practice and artistic research. I was always fascinated by historical places that are used every day (as for example the medieval castle in Durham, now used as accommodation for students and staff). We pass by without thinking about how much information is hidden in such places. Often we prefer to believe in myths which we are told about the past, instead of investigating the true story. However, we cannot know the whole truth because writers can only present their mediated version of historical events. Similarly, sculptors can present in their portraits only their perception of their subjects' characters: we cannot see directly into these people's thoughts. Moreover, even if we have immediate access to a story or a person, it is not always possible to understand the story as it is experienced by the participants or the person as she or he understands themselves. This is the case even if the people concerned are our parents (Figure 6, p.26).

Figure 6. Goshka Bialek; *What's Left*? 2004;

Cast bronze and glass on marble base;
Photographed by Tim Adams.

The empty brass head is a real image of my dad, with a print of his skin. And the solid glass head represents his unreadable thoughts, that can never be recreated by anybody else (Figure 6, p.26).

Only a few years ago I discovered by chance that I was adopted. It was a big surprise to me, but at the same time, it helped me to explain the meaning and origin of some of the images I had in my head. This subject was illustrated by a series of my self-portraits (Figure 7, p.27). I used these self-portraits as test pieces in the technological experiments I was conducting but they were also illustrations of my thinking at that time.

Figure 7. Goshka Bialek; *Self-portrait I & II*, 2017;

Inclusion of nickel, lead and tin alloy in Cristalica glass; hot pouring into the mould;

The second thread in my sculptural practice was to understand the phenomenon of different interpretations of the same fact, or different perceptions of the same object when viewed by different spectators. This is a particularly significant issue at this stage in the history of our global society, where real experts are often not respected and are not being listened to, while so-called experts who lack moral principles have the support of a large part of society.

To explore this subject in my work I needed to consider an additional space to apply inclusions and illusion of perspective in my sculptural practice. This led me to the idea of utilising the additional space in sculpture (particularly internal space) created by using transparent and semitransparent materials (Figure 8, p.28).

Figure 8. Goshka Bialek; *Different interpretations from different perspectives*, 2017;

Inclusions of nickel cut by a waterjet, cast in lead Gaffer glass.

An early example of my experiments using inclusions in glass is shown in Figure 5 (p. 24) and Figure 9 (p. 29), which incorporated the immersion of screen-printing images on glass and on transfer paper in glass.

Figure 9. Goshka Bialek; *Imagination*; 2001;

Cast uranium glass with immersion of printings

H180cm x W50cm x D30cm; Photographed by Tim Adams.

My initial research during my MA was concentrated in general on the use of inclusions (such as fabrics, metals, organic objects, clay and images) in cast glass (including sand cast technique, cast glass in the mould, hot cast glass). Following these experiments, the investigations began to focus on inclusions, such as prints, photographs, and holograms, and on the capabilities of controlling their shapes during the casting process. As a result of these studies, I have developed a process to immerse screen printed images on glass and on transfer paper into cast glass (Figure 5, p.24 & Figure 9, p.29).

It was difficult to control the shape of the inclusions in glass cast in a mould, so it was necessary to find a material that would better meet the objective of retaining the inclusion shape. Therefore, these studies were concentrated on the search for a suitable material which would satisfy these objectives. Upon reviewing the literature and conducting experiments, metal was selected as the most appropriate medium for this project of adding inclusions into glass (Figure 10, p.30).

Figure 10. Goshka Bialek; *Different interpretations from different perspectives*, 2017;

Inclusions of nickel cut by a waterjet, cast in lead Gaffer glass.

Metal inclusions constitute a necessary element in the further development of my artistic practice. However, I have found that the palette of metals used by artists is restricted and the present technologies available for artists, which are widely drawn from the industrial sector, have many limitations. Therefore, it was crucial to extend the range of systems for other artists' creative practice. So this research investigates the possibilities of creating new techniques or adopting existing industrial technology in the application of metal inclusions for creative use. The research also considers the perception of space inside a sculpture, which becomes visible to a viewer through glass and through optical phenomena obtained using glass and inclusions of metals in a hot state. This study gives attention to sculptors and glass artists who use combinations of glass and metal and the kinds of problems these mediums bring. In addition, the research investigates the adaptation of existing technology, particularly metal casting into moulds, to the possibilities of immersing different kinds of metal inclusions into glass sculptures in order to utilise the space occupied by the investigated object. Finally, metal as an inclusion medium was chosen in this project for a number of other reasons than those suggested by experimentation and the review of literature as mentioned above. Firstly, a similar technology is involved in casting both metal and glass (Figure 6, p.26). Both materials can be turned into liquid and back to a solid state many times. Also, some solid brittle metals, for example Gallium, fractures conchoidally like glass, which means that these materials fracture as waves rather than following any natural planes of separation. These similarities can be helpful because most sculptors are familiar with the metal medium, which should help them to understand the technology of the glass medium more easily and give them confidence to adopt glass as a medium in their artistic practice. During my BA and MA study I had the opportunity, as had most of the Fine Art students in the University of Sunderland, to gain experience casting different kinds of metals, including bronze, brass, aluminium, lead and tin (Figure 6, p.26).

Secondly, some metals can be turned to amorphous material, also known as glassy metal, by extremely rapid cooling, physical vapour deposition, solid-state reaction, ion irradiation, or mechanical alloying (Ojovan, Lee, 2010). A third reason was to introduce new metals (other than those usually used by glass artists in the past) for utilisation in inclusions in glass.

Also, metals were chosen for their symbolic significance. Metals were used in the past as a base for inscriptions. For example, Latin inscriptions are carriers of information about evolution of the art and the history of the Roman Empire, but also more mundane affairs between people living at that time. It is likely that most of the Latin metal inscriptions were on bronze, lead, gold, or silver (Gordon, 1983). Metals and quartz (Figure 11, p.32), which is a component of glass consisting of silica in amorphous (non-crystalline) structure, are mediums which contemporary scientists still use to store data for future civilizations using high-tech technologies (Laursen, 2013, pp12)

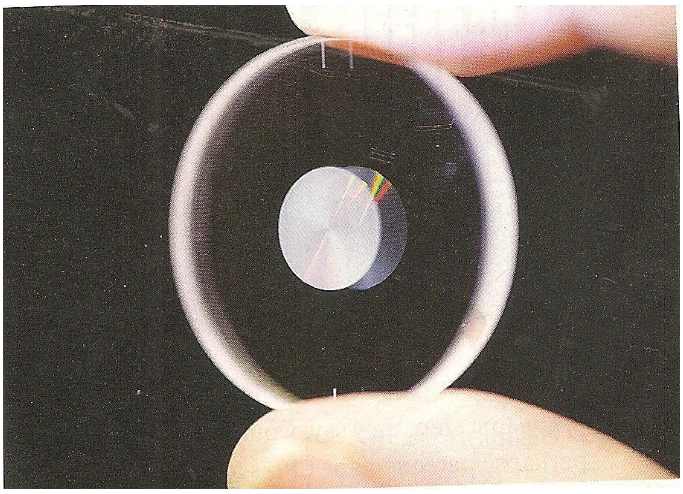

Figure 11. Storage data on quartz disc using new optical techniques that could preserve the text for millennia;

(Laursen, 2013, pp12)

Chapter Six (p.192) briefly investigates additional visual effects created during the preparation of 2D shapes cut from metals, which are going to be the inclusions in glass sculpture. These additional effects employ Patrick Hughes' discovery of reverse perspective (Flynn, 2006), which he applied in his paintings. Hughes' canvases are designed with 3D shapes, causing an optical impression of the changing perspective of the image (Figure 12, p.33).

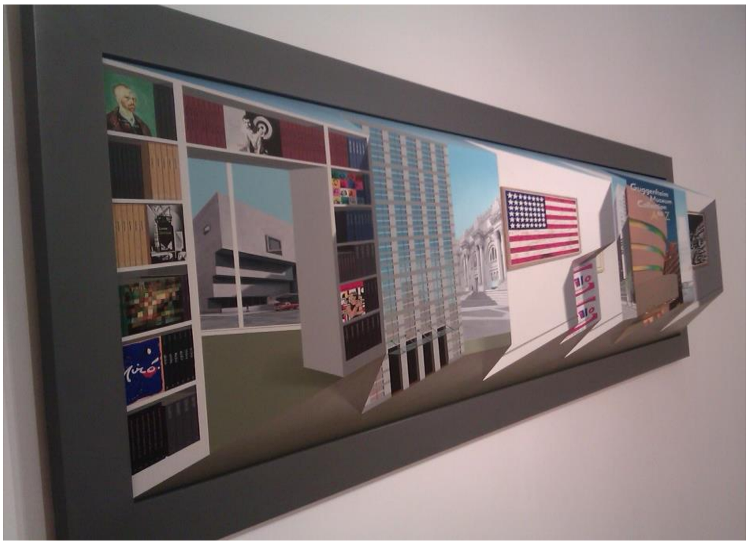

Figure 12. Patrick Hughes; 3D painting. 2006;
Durham University Collection

The most important reason for the research was to achieve a theoretical understanding of the application of inclusions, as this always brings some technical problems (Chapter Three, p.106 & Chapter Four, p.155). The process of intentional inclusion always involves seeking to achieve a positive balance between materials if a combination of two or more different materials are involved and especially if one of them is glass. Glass is a very complex material to work with and involves a great deal of knowledge and experience. Even experts cannot answer some questions to solve some technological problems (Zasadzinski, 2013; Hand, 2014; Greiner-Wrona, 2013).

The investigation concentrated on a choice of the most suitable materials and adapting them and the techniques of applying them to achieve the research goals. The main problem was to develop a technology which would deliver the desired results despite the problems encountered during the process of the experiments. These problems were associated with the quality of glass and materials available to artists on the market; the lack of information about the chemical and physical parameters of these materials; the compatibility, strength and thickness of inclusion materials; oxidation; fusion of glass, mould and inclusion surfaces due to the high wetting parameters of materials at high temperatures. Most of these problems were solved during the investigations of this research, and through collaboration with metal and glass scientists. More detailed accounts of solving these problems are in Chapters Three (p.106) & Four (p.155). In the final research two types of metals – nickel, and lead and tin alloys – were chosen were chosen because their chemical and physical properties are so different from each other (Table 11, p.131). The most important difference is their melting points: nickel's is above the melting point of glass, which is around 600°C, whereas lead's is below that temperature. On the other hand, they have common features, which are also very important for this research. They are both sheen silver and corrosion resistant. Thanks to these properties and, at the same time, their diversity, I hope to realise some of their potential in their application in art works, and to further an understanding of the problems which the application of metal inclusions can involve.

In addition, it was necessary to explain problems of internal space in sculpture that arise because of the inclusions and the transparency of the material used to contain them. If an object is opaque, the only part that we can see is the boundary between the space occupied by the object and unoccupied space. In this case the object defines a shape in space by delimiting it. It is the sculpture's facade behind which we assume space hides, but we are not able to see further in (George, 2014). Space is one of the most important parts of form and it is the space we need to see. Futurist sculptors Umberto Boccioni or Umberto Mastroianni introduce us to the question of visible space with their method of working simultaneously in space and time (Clough, 1969). We see the space surrounding the futurists' sculpture as organised by our sense of the potential for movement. We have the illusion that surrounding space is located as part of sculptural space. In this case, part of space is visible even if in our interpretation it is occupied by the sculpture.

Another innovative approach to internal space can be seen in the work of Barbara Hepworth, who made a hole in the solid object, thus creating the possibility for this new space to be turned into its own form (Hammacher, 1987), and the inner space itself therefore becoming a new and important medium in sculpture. However, it is not space itself that becomes visible, only its absence. By using glass, it is possible to make space inside sculpture visible and solid, and to create new forms within this space. Glass artists such as Bertil Vallien use space inside their sculptures. Indeed, Vallien is “more interested in what goes on inside the glass than...in the outer shell.” (Vallien, 2012).

The aims and methodology of this study therefore reflect its rationale of in seeking to engage the arts in a utilisation of internal space by using inclusions (predominantly metal ones) in glass to create new tools and methods of combination of the two materials. The study explores and employs knowledge and technology from a variety of disciplines to utilise internal space in objects through the advanced use of metals inclusions in glass. This research is focused on providing new insights into art practice from the perspective of the glass artist, sculptor and maker.

1.2. Research questions

The research questions based on my earlier experiments using glass and metal in my artistic practice and preliminary investigations of the problems are:

Q1. How might internal space in sculpture and inclusions be used in artistic practice; and what are the potential creative benefits of metal inclusions in glass?

Q2. What kind of problems and principles influence artists in the selection of metals to include in glass?

Q3. How might problems of metal inclusions in glass be reduced in creative practice?

Q4. Is it possible to extend the range of metals that might be used with glass?

1.3. Aims of the research

The questions led to the development of the following three aims:

Aim 1. to define, explore, evaluate and document potentially viable ways of utilising internal space and inclusions in glass sculpture (predominantly metal inclusions) as they have been used both in the past and in contemporary artistic practice

Aim 2. To develop the technology to enable the assembling of glass sculptures with the inclusion of metals, while keeping unchanged the shape and/or color of the metal

Aim 3. To develop a list of metals, with their parameters, which are compatible with glass and can be used in artistic practice.

The table below indicates the extent to which these aims correspond to the questions:

Questions→ Aims↓	**Q1**	**Q2**	**Q3**	**Q4**
Aim 1	**X**	**X**	**X**	
Aim 2			**X**	**X**
Aim 3	**X**			**X**

Table 1. The aims developed from the earlier stated questions.

1.4. Objectives of the research.

The aims and methods of the research (see sections 1.3, p.36 and 1.5, p.38) led to the development of the following objectives, which became the basis of successive stages of the research:

Objective 1. To identify similar approaches to the use of inner space in sculpture, as well as materials, techniques and influences among contemporary artists; also to examine the development of inclusions by artists in the past when working with glass and metal (see Chapter Two, p.47)

Objective 2. To collect information about existing glass and metal technologies in science and industry in order to develop new processes for glass and metal applications for creative use in artistic studios (see section 2.3, p.89)

Objective 3. To identify creative parameters for combining glass and metal, and to develop methods of applications of metal in glass to avoid problems arising from incompatibility between these materials (see Chapters Three, p.106 & Four, p.155)

Objective 4. To experiment with process routes that allow the combining of these materials in the hot state, and to create a body of metal inclusions in glass objects as outcomes of the testing of these materials in the studio environment for artistic practice (see Chapter Four, p.155 & Five, p.183 & Six, p.192).

The research objectives' connection to the aims are indicated in Table 2 below

Aims → Objectives ↓	Aim 1	Aim 2	Aim 3
Objective 1	X	X	X
Objective 2		X	X
Objective 3	X	X	X
Objective 4		X	X

Table 2. Objectives developed from each aim.

1.5. Methodology

The purpose of this study is to investigate methods of combining two materials, metal and glass, and the development of the technology to apply inclusions in glass sculpture for creative use. Current practice in this field is illustrated through an evaluation of the works of artists who employ glass and inclusions (predominantly metal). Some artists were chosen because they have connections with industry or are interested in the technology of glass and metal and they apply this in their artistic practice. The research also investigated artists' personal technical procedures and the specific reasons for the development of their procedures. The artists were asked, wherever possible, to provide a statement relating to their technical and creative practice, as well about the limitations encountered. The collected data was used to determine further directions to develop this research area.

A review of the literature related to the research methodology contributed to the range of suitable research methods. It involved a literature and contextual review, a review of current practice and an engagement with interdisciplinary research; developing creative practice through case studies exploring the use of glass and applications of a variety of inclusions. This research project has to some extent been viewed as a process of discovery and this is the reason why it has also involved experiential learning by active experimentation (Kolb, 1984) and tacit knowledge theory within its knowledge management process. There are three major approaches to the capture of tacit knowledge from groups and individuals: interviewing experts, learning by being told, and learning by observation (Parsaye, 1988, p.365).

According to Alan Frost (2010, pp3), knowledge management ("the process of creating, sharing, using and managing knowledge and information") is a process by which the expert's thoughts and experiences are captured; a knowledge developer collaborates with an expert to convert expertise into a coded programme. The aim is to simplify the definition and to discover how experts know what they know. However, according to Donald Schön (1983), professional education is acquired by learning by doing and developing the ability for continued learning and problem solving throughout the professional career.

Table 3 (p.39) presents the tools applied in this research to capture 36 artists' tacit knowledge.

Interviewing experts	Survey research: mail surveys, in-person interviews, telephone interviews, internet surveys, and questionnaires.
Learning by being told	By interviewing or by task analysis
Learning by observation	By presenting the case study from diverse disciplines. To observing the process used to solve the intriguing problem

Table 3. The classification of tools applied in this research to the capture of tacit knowledge.

Individual interviews are not easy to arrange and are time-consuming but I generally preferred them to questionnaires because of the improved response rates (Oppenheim, 2000) and quality of the answers. However, "the role of questionnaires is a tool for data collection" (Oppenheim, 2000, p.8). Questionnaires used in this research were designed: to collect information about kinds of inclusions employed by artists in their artistic practice around the world; to identify reasons why sculptors used or did not use glass; and to recognise the problems which associated with using glass and inclusions (Chapter Two, p.47). Qualitative inquiry in this research involved a case study and a collective case study (Stake, 1995), which means that it involved more than one case study. The focus was on specific cases because of their uniqueness and other cases were used instrumentally (Creswell, 1998) to illustrate the issue investigated in this research. All results obtained through using these research methods were analysed in order to convert tacit knowledge into explicit knowledge. The research results are in the form of a written thesis, visual materials created during the research process and a body of artwork. The selection of the chosen research methods employed a pluralist, multi-disciplinary approach combining the application of various method techniques, including 89 interviews, 2 questionnaires, discussions with artists' groups on the internet (Facebook groups: Glass Secessionism, - 21st Century, Glass Artists; or LinkedIn groups: Fine Arts, Contemporary Art News, Artists and Sculptors), alongside the more conventional literature review.

1.5.1. Literature review

The literature review includes professional websites, professional library collections (for example, the Rakow Research Library at Corning, New York), scholarly and trade journals, and PhDs in art technology. The review highlighted the fact that contents of publications about inclusions in glass (particularly metal inclusions) are quite limited (Table 4, p.41 & Table 5, p.60). Moreover, most of these publications are concentrated on inclusions in fused glass rather than in glass objects cast in an open mould, which give the artist more possibilities to apply different shapes and metal inclusions in their artistic practice (Table 4, p.41).

Author	Inclusions
Anderson, H., 1970	Copper wire, leaf and foils, gold leaf
Charleston, R.J., 1977	Tiny specks of metallic particles in aventurine glass, the mica particles in silverina glass, fine white flecks.
Cummings, K., 2001	Enamels, glass powders, fibreglass, air, organic objects. He encourages experimenting with everything – for example with found objects; and metals in powder, foil, wire grid, wire – but he writes about an application of standard metals only, as copper, gold, silver and nichrome wire.
Eberle, B., 1997	Metal oxide (cobalt, copper, uranium iron) , silver compounds, selenium, gold, manganese dioxide.
Flavell, R., Smale, C., 1974	Metallic oxides as a colouring agent.
Halem, H., 1996	Gold, platinum, palladium, and copper; inclusions as defects; air bubble.
Kervin, J., Fenton, D., 1997	Homogeneous frit cast, lampworked objects, thin metal foils, leaf and screens, so long as they are small and completely encased.
Lundstrom, B., 1991	Gold leaf, metal salts, iridizing glass
Reynolds, G., 1990	Copper wire 18, 16 and 12 gauge (not stiffer copper-coloured alloy); sheet cooper 36 gauge (only thin foil).
Schuler, F., Schuler, L., 1971	Inclusions as defects: trapped bubbles, particles of colouring agents.
Tsuneo Yoshimizu, 1998	Metal oxides, thin bronze foil.
Walker, B., 2002 Walker, B., 2010	In his opinion, aside from air bubbles the most frequently used inclusion is copper. But he mentioned also mica, fibre paper, paper currency, organic materials and metals, such as: aluminium, zinc, gold, platinum, palladium, silver, copper and its alloys as brass.

Table 4. Review of the cast glass craft literature related to the application of inclusions in glass.

The review of PhDs relating to the application of inclusions in glass sculptures uncovered only a few researchers. One of them is Jessamy Kelly, whose research focuses on the combination of glass and ceramics (Kelly, 2009). Others are Joanne Mitchell (2017), who has researched air inclusions in glass, and Jeffrey Sarmiento (2013), who has investigated colour glass inclusions cut by a water-jet. However, most of the research by artists concentrates on inclusions in fused glass, whereas this research looks at inclusions which are used in cast glass and hot glass in a mould. The use of these techniques allows artists to work on more complex shapes, textures and patterns. The limitations of the literature in this subject (Table 4, p.41) necessitated a wider search in art and technology.

1.5.2. Contextual review methodology

The diagram in Figure 13 (p.42) indicates the different types of sources accessed during the study. However, an exploration of inclusions' chemical, physical properties and the method of application was also required. The approach used also demanded the methods of analysis of materials used during application of inclusions (predominantly metal) and material sources to be investigated. As the research progressed a structure for locating the new metal inclusions was developed through studies of carefully chosen contemporary artists who use inclusions in their artistic practice.

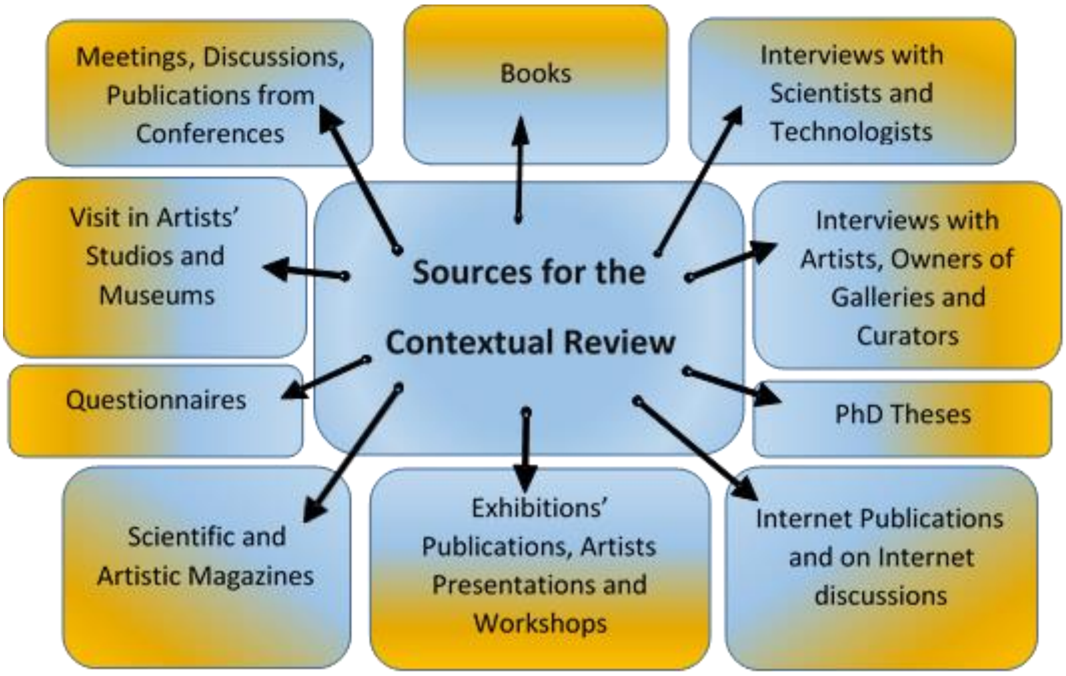

Figure 13. The list of sources accessed for the contextual review

1.5.3. Methodology for development of studio practice

In this research, the development of technology for the application of metal inclusions in glass plays a very important function. It was one of the main aims in this research to develop and introduce new tools for studio practice. This PhD project draws on the pervasive nature of glass sculptures to consider the possibilities for the application of new inclusions or ways of approaching metal inclusions from functional perspectives, process perspectives and aesthetic perspectives.

Throughout this process, I had to be engaged with cross-disciplinary approaches in order to explore how knowledge gained from industrial glass and metal practice could be applied in the glass sculpture area, while acknowledging that technical expertise is based on 'experience, tacit understanding and an intuitive grasp and judgment of processes and situations' (Dreyfus & Dreyfus, 1986, p.25). In this part of the research, it was also necessary to take an overview of the literature on metallurgy and annealing of metals, and have consultations with scientists in the field. In this way, it was possible to collect parameters of the annealing of metals and tailor them to the research needs. On the basis of these results firing programs of cast glass with metal inclusions taking into account annealing for both materials have been established

Artists in general and sculptors in particular are constantly struggling with technological problems, such as the compatibilities of materials used in their artistic practice. To solve more complex technological problems, they have sought help and expertise from technologists, engineers, scientists, etc. This research aims to contribute to advancing glass sculpture by investigating methods, technology, materials and processes. It offers a means for extending collaboration between technologists and artists, and for exchanging information, resulting in widening the techniques and materials available for artists. It is concentrated on the application of metal inclusions in glass. The research explores and experiments with a range of metals to try to determine possible alternative techniques with a view to applying these in new and innovative ways. It is generally known that solid metals confer many problems, and in order to avoid these problems attempts have been made to use thin metal layers on other materials (mostly glass). Consequently, I agreed in cooperation with Professor David Wood and his team at Durham University to learn to understand and practise the application of metal coatings on glass. Professor Wood has conducted experiments only with borosilicate glass, whereas I worked with studio furnaces glass, namely Gaffer, Glasma and Cristalica glass. Therefore, it was necessary to carry out analyses of the glass to predict the reactions occurring between the glass and metals. The analyses have been made in the laboratories of the University of Durham in cooperation with Leon Bowden and Professor Chris Greenwell. The comparison of chemical analyses of glass (Table 6, p.110) shows differences between glass. Likewise the comparison of chemical analyses of metals and their alloys is shown in Table 13 (p.149), Table 14 (p.150) and Table 15 (p.150). All compositions in wt%, such as Gaffer and Glasma glass and metals composites, are tested by EDS analysis (electron diffraction spectroscopy), which as a means of quantitative analysis is more reliable for homogeneous materials than for non-homogeneous materials. In non-homogeneous materials an approximate estimation of the composition is necessary, though there might still be some elements that cannot be detected very well. Calculations of results were done in cooperation with Dr. Oana Bretcanu from Newcastle University, who specialises in glass. The results of the research into possible inclusions form the focus of the protocol that was tested and probed during the study.

In the last century, there has been considerable interest in the industrial application of a combination of metals and glass. Additionally, there have been examinations of unwanted inclusions in the glass, such as stones and cord, and the problems associated with these. This has resulted in the development of useful practical information in the form of articles published in a variety of sources, including professional magazines, note books, conferences, exhibitions and workshops. In glass art, particularly in the subject of hot glass, the application of inclusions has been established through personal experience, and through research studies on various materials throughout history. An experiment-based methodology influenced by a cross-disciplinary approach was carried out using the perceptions of sculptors working within the creative glass area.

1.6. Summary of methodology involved in this research

The following methods were identified and refined throughout the research practice:

1. A literature search and review identifying and exploring the historical, cultural and creative/artistic engagement with metal inclusions in glass, combining practice and conceptualisation of:

- application of inclusions, particularly metal inclusions (in section 2.1, p.48 and section 2.2, p.60),
- using internal space in sculpture, particularly glass sculpture (in section 2.2, p.60 and section 2.4, p.93).

The literature search includes suitable technologies relating to the application of inclusions in glass and technologies which are approachable and adaptable for sculptors and glass artists (in section 2.3, p.89).

The literature review covers writings from a variety of sources, including PhDs in arts technology, in addition to more traditional texts. Data has also been gathered from 39 artists and 22 scientists in 89 interviews over a period of 20 years. This has been used to develop a framework to reflect my personal experience as an artist and practitioner.

2. Practice-based research and experimentation involving specific exemplars, exploring the theme of internal space in sculpture and inclusions.

3. Production of key examples in 2D and of sculptures which are relevant to the various stages of the research protocol.

4. Attendance at seminars and conferences, in order, to test ideas and theories and engage in critical debate.

5. Interdisciplinary interactions with experts from a wider field of research with a view to applying inclusions in glass sculpture, including scientists, artists, historians, curators, philosophers, engineers at institutions including the Universities of Durham, Sheffield and Sunderland, Krakow Academy of Technology, the Society of Glass Technology, the Academy of Fine Art in Warsaw, Krakow and Wroclaw (Poland), the Jagielonien Library, the Stroganov Academy in Moscow, the Russian State Library in Moscow, the State Hermitage Museum in Saint Petersburg, the Rakow Research Library at Corning New York, glass and metal companies, such as Hempel Metals, Goodfellows, Bullseyes and Warm Glass.

A process of mapping, reflection and experimentation on approachable and adaptable technologies for the application of inclusions in glass in an artists' studio environment was carried out. This process captured the complexity of the context and processed data that were collected from a variety of sources, including: interviews, questionnaires, case studies, cooperation with chemists, engineers and experts from glass and metal industries, and participation in conferences. Records were also collected in technical notebooks, journals, sketchbooks, models, photography and recorded on Dictaphone tapes.

2. Contextual review

This chapter provides the context of the research and includes: definitions of key concepts; the history of inclusions in glass, their aesthetic function in craft and art; the perception of space occupied by inclusions; how contemporary artists combine inclusions and glass; techniques of metal applications in glass developed by contemporary practitioners; relevant development of technologies used by scientists; and, finally, industrial applications of the metals inclusions in glass. The overview identifies problems in this field and establishes the context within which the practical research has taken place.

Figure 14 (p.47) presents the diverse aspects included in the contextual review.

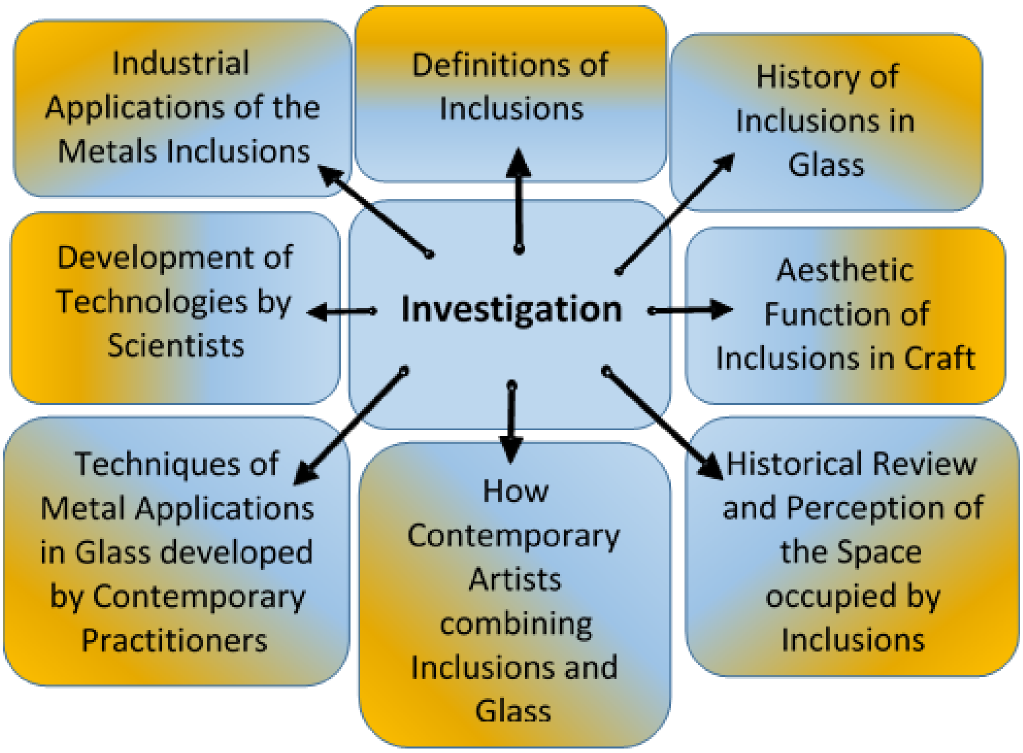

Figure 14. Summary of subjects underpinning this research.

Each of the outer boxes represents different aspects of the review which are explored in more detail within sections of the chapter.

2.1. Inclusions

Inclusions are the basic most well-known tool used by glass artists to work with the internal space of glass objects. However, the application of inclusions creates many technological problems in artistic practice. This section will concentrate on this subject from a historical, functional and aesthetic perspective. First, it will focus on the definition of inclusions, and then show how this tool was used by artists in the past. On the basis of this information it will offer an approach to the topic and a justification for the choice of medium and the shape of inclusions investigated in this project.

According the Oxford Advanced Learner's Dictionary ‘inclusion’ is defined as “the action or state of including or of being included within a group or structure” (2014). The Corning Glass Dictionary (2002) defines inclusions as “a collective term for bubbles, metal and glass particles, and other foreign materials that have been added to the glass for decorative effects”.

Regularly in science, inclusions are defined as “strange particles” (Sabela, 1998) contained in the main body, and during the creation of glass these imperfections, known as inclusions, are incorporated into the structure of the glass in the initial heating process. However, in my opinion, inclusions are defined most aptly in the introduction of Clark-Monk & Parker’s book: *Inclusions in glass have been both a scourge and a fascination to the glass maker for centuries* (1980, p.2)

To summarise, inclusions are anything that can be fused between layers of the main body of an object and these foreign particles add colour and/or texture to the object. We have already learned from geological investigations of natural processes in the formation of stones that the microscopic inclusion of certain minerals are responsible for the colour of some stones. For example, there are different colours of quartz owing to microscopic inclusion of iron, iron oxide, aluminium, calcium, lithium, magnesium, manganese, titanium, chromium and mica (Deer, Howie, Zussman, 1966).

Charles Bray in his Dictionary of Glass (Bray, 2001), defined inclusions as "a general term for materials or bubbles incorporated into glass objects as decoration. Industrially, this also refers to faults in the glass". The Retro Art Glass (2014) definition says that "inclusions can be classified as unintentional or intentional". An unintentional inclusion is usually the outcome of an artist's inaccuracy during the creation process of objects. It can be a trapped air bubble, dust from mould or kiln, raw material, or a gas bubble on the surface. On the other hand, artists can deliberately add some foreign objects to the glass and intentionally control the whole process. In this case, we will call it an intentional inclusion. In general, both kinds of inclusions are detrimental to the mechanical properties of glass but much depends on their number, size, shape and distribution. Artists like to experiment with inclusions which have unidentified coefficients of expansion which are quite often very different from that of used glass. Analyses of metal and glass courses, which are organised by educational organisations, show that they stipulate the use only of "metals that are compatible with glass – these being copper, aluminium in varying forms: sheet, wire, mesh, etc., or nicrothal wire" (Chrysopoulo, 2014). Handbooks and publications for glass artists emphasize that for the best results, they should "use an object that is thin and light. This will allow the fusing glass to expand and contract around the piece." (Ehow, 2009). Assuming that this is true, the thickness and weight of the object suitable for immersion in the glass need to be determined. The experiments relating to this problem are described in Chapters Three (p.106) & Four (p.155).

2.1.1. Historical Review of the glass crafts, with particular emphasis on metal inclusions in glass

To understand how inclusions were applied and why, we need to know the history of the use of inclusions by man from the beginning, approximately four thousand years ago (Matsuo, 1998). Glass with its inclusions have been known to humans since they started to use tools. In the Stone Age (from 3.4 million years BCE to 8000 –2000 BCE), cave people made tools and weapons from natural volcanic glass which contained metal inclusions. Most historians of glass are agreed that techniques for making glass were first discovered in the Bronze Age around the end of the third millennium BC. This means that the process of melting and casting metal was already known and this knowledge was useful in the production of glass. Humans have been producing glass by melting raw materials for thousands of years. First beads, which were supposed to be substitutes for semiprecious and precious stones, were the most common glass products, but glass rods, inlays and other richly coloured items were also produced (Grose,1989). Researchers from the Corning Museum noticed that it was at the very beginning of the emergence of glass that inclusions were introduced (Brill, Moll, 1963). This does not mean that these inclusions were always added deliberately. The first inclusions probably occurred accidentally in the glass, because they were in the sand or other components used in the process. Nowadays it is possible to investigate ancient glass objects with modern scientific instruments. For example, the electron beam probe can perform microanalyses of inclusions. Thanks to this, it is possible to identify the contents of glass, and understand the development of the technology for producing this medium.

Robert H. Brill from the Corning Museum of Glass and Sheldon Moll from Advance Metals Research Corporation, USA (Brill, Moll, 1963), analyse different kinds of coloured glass in several objects and mosaic plaques of the Roman period. During this investigation inclusions of microscopic dimensions were found in Roman ancient glass. Several stones, opacifying agents, metallic inclusions, and weathering crusts were further studied in this research. Analysis of ancient Roman glass demonstrates that opacifying agents were intentional inclusions containing iron oxide, cuprous oxide, potassium, magnesium, aluminium and lead oxides. Analysis of glass from later periods between the 5^{th} and 12^{th} centuries has shown the presence of tin and lead (Brill, Moll, 1963). Commonly the inclusions in ancient glass were applied predominantly as colorants and opacifiers. It has been noticed that at that time only a few metals were used intentionally as inclusions. Grose (1989) mentions two examples of inclusions: the slabs of glass with inclusion of gold leaf and the inclusion of gold used in the Mesopotamian star – a disc pendant from the 15th century BC. These kinds of products were more frequently used by Romans for vessel manufacture or wall mosaics (Grose, 1989). Gold and gold foil were the first metal inclusions used in glass. Next were followed inclusions of precious metals like silver or platinum and less precious metals like copper and copper alloys. The first glass item inlayed with the inclusion of an object is dated from the 16th century, made in Bohemia. It was a glass goblet with ivory inclusions. At the same time appeared more craft products with inclusions of medals, metal coins and other objects. However, this type of object was made by employing a cold glass manufacturing process (Hartwig, 2014). This means that an object was enclosed in the hollow in an earlier shaped piece of glass then covered with a second piece of flat glass. It has been noticed that demand for creating inclusions with imitation antiquarian objects originally began after the excavations of the sites of Pompeii and Herculaneum in the 18th century elevated curiosity about classical art. Of course, increasing demand for classical objects was the main reason for the development of these techniques, but a similarity of glass and lava, which both can contain inclusions, could also have had some influence on the imagination of artists. For this purpose Bohemian craftsmen conceived the innovative concept of encasement of porcelain in hot glass. This technique was perfected and patented by Apsley Pellatt in 1819 (Jokelson. 1968). These porcelain Cameo inclusions in hot glass were called sulphides because of having the same appearance as silver sulphide (Figure 15, p.52).

Figure 15. Apsley Pellatt; *Crystallo ceramie portrait of Queen Charlotte*, 1830;

Porcelain embedded in hot glass, a cut-glass scent bottle

The Victoria and Albert Museum, London; V & A Picture Library

It is very difficult to find in literature any information about the applications of metal inclusions in hot glass in the past. During the twenty-three interviews with glass specialists from such different organizations as the Corning Museum, the Rakow Library, the Society of Glass Technology, the British Glass Society and Krakow Academy of Technology, which were carried out for this research, only one example of metal inclusions in glass was pointed out. A historian from the Museum Portable Antiquities Scheme, Justine Bayley, who specialises in glass and metal, has pointed out inclusions of valuable coins in a few antique Roman glass pieces (Bayley, 2014). However, she adds that the main known examples of enclosed Romans coins are only ceramic replicas of coins in glass mostly from the 18th or 19th century and made by first the French, then the English and finally the American glass industry. Another example of experimental production of coin replicas was introduced during World War II when copper was needed for ammunition in America (as original coins were made from copper). The Blue Ridge Glass Company in Tennessee made experimental pennies using tempered glass with coins' impression and metallic colour inclusion (Meyjes, 2017).

At the end of the 19th century and during the first half of the 20th century the development of mass production of glass slowed down the progress of small glass craft manufacture, which was the driving force in the development of new techniques in the production of glass and new experiments with inclusions. The beginning of the 1960s, however, brought about a dramatic transformation in glass art and the development of glass studios run by artists themselves. Also, the exhibitions of Czech glass (1968) for the international public were quite an important turning point in the process of treated glass as an art medium. Further development pushing boundaries using glass as a fine art medium took place in the 1970s. In the introduction to the catalogue from the first major international New Glass exhibition organised by the Corning Museum in 1979, the current President of the Corning Museum, Thomas Buechner, stated that a dramatic change was taking place in the history of glass, after thirty-five centuries of utilitarian use of this medium. The Studio Glass movement has been characterised by the exchange of ideas between artists and provides artists with possibilities to explore applications of new materials as inclusions in glass. The International New Glass exhibition organised in 1996 in Venice was a fantastic opportunity for exchange of new ideas between artists and brought an even more dramatic transformation to glass art (Dorigato, 1996) and inclusions in glass. Thanks to the radical development of glass studio technology, artists could advance using inclusions in their artistic practice. Publications on the subject became available to a wider audience. However, only metals which had been used as metal inclusions by artisans in the past (such as copper, gold, silver), were exploited by the artists in their artistic practice, probably owing to the unsatisfactory results obtained from experiments with other metals.

From the very beginning, the new Studio Glass movement was international and many international conferences were organised by and for glassmakers to have an opportunity to exchange ideas. Harvey Littleton and Dominick Labino organised the first glass workshops at the Toledo

Museum of Art in the 1960s to explore the possibilities of melting glass in artists' studios (Cummings, 2002). Following the success of this event, a series of international workshops and conferences were organized for artists, curators and technologists, which addressed the different applications of glass, as well as the combination of glass with other materials, such as ceramics. One of the newest initiatives in this field was GLASSTRESS, at which invited artists, architects, and designers were given the opportunity to express creatively their thoughts and ideas using glass. It led to more and more contemporary sculptors and conceptual artists working with glass, such as Sir Tony Cragg (Figure 16, p.54), Louise Bourgeois (Figure 17, p.55), Mona Hatoum (Figure 18, p.55), Cesar, Miroslaw Balka, as well as two artists/researchers from the University of Sunderland – Dr Erin Dickson and Dr Jefferey Sarmiento (Figure 19, p.55)

Figure 16. Sir Tony Cragg, *Untitled*, 2015;

Hot glass Berengostudio; Glasstress 2015.

Figure 17. Louise Bourgeois, The Couple, 2002;

Glass and metal combination; Glasstress exhibition (2009)

Figure 18. Mona Hatoum; *Kapancik*, 2012;

Metal and glass combination; Glasstress exhibition (2013)

Figure 19. Erin Dickson and Jeffrey Sarmiento; Emotional leak, 2011;

Black glass, cut with Waterjet, assembled on metal construction; Glasstress (2015)

Many new aspects have come to enrich artists' way of viewing glass as an art medium. Besides meticulously designed objects, realised with the highest precision, works with a more conceptual approach are becoming increasingly important (Figure 20, p.56). New solutions for turning creative ideas into reality are opening, made possible by new production and processing techniques.

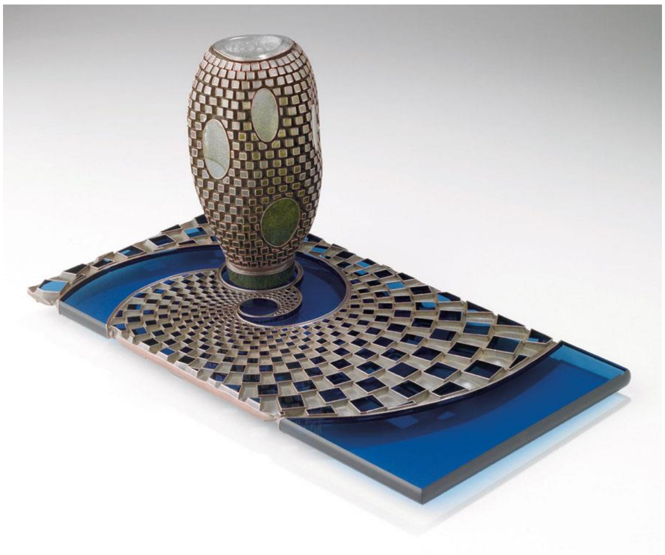

Figure 20. Michael Glancy; *Spuyten Duyvil*, 2009;
Cast glass object, blue industrial plate glass, and copper;
Size 8 x 15 1/2 x 8 inches; Courtesy of Michael Glancy.

Unfortunately, some technologies or materials are still quite expensive and difficult for artists to apply in their works or research, such as 3D printers to use for mould making, or some metals and their casting process. Some artists have the opportunity to directly work in industrial workshops, which certainly helps them make better use of materials and technologies in their artistic practice. In Scandinavia, glass art is still closely linked to the glass industry (Dawson, 2000). One of the most well-known Swedish artists, Bertil Vallien, has been allowed to transform a glass factory to meet his own needs and thanks to this he could develop, on a large scale, sand-cast glass with different kinds of inclusions. In Finland, also, art glass is still associated with the glass and design industries. Finnish glass artists Markku Salo (Figure 21, p.57) and Vesa Varrela, follow the trend of using mixed media in their artistic practice (Dawson, 1996). The Scandinavian artists mentioned above often combine glass with metal in their work.

Figure 21. Markku Salo; *Madonna on the Meadow*; 2003;
Hot and cast glass, metal; Courtesy of Markku Salo.

Having very limited knowledge about chemistry, physics and materials engineering does not help artists to incorporate new materials and technology successfully in their work. A lack of technical knowledge and language also hinders their communication with experts and practitioners in industrial glass production. Analysis of the questionnaire, which was produced for the purposes of this research on the application of inclusions in glass, and was carried out among glass artists, confirms this view, as well as the restricted number of metals used by artists to form inclusions in glass. On the basis of the literature review; “Metal and Glass” courses delivered around the UK and USA; interviews with artists and art instructors; discussions with group artists on the internet and from the analysis of the questionnaire, it might be argued that the list of inclusions is quite long. Some materials used for inclusions were explored in depth. For example, printing in glass is deeply explored by Professor Kevin Petrie in his publications (2006, 2011), ceramic media is investigated by Dr Jessamy Kelly in her PhD thesis (2009), and inclusions by water-jet (coloured glass and print images in glass) has been investigated by Dr Jeffrey Sarmiento in his PhD dissertation (2011). However, knowledge about some of the media, for example metal inclusions, is still quite limited. This is the reason that this research is focused on the possibility of applications of this kind of inclusions.

Combinations of glass and metal are employed by artists for decorative and constructive purposes, or as a necessary artistic quality in the creation of an object. The first manmade glass was used to produce artisan beads. Metal inclusions were used in the production of beads by ancient craftsmen. These techniques, developed by artisans and artists long ago, are still used by contemporary artists (Figure 22, p.58 & Figure 23, p.58).

Figure 22. Pam Dugger; *Ocean Triggerfish.* 2004;

Decorated with silver, copper and gold leaf. Soda-lime glass; Courtesy of Pam Dugger.

Figure 23. Donna Milliron; *Untitled*. 1998;

Pate de verre, lampworked, heat and gravity shaped;

dichroic glass, niobium wire, soda-lime glass.

The most common metal inclusion used by artists around the world is copper, even though, and sometimes because, it always gives unpredictable results (colour, texture, pattern), but also because it is compatible with most glass, is trouble-free to work with and readily available.

Some luxurious metals like gold, silver, platinum and palladium are familiar metal inclusions in glass and probably every textbook for glass students incorporates information about them (Table 4, p.41 & Table 5, p.60). Additionally, they are trouble-free to work with, but unfortunately these metals are very expensive and do not meet the research requirements. Moreover, they react with glass and are stained it.

List of materials used for inclusions in glass by glass artists	
Glass	Coloured glass, beads, threads, glass powders, bearing glasses, "glow-in-the-dark" powder, sand, beach glass, etc.
Organic	Dried plant materials, leaves recycled plants, reactive earth, brown-green earth, plant materials, sea shells, human and animal remains (bone).
Ceramic	China clay, vintage plates, some pottery "washes”, porcelain, Egyptian Paste.
images	Integrated glass printings, printed transfers, direct screen-printing onto the glass, sandblasting, etching, photographs, digital and laser prints and many others (Petrie, 2006).
Metals & metallic materials	Mixed glass containing reactive metals, such as copper, lead, sulphur, selenium, to produce reactions; copper dust, copper thread and wire, copper leaf and sheet, silver leaf, gold leaf, brass silver foil, 24K gold foil, palladium, brass, copper wire reclaimed from old electrical items, thread, wire, shavings and sheet, aluminium foil and sheet, palladium, rusty metal found on the beach, dichroic extracts (metals: lead, sulphur, copper, and selenium), oxides (chrome green, cobalt blue, vanadium yellow), nichrome,

List of materials used for inclusions in glass by glass artists	
	iron mesh, zinc, steel and related alloys, metal coins with a fairly low melting point (Walker, 2010).
Other	Luminescent glass (Almeida, 2010), Kaiser enamels, Glassline, Bullseye thinfire paper, fibre paper, mica, bubble agents, air bubble, flexible glass, concrete, semi-transparent concrete, lights.

Table 5. Classification of inclusions in glass.

It is important to experiment and push boundaries so that art work does not get stale or predictable. In the last two decades, artists have dramatically changed the nature of what had been considered glass art. It became natural to combine glass with clay, bronze, wood or anything else, but unfortunately it does not imply that crafts skills always follow this transformation.

2.2. Artists combining inclusions, particularly metal inclusions and glass in their artistic practice

In this section, it was decided to include a group of fine artists that use internal space as a form of expression. Among the artists, it is possible to isolate a group of sculptors using a variety of inclusions to penetrate the internal space of their objects. Hence both sculptors and glass artists who are trained as sculptors, and the way they use internal space in sculpture, are considered in this part of the research. A recurrent theme of some of this work is metal inclusions which are visible in a transparent material such as glass. Additionally, it was decided to look at practitioners who use inclusions in glass in consequence of an interest in developments in technology. However, mostly artists who employ glass and metal inclusions in their artistic practice were investigated.

Metal is an incredibly versatile material: from high-tech lightweight aluminium to air-purifying titanium dioxide, and from crude and raw Corten steel used in marine transportation through to gold leaf. Applications of metal inclusions into hot glass involve techniques with the most unpredictable results. To control these processes requires a lot of experience, knowledge and ability, and even more to experiment and push boundaries to play with the materials both visually and technically. The research explores the development of technology by artists as part of their artistic practice and as well the artistic practice of glass artists initially trained as sculptors, who combine inclusions in their works.

Keith Cummings is one of them. He is an internationally known glass artist, teacher and writer about the subject of kiln form glass. In his interview, Cummings (2009) mentions that he studied Fine Art at Durham University and during this time he started to employ glass in his sculptures. He has been working with glass and metal for almost fifty years (Figure 24, p.62), but he is conscious that both he and the materials have changed during this time (Cummings, 2009).

He plays a central role in the history of glass artists' education in Great Britain. His first publication "The Technique of Glass Forming" (1997) is still the most important publication for the new breed of glass sculptors, as are his many following publications. He advocated the use of glass-forming methods which looked back to Mesopotamian, Egyptian and Roman techniques (Figure 25, p.62), but he presents new techniques in his publications too (Cummings, 2001, 2007, 2009). He also writes about inclusions (Cummings, 2007, p.67-71) and conventional decorative materials for lamination, particularly enamels and glass powders, fibre glass, ceramic glaze oxides, air, metals and organic materials. In his books, he encourages readers to experiment with other materials in order to get unexpected results (Cummings, 2007, p.71),

Figure 24. Keith Cummings; *Pennant*. 1998;

45cm long; glass and bronze; Photographed by Simon Bruntnell

Metals which Cummings mentions in his publications are mostly used as a decorative function of coloured glass. However, in his publications, he also briefly mentions the applications of metals in the form of powder, foil or wire. Mostly he describes how to work with copper, because, in his opinion, this metal is the easiest and most predictable. He mentions that other metal foils can be used providing they are thin, and therefore weak enough to allow the glass to expand. Professor Cummings indicates the problem of glass fused "to the surface of the metal due to the wetting action of the glass during fusion" and the problem of oxidation of metals during the heating process (Cummings, 2007, p.69). However, he does not explain further these significant problems, nor does he give any solutions for them.

Figure 25. Keith Cummings; *Crest,* 2002;

Cast bronze with cast and polished kiln-formed glass;

Size: D8.5cm x W14.5cm x H11cm; Courtesy of Keith Cummings.

Professor Keith Cummings stated in his interview (2009), “To approach glass from a sculptural viewpoint is an attempt to free it from its practical/decorative traditions and develop a wider repertoire of shape, texture, and formal relationships”.

Another influential figure in the world of the glass is Charles Bray (Figure 26, p.63), who lived in Cumbria, was a Fellow of the Society of Glass Technology and a Fellow of the Royal Society of Arts. He was also the author of important glass art and glass technology reference books, including the Dictionary of Glass (2001). In his books, he describes many important processes taking place in the creation of glass objects. He provides a practical guide to the material; founding and batch melting; equipment and tools; the shaping process, including reduction, annealing and compatibility; seeds, stones and cords; colloids, colour, iridescence and enamels. Although he defines inclusions in glass, he hints only superficially at the problems associated with the process of inclusions lamination.

Figure 26. Charles Bray; *Light Project*; 1975;
Metal, wood, glass tubes and rods.

The next artist whose work is included in the study is Antoine Leperier. To the wider public Leperier is known as a glass artist but he was also trained as a sculptor. He gained his first degree in philosophy and fine arts, and his master's degree and postgraduate diploma in arts and art sciences at the Sorbonne University, Paris. At the start of his career Leperier was closer to fine art but was always interested in technology. When he inherited the studio of his grandfather (who was one of the most known glass craftsmen) he notes he further developed his skills working with glass, and technology did not limit him very much in his artistic practice. However, when he has technological difficulties he seeks help from industry in China (they produce forms with 3D printers for him) or from other artists. He had some problems with finding a porcelain which was compatible with glass and which he used to develop his sculptures (Figure 27, p.64). On this occasion he found help from Dr Jessamy Kelly (Leperlier, 2002-2014). She is a glass artist and her research field is the combination of ceramic with glass.

Figure 27. Antoine Leperier; *Verriales*; 2013;
Serge Lechaczynski (2013).

Antoine Leperier has for a long time tried to create 3D shapes in glass. He mentions in his interview (2012), that painters have for a long time represented 3D in 2D images, and so similarly Antoine represents what he calls a fourth dimension in what he sees as 3D images. This internal space is like a snapshot of reality for him, and he sees it as an analogy of the mind, in which hollow thoughts float in space. On top of this he creates bubbles in the images so that during firing when they try to escape an instant is caught, which expresses the 4th dimension which for the artist represents time. Furthermore, he focuses on the concept of fix and flux, movement and stability, thus combining the philosophies of Heraclites and Parmenides, and so evoking the movement and stability of eternity. He sees there being two natures of time: the quantified time of the world around us, and the psychological time that passes through one's duration in this world. He represents this through the contrasting materials of ceramic and glass: one as stable crystalised and formed, the other as flowing, unstable and reversible. He uses colours in his ceramics to form a connection between the two materials, and a flow within stability (Leperlier, 2002-2014). He has not used metal in the past but he states that if he finds a conceptual reason to use metal, he will. However, by using ceramics that contain metal oxides that are used to give colour, possibly without considering it, he has in fact used metal. He sees technique as simply a means for an artist to achieve what they set out to achieve, in stark contrast to a craftsman whose technique is part of who they are and what they are creating. His technique is formed as he creates his pieces (Leperlier, 2012-2014).

Jessamy Kelly is another artist whose work with ceramics utilises techniques which could be informative regarding metal inclusions in glass. She is an artist, a teacher and researcher who investigates the possibility of combining glass and ceramics (Figure 28, p.66). Jessamy Kelly has not worked with metal or even metal oxides, but she created a new bone china ceramic (Kelly, 2016) which was compatible with lead crystal. She concentrated on this application in a hot state, as a means of artistic expression in studio practice. I wanted to discuss her research because she had experienced the problems of compatibility between two different materials. In her opinion glass and ceramics have many related material qualities and are processed in similar ways. Chemically they are alike, however structurally they are very different, which creates compatibility problems when they are combined in a hot state. Through controlled processing, the materials' properties can alter when each is partially converted into the other. It is recognised by artists in the field of studio ceramics that porcelain can partially convert into a glassy form when high fired to create a translucent material. Likewise, it is recognised in the field of industrial engineering that glass can partially convert into a ceramic form when processed in a controlled way to create a glass-ceramic material; this material is not used by practitioners and would be difficult to develop in a studio environment (Kelly, 2014). There is a similarity here with the area of this research, because metals too can be transformed into a material with a similar structure to glass, but the subject will be expanded upon in Chapter Three (p.106).

Figure 28. Jessamy Kelly; *Wedge*; 2009;

White and clear, kiln cast glass sculpture with a pâte de verre & bone china core;

Size 40cm x 30cm x 20cm; Photographed by David Williams.

Another approach to the application of metals is represented by Peter Stanicky. Stanicky's work uses metal as a bridge which balances the fragility of glass in his structures. He used lead and glass in his first project (Figure 29, p.67). using lead pipes in a sculptural way. Some of the pipes are old, recycled from his street. The series of erected sculptures was a reaction to his situation and the condition of his house.

He used tin and lead because they have a warm feeling and are soft and at the same time are related to death. The techniques he used did not follow any traditional methods and to erect his works he alternated his techniques. Most of the techniques he developed by himself. The technological processes play a very important role in his work in achieving a visual solution. He would learn new techniques, if this helped him to erect new ideas, which is important in the development of his works. He had already studied how to weld metals, to join glass, carbon tubes and to work with wood. He always admired real craftsmanship and has great respect for it. Mediums which he used in his studio, are mostly recycled materials found on the streets around his Prague studio. The reasons that he employed the metals in his work, mostly is the feeling and character of the material. He used tin and lead foil in his Anthropoid object (Figure 29, p.67).

Figure 29. Peter Stanicky; *Anthropoid 42*; 2009;
glass, lead; size: 150 x 215 x 6 cm; Courtesy of Peter Stanicky.

He has also used cast iron because it has a real earthy feeling, and wire structures for an illusive architectural character. His techniques and meanings mainly reflect his own emotional states at any one time (Stanicky, 2014).

Keith Sybart is another artist for whose art is *"...object making; conceptually driven and materials based"* (Sybart 2006). He gained an MFA degree in sculpture and at the beginning of his artistic practice he worked as a sculptor. Technology always plays an important part in his artistic practice. The pieces are constructed by assembling elements that have been both found and formed. He employs a diversity of techniques including hand modelling, mould making, carving, and many others. He also employs a variety of mediums in arrangements to create a metaphorical hierarchy: the fundamental and apparent value relates to their distinctive and assigned meanings. In his opinion the apex of this pyramid is glass – amorphous, immutable, incorruptible, while the other materials are subject to the vagaries of time: rust, rot, erosion. For him glass resists and encompasses entropy; it remains inviolate. The reliability of all the mediums is essential, but glass holds the essence of these works; its contradictory strength and fragility create the structure (Sybart, 2006).

Keith Sybart very rarely employs inclusions in his works. But his approach to working with a variety of materials (especially glass and metal), various techniques (especially casting glass and metals), and solving technological problems, made it important to include a description of his artistic practice in this research, and has helped in the development of a methodology to investigate the subject of the application of inclusions in glass so that it was understandable not only for glass artists but also for sculptors. Moreover, he, with Angela Thwaites, marked the beginning of research into moulds resistant to high temperatures. Angela Thwaites' continued research in this subject was published in her book, *Glass Handbook: Mould-making for glass* (2011). The results of these studies were used in this research (see Chapters Three, p.106 & Four, p.155).

Another sculptor who explores the relationship between metal and glass by a technique of binding together the glass elements of his work with wire and metal clamps (Figure 30, p.69) is Clifford Rainey. His provocative and allusive sculptures are inspired by his lifelong experiences. He likes to travel, studying cultural history and exploring ethnic groups. Clifford Rainey's work is symbolic and very often autobiographical. He was born into a family of farmers and linen weavers. As a child, he made wood carvings, and as a young artist he worked with cast bronze, and finally he mastered his skills studying glass at the RCA.

Clifford Rainey is a sculptor who combines glass with other mediums, such as bronze and metal wires. Mostly he employs a process of cast glass into a wax mould, but sometimes he combines bronze with glass (Figure 30, p.69).

Figure 30. Clifford Rainey; *Philosophical Boy;* 1998;

Glass, ceramic apple, wire, pins, gesso;

Size: 108cm x 47.5cm x 37cm; Photo: Lee Fatherree

Rainey's work, shown above (Figure 30, p.69), is very interesting, especially for this research, for two reasons: first, the sculpture is a combination of two media, such as bronze and glass; and second, it is a fantastic example of the casting of two materials together in one form, as the bronze became fused to the glass during firing. It is not known what materials he used to make the mould, but it can be assumed, after carefully viewing the surface of the metal part of the sculpture, that the mould was probably made for casting glass because there is a noticeable contamination and damage to the metal surface. In this case the artist used bronze, a popular metal which is based on copper and is compatible with glass. Because of the interesting process of combining metal with glass, I attempted to obtain confirmation of assumptions about the casting process and to get clear information from the curators who exhibit the artist's work, as well as from the artist himself, but the questions were left unanswered. However, Cummings (2007) was able to ascertain that the technique for Figure 31 (p.70) was glass and metal cast together in a ‘lost wax’ mould that comprises the features formed part of the mould and became fused to the glass during firing.

Figure 31. Clifford Rainey; Freedom of Conscience; 1991;

Optical glass and bronze; (Cummings, 2007, pp. 98).

The next artist who has interesting approaches in working with metal and glass is Mary Shaffer. She is recognized as one of the founding artists of the American Studio Glass Movement. She studied painting at the Rhode Island School of Design in the 1960s. In the 1970s, she developed a unique technique adapted from the auto industry, which she calls "mid-air slumping" (Shaffer, 2016). It allows her to use gravity to soften plate glass into a form, which she often combines with metal. Her sculptures range in scale from small objects to room-sized installations and public works.

Her early work was very materials-based. Materials inspired her without restricting her ideas. Shaffer is an artist who industrialised her technology by self-taught methods. She developed structural systems to place the plate glass in the kiln that allowed it to move with gravity. She makes most of her works herself. However, for some of her glass objects she gets some metal supports welded. Also, she asks for help with big cast glass projects. Mary Shaffer uses "all kinds" (Shaffer, 2016) of metal in her works because she likes the contrast between soft and hard, the moving fluid glass and the rigid metal forms (Figure 32, p.71 & Figure 33, p.72).

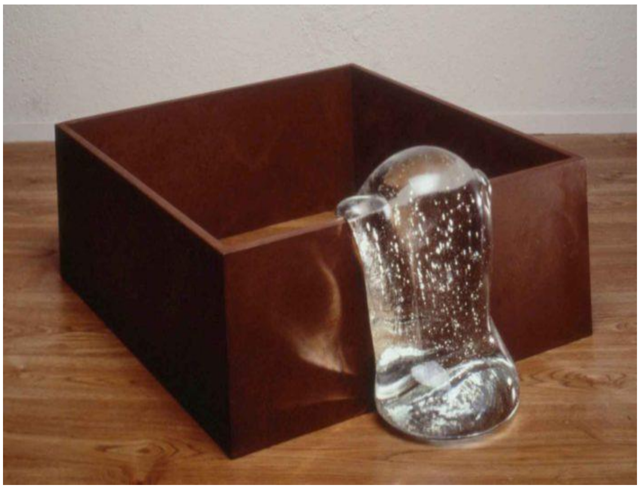

Figure 32. Mary Shaffer; *Square Fold*; 1997;
Fabricated still and slumping hot glass;
Size: 76cm x 84cm x 25cm; Photo: Dan Morse Firefly Studios.

When asked about the problems associated with the use of metal with glass, Shaffer very enigmatically replied: "Sometimes you need a release agent between the glass and the metal" (Shaffer, 2016)

Figure 33. Mary Shaffer; *Red/Green Open*; 1998;
slumped glass and fabricated metal;
Size: 145cm x 80cm x 69cm; Photo: Dan Morse Firefly Studios.

In her opinion, if artists are making large scale public works then they need to talk with an engineer to make sure they are complying with building standards. Otherwise she prefers working out problems herself. Her opinion is that everyone is different, and they should work the way that is best for them.

This attitude led to the creative work of Uta Majmudar, who, when blowing borosilicate tubes with a lamp, tried to make colours with metal oxides, instead of the usual colourless glass. So, between two tubes she tried silver nitrate for a yellow colour, cobalt oxide for blue, chromium for green and copper which makes either red (with lots of air) or brown. She also used silver foil, cut in figures between tubes. Next, she used copper wire, silver gold and stainless-steel wire. Copper and silver give a graphic design, gold also, depending on the way the glass is melted; and steel or iron wire give a certain form, depending on the wire. She made a female figure like the "Venus of Willendorf" female goddess figures.

Later she made huge nets from stainless steel wire to make larger objects than her oven could melt (Figure 34, p.73). She made a chair of normal size and a shirt (she called it body form) to put on it. The largest object is a waterfall three meters high. Her difficulty has been to keep glass pieces together in certain forms, so, she has used metals not only to give colour, but also strength, to certain forms if between glass and then blown. Graphic designs with melting wire (gold or copper) keep glass pieces together to make large objects by a technique that she discovered by herself, after conducting hundreds of trials (Majmudar, 2014).

Figure 34. Uta Majmudar; Streckt die Arme; 2007;

Size: 30cm x 10cm; Courtesy of Uta Majmudar.

At this point it is important to mention Paul Stankard, as he is a self-directed learning artist, as Majmudar is, and he works with metal oxides to add colours to his objects, as she did. Paul Stankard is particularly renowned and respected for his flame-worked floral motifs expressed in crystal paperweights, rectangular columns and orbs. Stankard was trained in scientific glassblowing and worked in industrial scientific glass during most of the 1960s. Challenged by an inner sense of creativity and the need to establish his creative independence, he started making paperweights in the early 1970s. Attracted to the emerging studio glass movement, recognized as a maker of fine paperweights, and driven by an intense and incessant pursuit of excellence, Stankard was by the 1980s recognized as a highly accomplished glass artist, and a member of the pioneering generation of glass artists in America. As the emotional, intellectual, and spiritual dimensions of his art matured, and as he continued to develop new techniques for expressing his art, he also assumed more prominent influence in the development of educational programs and institutions that celebrated and expanded art in glass. He used the flame-work coloured glasses in botanical components as inclusions because he wanted to encapsulate the designs into clear glass. He also used metal inclusions (Figure 35, p.74). Fine gold leaf is used to suggest the ethereal or spiritual relationship to the natural world. He has invented the techniques to articulate a personal vocabulary in order to express his ideas. His inclusions are quite a big size, up to two inches in diameter before encapsulation in clear glass.

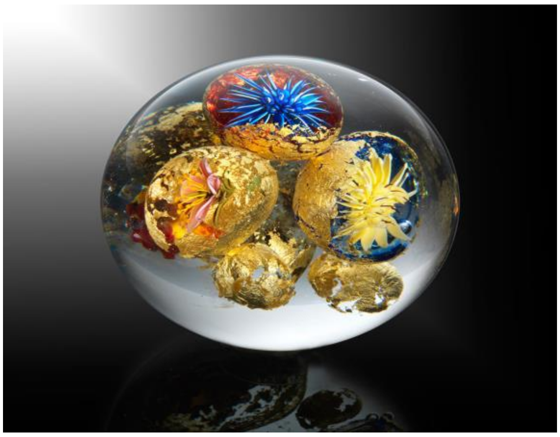

Figure 35. Paul Stankard; Golden Orbs Floating in a Sphere; 2008;
Artistic Glass Paperweights; Photo by Ron Farina.

Paul Stankard mentions, during the interview, his problems with the application of larger metallic inclusions in the glass, and describe how he solved his problems by using thin wire and or gold leaf (Stankard, 2014). As can be seen, even artists with technical education (Stankard at first studied Scientific Glassblowing Technology in Salem Community College) solve their problems by reducing the size of their inclusions.

Another artist is Jeffrey Sarmiento. His inclusions (Figure 36, p.75) are often equally as colourful as those in the work of Stankard, but depend on totally different technologies. Jeffrey Sarmiento employs silk screen printing inclusions in glass. Additionally, he works with coloured glass inclusions in glass by using a water-jet.

Figure 36. Jeffrey Sarmiento; Encyclopedia III; 2013;
Printed fused and polished glass; Photo: Jeffrey Sarmiento.

Through the application of these techniques he has learned to penetrate internal space and develop further opportunities in this area. He defines himself as a glass artist. He states in his interview (2011) that everything he makes is in glass, and every show he displays is usually related to glass art. His use of inner space in glass comes from the idea of using glass as both a literal and cultural lens. This comes from a long history of his practice in which he juxtaposes historical and contemporary images to expose aspects of contemporary ethnicity. He is interested in using glass not just as a surface for the image to sit on, but rather he is developing the use of the space within the glass to present the image or images. Layering, deconstruction and reconstruction of images give many possibilities of interpretation (Sarmiento, 2012).

Jeffrey Sarmiento and many other artists working in the University of Sunderland workshops have a unique possibility to master some industrial technologies. Mostly, these capabilities are only available to artists working in glass factories.

Some Scandinavian artists work with glass in a quite different way than the rest of the world. In Scandinavia glass art is still closely linked to the glass industry and this gives them sometimes further possibilities to apply more expensive technology (Dowson, 2000). Two case studies were selected: Swedish artist Bertil Vallien and Finnish artist Markku Salo because they both incorporate metal inclusions in their works and consider internal space in their art practice.

Bertil Vallien, at the beginning of his artistic career, worked as a ceramic designer. Only by accident he started to work with glass when he was given an offer to work for Åfors glass-factory as a designer. He has worked for this factory for nearly 50 years. “He is a man who understands a factory” (McGregor, 1997, p.8). He always works with seven or more people in a team. He considers himself as a sculptor (Vallien, 2013).

Because glass is unpredictable and a very demanding medium there must be a good reason to work with glass. For him it has to do with the process as much as the material. Glass started to be his most inspirational medium with the huge development of sand-casting methods. He considers himself “as the first artist to use the method in modern time” (Vallien, 2013). His sand-casting process gave him the opportunity to use the medium in a more personal way without the restrictions which other available tools and processes offered. His method required enough time for the preparation of the moulds and for control of details in the design of internal space before and during the process (Figure 37, p.76).

Figure 37. Bertil Vallien; *Janus*; 2011;

Sand Cast Glass Sculpture with copper and colour oxides inclusions;

Courtesy of Bertil Vallien.

Additionally, thanks to this method he is not restricted by size. Some of his sculptures are up to 14 feet long (Giubilei, F. 2012). In his subconscious he always feels a minimalist, but in reality, he is a “storyteller” (Vallien, 2014). Bertil Vallien is conscious that over-exploitation of decorative inclusions (he calls them ‘cheap effects’) can be a reason for losing real meaning. He has tried not “to be seduced by the obvious beauty” (Vallien, 2014). He always hides his story under the rough semi-transparent surface. For him the quality of the glass is not important but he prefers to use lead crystal glass because it is easy to anneal and soft enough for cold working. Usually he uses transparent glass but by mistake one hundred times more cobalt oxide was added to colour a batch of glass and this was the beginning for a new series of his sculptures. He was attracted to the transparency of glass, but on the anther hand, “he always wanted that his designed story in final effect is “mysterious, hidden, or gone” (Giubilei, 2012, p.21).

An important part in his investigations concerns the medium for inclusions. He uses coloured glass powders, enamels, found objects, little sculptures cast in glass, and many more, besides metals (Figure 38, p.77). He has experimented with silver, iron and others but chose copper because it seemed to work the best for him. He is aware of copper’s different rate of expansion from glass but it is “accepted by glass as an implant” (Vallien, 2014).

Figure 38. Bertil Vallien; *Boat*; 2016;

Made for American collectors on 17th May 2016; Photo: Lena Gunnarsson.

Sometimes he uses quite thick rods and bits of copper but mostly inclusions in the shape of small figures are made from 0.15mm copper sheets. In this case, he does not bother about technology. He noticed that copper reacts in different ways and changes colour, though is not concerned about the reasons for this (Vallien, 2013). Bertil Vallien's technique of pouring hot glass into sand moulds was the inspiration for the study shown (Figure 39, p.78). Sand-casting cannot give fine details to the sculpture's surface (for example, wrinkled human skin) or high transparency, and for the purposes of this study, it has been necessary to cast glass in a refractory mould. This resulted in the need for further modification of the method. More about this can be found in the following chapters.

Figure 39. Bertil Vallien; The process of sand casting his objects; 2015; Courtesy of Bertil Vallien.

Another Scandinavian artist, Markku Salo, one of the Finnish artists at the Nuutajärvi glassworks, is known for his large glass sculptures employing steel structures and intended for public spaces, and also for his amusing bottles blown into steel netting.

The fact that you can see into glass is a property that only few materials have. "One can use the internal space or leave it unused"; "for me nothing exists beyond the space. Space alone shapes the works" (Salo, 2013). In his opinion, different kinds of techniques can be used inside the glass object, and they will, naturally, show on the outside. The internal space gives the artistic expression more possibilities. If there is nothing inside the glass and the glass is transparent, it is significant as well, as there is no other material one can see through so vividly. The thickness of the walls affects the way one can see through the glass.

Markku Salo uses the metal net in order to give one more surface to the glass object. The metal net is like a decoration technique of glass. He began to use metal nets when he was searching for new perspectives on glass (Figure 40, p.79). In his opinion (2013), one way to find new perspectives is to combine glass with other materials.

Figure 40. Markku Salo; *Overload*; 1996;

Fixed blown glass into a mesh; Length 42 cm.

Courtesy of Markku Salo.

In addition to the metal nets, he combined glass with wood, rock and “technics” (industrial robots). He also uses metal in his larger works as a structural material. In this situation, the metal is not usually on the surface – its main duty is to support the other parts of the artwork. He uses in his works black metal and ordinary steel (Salo, 2013).

The next group of artists examined as part of the review apply a thin layer of metal on glass by attaching electrodes and placing the object in a chemical bath. This is known as an electroformed process. There were several reasons for choosing to examine this group of artists. The first was to learn about the techniques in their practice, but secondly, to understand the problems they encountered, which metals they utilized, and whether their techniques could be used in the application of metals as inclusions in glass (this last reason is considered in Chapter Three, p.106).

Michael Glancy is an artist who has fully mastered his technology. For him glass and metal retain a precious quality, and because of this attitude to his materials, his objects are, in his own words, “living things” (Glancy, 2014). Metal reacts differently depending on its environment – for example, the moisture content in the air. He patinates the metal to simulate nature, using organic chemicals for his patinas, such as vinegar or salt water from Narraganset Bay. But he prefers the metal inn his objects get these colours naturally, which involves changes occurring as the applied metals oxidize over time (Figure 41, p.80).

Figure 41. Michael Glancy; Resilient Corrosion in Lavender, Detail; 1989; A thin layer of metal on glass by electroformed process; Courtesy of Michael Glancy.

For Michael Glancy, shape and colours are very important. His objects also find their basis in natural patterns, rhythms and symmetries. Titles of his works are part of his objects, and without a title an object is not finished. For him it is very important to control and to understand the making process. In his view, you cannot take credit for those “happy accidents”. However, if one understands the phenomenon, one can take credit for figuring out how to repeat the accident again (Glancy, 2014).

Glancy was inspired by the French artist Maurice Marinot, who was a pioneer in the development of glass as a studio art form in the 1830s and 40s, long before the development of glass studios in America. Marinot used electroforming methods to apply metals and sandwich the metal in crystal glass. Glancy read about the artist and his technique in his books. But as he said, "it was poetry, saying nothing'! No practical information" (Glancy, 2014). In the end, he mastered the method of applying metals himself by practice, but fortunately Glancy likes to share his knowledge and experience. This is unusual, for my research has shown that it is usually very difficult to obtain technical information from artists. Glancy primarily uses copper metal in his work, applied using electroforming- and electroplating techniques. He also uses silver, gold, cast bronze and cast stainless steel. The casting is done in traditional metal casting foundries. Essentially his work falls into a tradition of glass and metal that spans several millennia – probably because the two materials complement each other so well (Glancy, 2015).

Research shows that electroforming is traditionally done with copper and then plated later with other metals. This happened for practical reasons. It would be very expensive to electroform in gold and silver, because gold and silver are relatively soft so it would take a lot of metal to form a strong layer over an object. This is the reason that artists employed other materials than copper in their artistic practice.

Michael Glancy is "a proponent of performing the entire process of creating an object himself, from the creation of technologies to aesthetic planning and finished object. This is where the making of art becomes creation technology" (Oldknow, 2010, p.34).

Another artist who works with similar technology but with a different approach to aesthetics is Richard Ritter. After working as a professional advertising illustrator, Ritter pursued an interest in metalworking. His first contact with hot glass took place in 1968 when Gil Johnson built a glass blowing facility at the Society of Arts and Crafts. Ritter was interested in incorporating glass into the pewter castings he was working on at the time. He was then invited to build a glass blowing and teaching facility at the Bloomfield Art Association where he began to experiment using layers of colour and making very simple canes and murrini to decorate the surface of small vessels. The hot coloured glass gave Ritter the opportunity to explore many hot and cold murrini processes. Thus, he began to experiment using murrini, layered cane and lattacino incorporated into large platter forms. Soon, Richard Ritter was employing multiple layers of crystal and opal glasses to construct complex worlds within a glass matrix (Figure 42, p.82).

Figure 42. Richard Ritter; *Floral Core Series*; 2005;

Murrini glass and bronze; Size: 30cmx29cm. Courtesy of Richard Ritter.

In the mid 1980’s, he began working on his "Triolet Series" of large solid glass sculptures with complex abstract murrini patterns. He also returned to the portrait as a theme in many of these pieces. In the studio, Ritter continued to mix batch and melt opal and crystal colours in order to develop his own unique colour pallet. In the mid-90s Ritter had moved away from solid glass sculptures, and was now producing a series of "Grail" pieces. These consisted of a complex blown platter form with an attached faceted solid base. He also returned to experimentation with etched and copper electroformed surfaces on the surface of many of his pieces (Figure 43, p.83).

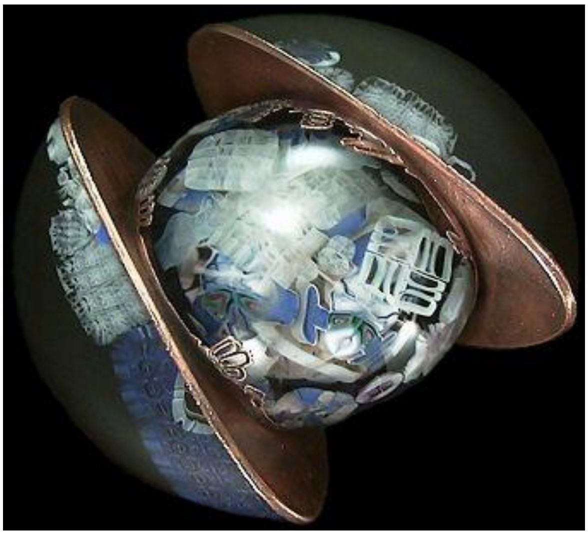

Figure 43. Richard Ritter; Copper, Crystal Core Glass Sculpture; 2006;
Black wings, etched and copper electroformed surface; Courtesy of Richard Ritter.

Anna Maria Dickinson is also part of the group. Her first degree was in metalwork and she has an MA from RCA specialising in glass. She continuously experimented with applications of metal on glass. She combined scientific curiosity with artistic sensitivity – qualities that helped her to apply industrial techniques in her studio (Dickinson, 1998). She chose containers in the shape of a vase, which were not at all functional, but because they had symbolic meaning in mythology (Dickinson, 1998). Her works are far from a useful, but they are sculptures, which for their relatively small size give monumental feeling (Figure 44, p.84). In her artistic practice, she uses blown-glass objects, which are cast, cut and polished for her by craftsmen who follow her design. Her glass is combined with metal which brings together two kinds of lustre. The surface of the glass is ground and polished to a mirror effect. By developing and adapting the present industrial electroforming technologies for use in her art studio, Dickinson's works emphasise the unique and contrasting qualities of glass and metal: transparency, fragility, strength and flexibility (Dickinson, 1999).

Figure 44. Ann Dickinson; Black & Silver African Stripe Vase; 1993;

Courtesy of Ann Dickinson.

Black and Silver African Stripe Vase forms part of a series strongly influenced by West African sculpture. In antiquity and myth, a vessel was not solely functional. The notion that it represented a place in which the entire cycle of human life and the hereafter took place was derived from its identification with the female body. However, even when she is technically able to blow glass herself, she orders glass from specialists. She likes her sculptural vases to be perfectly made.

The next section will deal with identifying contemporary artists' unsolved problems with metal and glass combinations in their artistic practice. This can help identify the areas which have not been previously covered in the literature for artists. Artists in general, and sculptors in particular, are constantly struggling with technological problems. The brothers De La Torre, for example, are sculptors who incorporate many techniques and materials in their artistic work. Though glass is a significant part of their work and they are most well-known for it, the brothers often rely on a mixed media approach they and they refuse to be classified as glass artists. They say that "without definitions, there is more room in which to move around" (De La Torre, 2014). They immerse different kinds of found objects in their works, but the properties of glass sometimes do not allow them to do so, especially when their works are of monumental size, so they are often required to use other transparent materials such as acrylic or epoxy. But they are still looking for technological solutions to use, without restrictions, all kinds of inclusions in their work.

Interviews were conducted with artists show that technological limitations are, in some cases, the reason why some of their preliminary ideas were not developed. Interviews conducted with Bertil Vallien and Colin Reid corroborate these views.

Colin Reid at some stage of his artistic career attempted to introduce metal inclusions in the form of bronze powder (to add some colours to his sculptures), but because he encountered a problem of compatibility between the metal and glass, he desisted from further applications of these inclusions. Instead he introduced gold gilding on glass tice (Figure 45, p.85).

Figure 45. Colin Reid; Still Life with Books; 2013;

Kiln cast optical glass, ground, polished, gilded

Size: 15cm x 50cm x 48cm; Photo: Colin Reid.

He likes the contrast between these two materials, which meet the aesthetic requirements of his artistic practice. Because he wants his work to be very finely crafted, the application of gold is made by specialised technology companies.

Another artist who confessed his technological “failure” in the battle with glass and inclusions was Bertil Vallien. As was earlier mentioned, Bertil Vallien works in a glass factory and he has developed the technique of pouring hot glass into a sand mould. In the first years of the introduction of this technology in his artistic practice, he made attempts to obtain a clean surface of glass which in the process of hot pouring came into contact with sand. He did not manage to achieve this, but he did not continue his experiments with clear glass as a result of changes in his aesthetic values in his glass sculptures. Presently he prefers that glass is less clear, and hence more mysterious for viewers.

In numerous interviews with the artists conducted for these studies it was possible to find only two examples of unsolved technological problems, which were described above. It has been noticed that the artists did not discuss their technological “failures” because they did not see them as failures, only as a next step in their artistic practice. For many artists, the unexpected results of attempting to include metal within glass sculpture have pushed forward their artistic practice and every unexpected result is not regarded as a failure as it would more likely be regarded within an industrial setting. Although there is a desire among both artists and industry to develop the technology for including metal within glass, the road to perfection is viewed by them very differently. Yet for both industry and artists, “failure” can be a developmental step forward.

Sally Resnik Rockriver has used “failure” to produce works she calls “self-blown forms”. In hot casting, she uses materials with a higher melting point because she is combining the hottest liquid glass with chemicals to make self-blown bubbles. The spherical forms are influenced by the reactive effect of heated chemicals. By trapping ceramic glazes into molten glass, the hot salts release a gas that provides enough pressure to blow a bubble. The resulting form is a hollow ball with exploded powder bouncing around the interior. When the gases remain trapped, they deposit a dark metallic smoke. Escape holes are melted into some pieces to allow fumes to escape. This results in a clear sparkling dome (Figure 46, p.87).

Resnick Rockriver is known for generating chemical reactions that make crystalline growths apparently from other planets. She blows work encrusted with ceramic glazes and casts her fume-blown world onto the piece during the break-off period. She approaches glass from a conceptual view with an emphasis on material realism (Rockriver, 2014). She is a glassblower who uses chemical reactions as a medium. While her pieces are reminiscent of unfound worlds and thermal formations, her approach is not representational. Works appear as though they are real geology, because they contain the same scientific ingredients found in nature.

Figure 46. Sally Resnik Rockriver; Self blown forms; 2008;
Size: 18cm x 10cm x 10cm; Courtesy of Sally Resnik Rockriver.

She activates glass and ceramic materials by using hot chemical processes. Her final pieces are enhanced outgrowths of an original experiment (Figure 47, p.88). A controlled framework emphasises the inclination of a material and results in new geologies not found on this planet (Rockriver, 2014).

Figure 47. Sally Resnik Rockriver; Copper Rising; 2004;

Size: 33cm x 10cm x 10cm; Courtesy of Sally Resnik Rockriver.

She is able to predict the results based on her past experience and knowledge of colour and thermal chemistry. She can anticipate results based on rules of colour, melting point, and the COE of each metal. However, in her opinion temperature is a key factor in the final product. When the glass is too hot, it will over-melt the metals. When it is too cold, there will be no chemical reaction. From the point of view of this research, the most interesting results of her experiments are those titled Vessels. In the blown vessels, the target is to get metals to stick to the glass without over-melting them. In her view, this is the most difficult part of the process to control. She uses crushed glass and flux agents to get the metals to stick. Then she heats them just enough to create a reactive bloom, but not enough to melt them into a flattened surface. In my own research, I had the opposite goal of preventing the surfaces of the materials used in the experiments from adhering to each other. This involved preventing metal from oxidisation even at high temperatures (above 900°C) at the same time that it was in direct contact with glass. I had therefore to look for a suitable separator or a process in which the separator could be produced alone (for example, gas bubbles invisible to the naked eye on the surface of inclusions (more on this in Chapter Three, p.106).

Sally Resnik Rockriver learned mostly through experimentation. She is self-taught and does not research applications of metals in art and glass other than those which she needs for her experiments. In technology, there have also been notable examples of “failure” which have moved forward the application of joining metal (aluminium) with glass. Some aluminium alloys react with glass and at high temperature they form substances with a structure like volcanic rocks. Professor Bernadeta Procyk from the Technology Academy in Krakow did experiments with aluminium and glass casting. From these experiments she developed insulating material. In the next section, technological approaches to the subject are considered.

2.3. How the technology has developed over time

The development of glass art was originally based upon accidents and failures – for example, stones being accidentally incorporated into glass in the production of architectural glass where the nickel sulphide impurities led to damage under the stress of size. Indeed, it is believed that glass itself was discovered by accident.

The history of both artistic glass work and industrial glass are full of challenges overcome and challenges that have led to other opportunities and creativity. Nickel sulphide is treated during the cooling process so that it is less liable to crack under the pressure of a large surface area. Also, thermally toughened glass is replacing heat strengthened glass to eliminate this problem and insertions are now intentionally added to glass for decoration.

2.3.1. Technologies developed by scientists and industry to combine metal and glass

Applications for glass and metal combinations range from domestic products such as the light bulb to aerospace industry components. A long time ago glass was recognised as a very good medium to bond or seal with many metals and their alloys, initially copper, silver, gold, and later also iron, nickel, chromium and cobalt alloys. The inclusion of gold foil in glass is many centuries old, and the sealing of platinum through glass has long been practiced by craftsman and technologists. However, the vitreous enamelling of iron or inclusions of metals in glass are a comparatively recent development. This was first utilised on a commercial scale in the electric-lamp industry, which still uses this kind of technology. The use of glass to metal seals in industry has focused attention on the need for studies of the many problems involved. As a result, substantial progress has been made in the techniques of joining glass to metal, so that today there is a wider choice of suitable glasses and metals but only at the industrial level. Some of this techniques and materials are too expensive and too difficult to employ by artists.

Glass to metal seals are the desired goal of industrial applications where airtight seals are frequently required, whereas artists do not necessarily want a tight seal because there are expansion differences for metal inclusions. Therefore, there is a wetting characteristic of glass and oxidisation of metal at high temperatures which cause unwanted bonding between these materials and possible surface damage. The experiences of manufacturers are important to artists, who can derive useful insights into the nature of the processes involved during the application of inclusions. Partridge (1949) and Donald (2009) mention in their books that in industry the following metals are combined with glass to form seals: platinum and its substitutes, gold, silver, copper, tantalum, tungsten and molybdenum and their alloys, nickel and Ni based alloys (nicrothal, nichrome), iron and Fe based alloys, steel, stainless steel alloys, cobalt, chromium, zinc, magnesium, aluminium, lithium, lead, tin and niobium. For artists, the list is much shorter because the use of some of these metals is inhibited by numerous factors such as expense, health and safety, and general process practicalities.

There is thus a need for a research which brings together under one cover the scattered data about metals and metal inclusions in glass and techniques which could be adapted to employ applications of metals into different kinds of glass in art workshops.

The manufacture of metals to meet the requirements just outlined calls for a high standard of metallurgical skill and control. The composition and properties of these metals and alloys can be found in books for engineers, also on the websites of manufacturers, distributors or organizations of engineers. Nevertheless, these data are not always accurate, and they contain only information necessary in their own field, which is not always sufficient for artists and craftsmen, since they often work with a different type of glass, or use other techniques that can be used in a studio environment. The composition and properties of these alloys will be considered in more detail in Chapter Three (p.106).

2.3.2. Techniques of metal applications in glass employed by contemporary practitioners

Stones and cords as unwanted inclusions in glass were always a problem which technologists would like to have solved from an early date. Decades of research and centuries of glass making brought practice to a point where glass is of very high quality and usually free of stones, with techniques for identifying stones and rapidly isolating most inclusions which occur in glass. However, the occurrence of stones is no less serious in modern glass production and the identifying of an unknown inclusion may cause many hours to be spent by technologists and involve very expensive equipment. For artists, this experience could turn into a happy accident and become a new technique in their artistic practice. Therefore, the research of technologists into unwanted inclusions is included in my investigations. Clark-Monks and Parker in their book *Stones and Cord in Glass* (1980), describe how that metal stones, such as lead, iron or various metal alloys which contain chromium, cobalt or nickel, affect glass and how they can be recognised. Another author, Hemsley (2015), discusses inclusions in glass and the problems which they can cause. My research improves our understanding of the reaction of metal inclusions with glass and enables us to choose suitable techniques for managing it.

19th century artists used porcelain objects, some of which were replicas of ancient metal coins or medals. These porcelain cameo inclusions in hot glass were called sulphides and had the same appearance as silver sulphide (Figure 15, p.52). This visual effect is created by a residual micro air layer between the ceramic cameo and the lead glass. It is caused by the bad inlay of the cameo porcelain. In this situation, again the imperfection turned into a very unusual artistic design. The technique they used is described in Paul Jokelson's book (1968). However, it was noticed that this interesting phenomenon also appears on the surfaces of some metals which are employed in the research. This phenomenon also helps in reducing stress between the glass and the inclusion of the applied medium during the cooling process. It is considered further in Chapters Three (p.106) and Four (p.155). Glass and metal have often been employed by artists even though this combination of materials has always been difficult to control and is unpredictable in its results.

In the next section, we consider the artists and their different approaches to inclusions in relation to the internal space of the sculpture.

2.4. The use of internal space in art

An element of art, space refers to distances or areas around, between or within components of a piece. Space can be positive (white or light) or negative (black or dark), open or closed, shallow or deep and two-dimensional or three-dimensional. Sometimes space isn't actually within a piece, but the illusion of it is (Esaak, 2014).

This section relates to space which is occupied by sculpture and which is used by inclusions in glass. Initially the focus of this research was to be the use of this internal space in sculptures made from transparent and semi-transparent materials. It soon became clear that without describing and understanding the technology and associated problems of applying inclusions in glass it would not be possible to develop this research. However, it was decided that in this section the subject of inner space should be explained first in order to establish what drives the research and the desire to understand and improve the technology.

“The place exists before the body that is brought to it...” Pomponius Gauricus, quoted by Barasch (Barasch, 1985, p.154).

The 1930s were the years of expansion and consolidation in modernist sculpture. The autonomy and purity of the media meant the autonomy of the individual. Rosalind Krauss wrote that in modernist sculpture “*behind the surface of ... abstract forms an interior was always indicated, and it was from this interior that the life of the sculpture emanated”* (Curtis. 2003, p.77). During this time, most sculptors who worked with stone used the process of carving as a verbalization of something that was already present in the solid block. Carving was a matter of bringing the stone itself to life. An innovative initiative was the work of Barbara Hepworth who made a hole in the solid object made from stone, and this new space turned into its own form (Hammacher, 1987). The inner space itself became a medium in sculpture. It was the beginning of the interest in the internal space in sculptures.

The easiest method of defining the internal space of sculpture is to calculate the volume of the object and location with mathematical tools. In the case of complicated shapes the calculation would be quite complicated, but possible nevertheless. The results obtained would be measurable, with an immediate possibility of checking the credibility of the result. This measurement could be the easiest way to compare the sculpture with other objects and the relation between them. Artists in the process of creating their objects are often forced to define the internal space of their sculptures by volume. For example, a volume assessment of the glass necessary for the execution of sculpture can be made by the principle of Archimedes Law.

This definition of the internal space is very helpful during the execution process. However, it is not sufficient in terms of aesthetics, especially when dealing with optical illusion or reflected images.

Sculpture in the round meets us fully in our own space. What it withholds from us no longer exists on the other side, but is what lies on the other side of its own surface as a three-dimensional object. A 3D object has a different structure from canvas, owing in part to its solidity. Solidity, however, also means the inability to probe what lies beyond the mask of its surface. It is as if the canvas of the painting wrapped itself around the work's own centre into the third dimension. A sculpture's secret is its inside.

Artists Christo and Jeanne-Claude wrapped objects in fabric, and for a period of a week or two, the silvery fabric, shaped by the blue ropes, created a spectacular flow of vertical folds emphasising the character and proportions of the imposing structure, as in the Monument to Leonardo da Vinci Piazza Scala, Milano, Italy 1970 (Folga-Januszewska, 1997). In this case the Monument turned into an inclusion in Christo’s and Jeanne-Claude’s sculpture.

Space is commonly defined as the possibility of extension. To this we can add that space is the possibility of being occupied. Space itself is abstract and empty. When space is occupied by an object we are not sure what is inside. As the sculpture completes itself in space by rounding back on itself, the space within it becomes invisible. The boundary of the sculpture, seen from the outside, prevents the inside from getting outside, holding it in. Sculpture is a mask behind which we assume space hides. Empty space is invisible, and only when space is occupied is anything visible. However, this space becomes visible if the sculpture is created from glass.

2.4.1. Historical review of use the internal space by artisans

It is clear, that a sculptor like Takashi Naraha, when working with granite, is seeking to establish a relationship of the space occupied that is not antagonistic. He is looking for a union of existence between exterior and interior. In his work, there is no opposition, but rather conversation between these two spaces. Naraha's work is linked to the great system of Yin and Yang, which "conceives the universe and its life as an incessant flux ordered by the interplay of two primordial forces that pivot on Emptiness". What is Emptiness? "Perhaps it is another name for Space as living energy at the heart of matter. Naraha points out that: "Stone is full of space" (Lambert, 1993, pp.2-6).

However, it is not space itself that becomes visible, only its absence. The object raises a barrier to further examination inwards, its surface reflects back our attempts to see further within. If an object is opaque, the only part that we can see of space is the frontier between the occupied and unoccupied part. The object defines a shape in space by drawing up the boundaries of it. The sculptor makes a statement about the difference between unoccupied space and occupied space by showing us the boundary of inside and outside. Viewers have no idea if the object is solid throughout, hollow throughout, or hollow in some parts and solid in others. There could be, unknown to us, other objects inside it. Polish artist Professor Jan Berdyszak concentrates on this issue of space, which he defines as the original being, and also density, darkness, void, transparency and potentiality. Since 1990 Jan Berdyszak worked on a series *Passe-pas-tout* whose continuation is *Apres Passe-par-tout*, which has been realised since 2000. The artist uses here the classical solution, which is a kind of painting frame which directs the viewer towards the empty inside. (Berdyszak, 1999)

Our sense of how the form of a sculpture occupies space is based on our perception of where that form comes to an end in space. Viewers assume that space, as we know it, continues inside the object, but ultimately, we do not know what is suspended from us. If the object is destroyed, the outside space will pour in and after that nobody would remember what had been there. Nonetheless this could be also some way to use that space for new artistic forms. Artist Cornelia Parker developed a project titled *Cold Dark Matter* (1991). She asked the army to blow up the garden shed filled with the shed's contents which belonged to the artist or her friends and things bought at a car boot sale, and then the bits and pieces, along with the fragments of the shed, were collected and suspended from a ceiling in an attempt to recreate the moment just after the explosion. The title indicated a whole new way of understanding the artwork, making us think of other dramatic moments of destruction and creation (Button, 1997), and the entire process gave us a new way to interpret the space inside the sculpture and duality of its meaning.

Another way to explore the duality of inside and outside, for example would be mind and body, where there is no common term with which to reconcile the two. Our body is in space, our mind is no-where in space, or it can be treated as an inclusion in our body. Antony Gormley considers space and the human form in many of his works (Gormley, 2009). He explores the interior space we feel within our own bodies "and the exterior space we feel around us, knowing that we are just dots in space and time." (Gormley, 2009). Antony Gormley's works plays with the human form in space whilst considering an internal space in sculpture too.

Takashi Naraha, also tries through his work to answer the question: What does space mean? The essence of space drags further problems into the realm of sculpture: How can space be made visible? What concept of spatiality applies here? In what interrelationship do space and material stand? How does the interlocking of space and time affect the perception of art works? (Lodermeyer, 2005)

A sculpture therefore is an object, whose inside is a mystery. Its outside, its visible part, establishes the existence of this mystery and by its form is suggestive of what may stretch out underneath. Naraha experimented with perishable substances, which would allow him to make visible the exchange between material and space, of space and the "determinability" of form. (Lodermeyer, 2005)

Sculpture seems to push out into our space from the hidden space within it, and raises the issue of what is the space, what space becomes at the moment it becomes occupied and we can no longer see it. In contrast, the painters can show the inside and the outside at once by superimposing them on a single plane (Golding, 1998). We shred the object, looking for its inside, into smaller and smaller pieces. However, we never seem to find an inside, just more space, more outside. What was before an inside, because it was hidden, is now only a newly exposed section of the outside.

Hammacher (1987, p.39) states that "Hepworth in her work *Pierced Form* in 1931 first introduced the 'hole' to British sculpture", which was the first step in her own attempt to solve the problem of the closed mass. Henry Moore's participation in this quest turned it into an English stylistic development of fundamental importance. He talked about 'holes' thus: "The first hole made through a piece of stone is a revelation. The hole connects one side to the other, making it immediately more three-dimensional. A hole can itself have as much shape-meaning as a solid mass..." This has been cited in the work of Hammacher (1987, p. 42). Hepworth's style reached maturity in the late 1930s and 1940s and her pieces became increasingly hollowed out, open and perforated. She skillfully contrasted the inside and the outside of her figures, sometimes linking surfaces with threaded string. Its form impressed Henry Moore so much that the following year he started carving holes in his works too. (Hammacher, 1987)

Most artists, craftsmen or architects should consider space during their creative practice. Even during the assembly of moulds, they should think about the basic classification of space to define negative and positive space in their work. It is very rare that other kinds of space are mentioned. However, architects consider many kinds of space in their works and they develop interesting interpretations of these spaces. In architecture, the definition of internal space is a very important element, as is the space used by artists, whilst on the other hand some architectural products are like big sculptural monuments, which we can compare to sculpture. Though the inside of a sculpture ultimately remains a mystery, it does not mean that a sculptor cannot engage in the process of trying to reveal it. This may account for the taken-away surfaces and holes in many modern sculptures. They try to probe the boundary line where visible and invisible mix. Whether by pitting, or scooping out, the result is that a fraction of space previously hidden is made accessible, but only by making it unfilled and thus in effect turning inside into more outside.

2.4.2. Perception of internal space using transparent medium, predominantly glass

More and more artists are trying to use glass as a medium to create their sculptures, probably, to a large extent, due to the optical properties of this material. As technology evolves, we encounter fewer restrictions, but still the biggest constraint when working with glass is a restriction of the size of glass sculptures.

Ai Weiwei‘s exhibition, Cubes and Trees included glass too. The work is in a variety of media, including sculpture, film, video and wallpaper. The series of four one-meter-square cubes are made from compacted tea, carved ebony, huali wood and crystal glass that relate minimalist sculptural forms with Chinese craft and heritage. Also, the crystal glass cube was on display at Art Basel in Miami in 2014. Here it was exhibited with Ai Weiwei's photo, which was taken during his arrest, in an elevator with the arresting policemen. In this case, the internal space of the cube is not the subject, but this work was chosen to show the largest sculptures in cast glass.

Figure 48. Ai Weiwei; Crystal Cube; 2014;

Crystal (leaded glass) cube 100 x 100 x 100 cm (1 cubic meter); Photographed by William Warmus.

The sculptures of Ai Weiwei are relatively large sizes if you take into account, that they are made of glass. In William Warmus opinion (2016), the *Crystal Cube* (Figure 48, p.99) relates to work “Pu'erh tea”, a desire to concentrate materials, and Ai Weiwei tendency toward minimalism.

Ai Weiwei and other respected contemporary artists who consider glass as a medium of expression bridge the interesting gap of contemporary glass to contemporary fine art.

Anish Kapoor also was seeking a transparent medium, for example a paint or glass, which could give him opportunities to make objects not visible. He described it in his presentation in Tate Modern (Kapoor, 2003) as “objects –non objects”. First his attempts to make an object-non object was a series of holes in the floor or in a wall, which visually turned to a solid object. A status of this was the absent object. He took this awareness beyond that, free standing stone objects were erected as containers for the absent object – again the dark hole visually turned into the solid object (Kapoor, 2015).

Kapoor pushed this idea of solid absent object even further in his “Air Space” sculpture (Figure 49, 100) by using resin he erected a transparent container for his absent object in the shape of huge air bubble within it. In his explorations, space started to be an object. He pushes the objects into the ground both inward and downward that suggests that this is an object. The object is a negative space like, for example, a hole in a block of stone painted with pigment. In his case the object is an inclusion in his sculpture. Kapoor also considered glass as a medium in this project, but technological limitations have meant that he decided to use resin (Kapoor, 2015).

Figure 49. Anish Kapoor; *Air Space*; 1998;
Resin; 53×105×104.5 cm; Courtesy of Anish Kapoor.

Glass sculpture, because of its transparency, is visible to viewers from any side at the same time. In sculpture, by moving in space, different elements of the sculpture change their spatial relation with each other. Elements can be made to hide from view others or reveal elements previously unseen. Elements can even exchange which is left or right of the other. The three-dimensional presence of a glass sculpture can be represented as the sum of an infinite series of separate 2D reliefs. A sculptor who uses glass as a medium for his final work during the process of creation has to work with an opaque medium first. He has to manipulate the form of matter in three dimensions. The sculptor can sometimes mould the entire work at once and begin with the total subject matter, the process in time after the inception of the work is sometimes not accessible visually to the artist until it is finished (e.g. taken out of a mould). However, the sculptor can also build up material bit by bit, joining and extending material. Sculpture can either grow or shrink through the time of the creation phase. The inside is not exposed *as* outside, although considering glass as the medium, the situation could be different. An interesting example is the work of Maciej Zaborski "Graver", an artist from the Wroclaw Academy of Fine Art. His engraving is quite unusual because he is sculpting inside glass by drilling holes, and part of his engraving is 3D inside in the glass, this could be classified as 3D inclusions (Figure 50, p.101). Sculptors who use glass as a medium very often work the same way and employ the same processes in their artistic practice, as sculptors who use another opaque media and only final outcomes are altered with the different perception of internal space.

Figure 50. Maciej Zaborski "Graver"; Chair II; 2005;

Size: H100cm; Photographed by Maciej Zaborski

In recent years, there has been considerable interest for sculptors in the creative potential of a glass medium. Unlike other fine art materials that are much more widespread because they are easier to use, glass is a very difficult medium from a technological point and requires both technical skills and knowledge. Sculptors find it difficult to employ this material for the development of artistic ideas because skills and knowledge are acquired only through many years of experience working directly with this medium. Part of this research protocol will provide additional tools to work with this medium.

The properties of glass raise unique sculptural issues. Glass is that which is able to open art's other dimension. For Vladimir Kopecký glass is not the subject of his expression, "it is merely a means for attaining obscure ends... I do not glorify glass" (Albrecht, 1999, p. 23). He even coined the term "ugly glass", but it is not always like this, only if he is working with glass to articulate his idea instead of decorations. He is applying paint in between glass sheets which is perceived "as a surface texture, as colour suspended in space and as three-dimensional matter built up, like a sandwich." (Albrecht, 1999)

There are vast differences between sculptures in glass and in other media, and because of the glass properties Libenskiy and Brychtova, leading glass artists, were obliged to invent new phrases like "colourful glass space", "coloured object in space", "space light dimension" or "light colour" to discuss their work. In referring to the hollow interior cavities that define the colour and luminosity, Libenskiy and Brychtova speak of having created an "inner glass space". (Kehlmann, 2001)

Bertil Vallien is another leading artist who was inspired by what he calls "of magic in glass, which has something to do with the light" (Vallien, 2014). For him glass could capture traces of past memories. His sculptures tell stories which are captured forever in the glass and only the operation of a high temperature can turn it to lava and restore it to its original form. The majority of his sculpture has only one transparent site. It means that the viewer has limited access to the internal space and the story which the artist wanted to tell. Mostly he uses transparent glass in his works but when his sculptures are not fully transparent or even not at all, only he knows what is captured inside the glass. (Vallien, 2012). When asked why he employed glass in his work as he often transforms the material in a way that it looks much more like rough stone. He said that he wants to change the classic image of glass, its seductive decorative qualities, because he does not like it and he wants to emphasise the contrast between the rough surface of his sculptures and misty fairy-tale appearance from the inside.

A different approach to glass is held by Antoine Leperier. In his opinion only glass can show a 3D image internally, while the 4D is specialized within the glass and this why he employed full transparency and clarity of glass in his sculptures. This internal space is like a snapshot of reality for him, and he sees it as an analogy for the mind; hollow thoughts floating in a space (Leperier, 2014).

Thanks to properties of transparent or reflective materials we can achieve unrealistic effects which look realistic, but they remain illusions such as for example two objects occupying the same space (at the same time). In the everyday world, two solid objects cannot literally pass through each other without one or the other being fragmented, expanded, or otherwise losing its shape. In sculpture, time has already happened and is now frozen. It does not matter that it is physically impossible to cause objects to enter each other; all that is necessary is that we represent what the result would have been like if they had (Leperier, 2012).

Jan Berdyszak, the Polish artist, is one of the artists, who used ready-made glass to study the internal space and to define it in his works. Space is a strategic material in his works, and always the starting point with new work is not “presence (of anything)” but absence understood as a main state (Ksiazek, 2002, p.15). Internal space plays a very central part in Jan

Berdyszak's artistic vocabulary and glass and its transparency is an essential medium in his artistic practice and the vehicle to communicate with the viewer. In his art darkness and light are inclusions which are captured in glass.

By using glass, it will be possible to make space inside the sculpture visible and create within this space new forms. Glass artists such as Bertil Vallien or Antoine Leperier both are using space inside a sculpture. Indeed, Vallien is "more interested in what goes on inside the glass than ... in the outer shell." (Vallien, 2012). For Antoine Leperier this internal space is like a snapshot of reality for him, and sees it as an analogy for the mind; hollow thoughts floating in a space. Antoine Leperier always interprets this space from a philosophical point of view (Leperier, 2002-2014).

In transparent sculpture the front and back curves begin to curve outwards and towards. We can see one continuous shape, which includes smooth transitions from seeing its outside surface to its inside surface. A transparent sculpture should keep their relationship with each other unless they are seen from different angles. A component in the front can change its one view composition with a given element on the rear by our shifting position. This sculptural phenomenon could be compared to a double exposure photograph. This observable fact is only a characteristic for transparent materials and particularly in the case of a glass medium and it was considered in the further investigation in the context of inclusion applications in glass.

2.5. Summary of the Contextual Review

This chapter has covered how the application of inclusions has been approached in the literature and how artists and technologists themselves have anecdotally expressed their experiences in this field. In addition to traditional literature review of texts, data has been gathered from 59 of artists in 89 interviews over 20 years. This has been used to develop a frame work to reflect on my personal experience as an artist and practitioner. The working definitions and techniques of glass inclusion have been explored from these sources and perspectives to present and describe the approaches used by current artists in their artistic practice.

A key element in the approaches to insertions is the understanding of “internal space” which has been dealt with in detail in this chapter as an understanding of the concept and use of inner space is an important element in understanding why artists are intrigued by its use. It is significant how the internal space in sculpture is used by artists who use glass in their artistic practice, because it is important to understand how to use the space by application of inclusions and its demands in the artistic process.

The cooperation between artists and technologists has also been discussed as this is an important area in the development of these techniques. This cooperation extends, not only to successfully planned experimentation, but also to the understanding of how unexpected results, or “failures” can be used to expand knowledge of the processes involved and even used as a base for artistic practice or new technological processes.

The chapter has identified the specific challenges and problems artists have had in the creative application of inclusions (Research Question 1, p.35) and the technological problems the application brings (Research Question 2, p.35) by exploring the variety of ways, both historical and contemporary (Aim 1, p.36), that metals and glass have been combined together.

3. Classification, selection and studio based tests of materials for application of metal inclusions in the glass for creative use.

In this Chapter, it was necessary to contextually review the materials considered in this research. However, the study focuses mainly on an investigation of the technological problems related to the application of inclusions in glass and the classification of materials used in the process, together with a theoretical explanation of phenomena occurring in the process (if possible). Correspondingly a studio experimentation methodology, used during the selection of suitable materials employed in the process, which has been based on, and guided by, the knowledge gained from the literature review is discussed. This provides the basis of the science, and aspects of the practical experiences of artists and technologists who use glass as a medium. Lastly, the chapter will make a final selection of the most suitable metals for the research.

In this stage of the research, preliminary studies were focused on investigating the conditions that must be met by materials for inclusion in glass, choosing the material suitable for use as an inclusion, and determining how best to use this material in the hot cast glass process. Problems associated with this process and arising during the application of inclusions in hot glass are investigated in Chapter Four (p.155). One of the aims of the research is to obtain a surface on inclusions which, during the casting of glass (temperature approx. 830°C), will not adversely react with glass and will retain its original colour (e.g. will not oxidise) and/or original shape. Initially the choice of metals considered in this study was made on the basis of the physical and chemical properties of these metals, but to achieve this aim it was first necessary to establish additional conditions (section 3.2.2, p.114).

A study of the following was required:

1. The property of glass used in the application of inclusions process and its impact.
2. Types of metals used as inclusions and their impact on glass.
3. Definition of metals and their properties.
4. Criteria of selection of metals used for further research.
5. Preliminary experiments to select the most suitable materials and techniques to apply metals as inclusions.
6. Consideration of problems occurring during the application of the inclusions and their theoretical explanation.
7. Final choice of metals suitable for my artistic practice.

In order to exploit the new technology creatively it was crucial to arrive at a technical understanding of the effects occurring during the process of application of metal inclusions, albeit from an artistic, rather than a scientific perspective. This part of the research rests on cooperation with scientists from Durham, Sheffield, Newcastle, Krakow and Wroclaw Universities and technologists from Hempel Metals, Warm Glass, Bullseye Glass Co., Goodfellows GmbH and The Society of Glass Technology UK. The aim was to identify the causes of the effects, such as oxidation, so that ways of controlling them could be developed for the purposes of making artwork.

3.1. The properties of glass

Glass is a non-crystalline solid material that exhibits a reversible transformation from a hard and relatively brittle state into a molten or honey-like state. Throughout its history varieties of glass have been mostly based on silica. Glass is traditionally formed by cooling from melted components. The first glass employed by humans was the natural occurring glass, which resulted from the cooling of molten rock. This glass contained alkali, alkaline earth, transition metal oxides and a major constituent was silica. This probably was the reason that very few non-silicate glass compounds were known prior to the 19th century. This glass was melted in high temperatures and this was the reason, that at that time, craftsmen could only to work in glass factories to develop their ideas. Now artists have access to glass, which melts in relatively low temperatures, and they can practice in their studios. But thermal expansion and a mismatch between different glasses is one of the bigger problems glass artists face in their daily work.

Several glass manufacturers serve the market, and produce many different clear batches of glass with different properties, expansions and viscosities. Some of the manufacturers (especially from China), show a lack of consistency in chemical composition within their own range of products, which causes confusion and difficulty in conducting research. Accessible assessments for glass artists to establish components of the used glass, are thread and ring tests. Those are not always reliable, particularly when comparing glasses from quite different glass families. It is possible to use industrial dilatometers to get better accuracy in the analyses of glass, but unfortunately the industrial dilatometers are very expensive and have measurable accuracy which can be inaccurate too. Regrettably by using dilatometers it is very difficult to get useful information if the set point or strain point of the relevant glasses being measured are unknown. Another, also expensive, device which is a viscosity meter disappointingly has only the same degree of accuracy as dilatometers.

It was decided that this research project should be approached using easily available studio materials only. In this case, five types of glass were considered, three types of furnace glass, because during the last eight years, the University of Sunderland Studios changed distributors of furnace glass three times: Gaffer, Glasma and Cristalica glass. The other two kinds of glass considered were soda lime silicate glass (commonly called window glass) and borosilicate glass (popularly known as Pyrex glass). The window glass was chosen because it is commonly used by artists and sculptors, and the borosilicate glass, which is used with lampworking techniques, allows for faster results in preliminary tests conducted.

3.1.1. Cast glass from furnace

Initially, research was carried out mostly with Gaffer glass and for a short period exclusively with Glasma glass, however recently research was continued only with Cristalica glass. The Gaffer and the Glasma glass; both have a COE (Coefficient of Expansion) 96 and a quite similar quality. Thanks to this, research was continued without any additional preliminary tests. Unfortunately, Cristalica glass is currently producing nuggets in COE 100. The producer explained that he only calls this glass COE100, but he made assurances that it is actually an international 96, as he measured according to the German measuring method. Also, the manufacturer stated, that John Croucher at Gaffer has tested the glass and found it compatible to their 96 colours. However, in the Cristalica leaflet the information is very confusing: “Theoretical value: COE coefficient of expansion 96x10-7 (+/-2); Practical value: COE coefficient of expansion 20° C - 300° C = 100x10 - 7 (+/-2)”. Nevertheless, experiments have shown that Cristalica glass has slightly different characteristics to Glasma or Gaffer glass. It was necessary to carry out analyses of the glass to understand differences between different glass and predict the reactions occurring between the glass and metals. The analyses have been made in the laboratories of the University of Durham in cooperation with Leon Bowden and Professor Chris Greenwell. The comparison of chemical analyses of glass in Table 6 (p.110). shows the differences between different glass:

Glass / **chemical**	Gaffer nuggets	Gaffer from furnace	Glasma nuggets	Glasma from furnace	Cristalica 100 nuggets
SiO2	61.10	61,88	62.39	61.53	69.0- 71.5
Na2O	25.79	25	17.35	17.15	12.5-12.9
K2O	1.72	1.75	10.90	11.06	5.0-5.5
CaO	2.90	2.93	3.70	4.06	4.0-4.5
CoO	3.34	3.57			

Glass **chemical**	Gaffer nuggets	Gaffer from furnace	Glasma nuggets	Glasma from furnace	Cristalica 100 nuggets
BaO					2.5-3.0
Al2O3	3.80	2.77			1.1-1.5
B2O3					1.0-!.5
ZnO	1.35	2.10	1.72	1.87	0.6-1.3
SO3			*	*	0.21-0.31
Sb2O3					0.2-0.5
Li2O					0.06-0.1
Er2O3					0.03-0.05

Table 6. Comparison of furnace glass, used in research.

All compositions in wt%;

* Kenneth Svensson (2013), VD/Managing Director of Glasma AB confirmed that they recipe contains sodium sulphate.

Gaffer and Glasma glass compositions are made by EDS analysis (electron diffraction spectroscopy), which is a quantitative analysis more reliable for homogeneous materials. Calculations of results were done with the cooperation of Dr Oana Bretcanu from Newcastle University, who specialises in glass. As materials are not homogeneous, the composition is probably a good estimation and there might be elements that cannot be detected very well. As was mentioned earlier in Chapter Two (p.47), nickel sulfide (NiS) inclusions could be a reason of glass breakage, because, nickel and its alloys were used in the research, as inclusions, in this case it was necessary to look for sulphur, which is sometimes added to the glass as a fining agent. The analyses did not detect any sulphur in Glasma glass, the component also was not mentioned in the producer's leaflet, but Kenneth Svensson (2013), VD/Managing Director of Glasma AB confirmed that their recipe contains sodium sulphate. This information is very important in the research, as the conjunction of sulphur with nickel could cause additional stress in glass, if NiS is cooled too rapidly. At temperature below 379°C NiS is in the beta-phase, but above the temperature it is in the alpha-phase. To smoothly transform NiS from alpha to the beta phase it needs to have a slow cooling process by the annealing. This is why it was considered in the research annealing programs (Chapter Four, p.155).

3.1.2. Float glass - Flat glass – Window glass

Window glass used in studio practice, is mostly Pilkington - Soda-Lime Silica Float Glass: Optifloat™ and Optiwhite™ (a low-iron extra clear float glass with very high light transmission). Properties of the glass are:

Type of glass / Properties	Pilkington* Optifloat™	Pilkington* Optiwhite™	Pilkington** General Properties
COE	8.3 x10-6 mm/mm.°C	8.3 x10-6 mm/mm. °C	9 x 10^{-6} /K
Softening Point ()	715°C	~732°C	740°C
Annealing Point	548°C	~559°C	555°C
Strain Point	511°C	~526°C	?

Table 7. Properties of Pilkington Float glass used in studio practice.

*(Pilkington North America, 2013)

**(Pilkington UK, 2010)

It is a relatively cheap glass and it is used by sculptors in its standard form, but it is also very popular among glass artists, mostly employed in fusing techniques. Two researchers: Dr Eileen Leatherland (2012) and Dr Jennifer Antonio (2009) have conducted their research with float glass and its surface metallic coatings. They used the features of the glass as innovative, decorative effects. The most familiar type of glass used by glass artists is annealed soda-lime glass. This glass has five base ingredients: silica sand, soda ash, dolomite, limestone, and sodium sulphate, which is used as a fining agent and a wetting agent to aid in melting the silica. These raw materials are heated in furnaces to 1480°C and then poured on molten tin. After that, the large sheets are taken through an annealing lehr, which prevents the glass from cooling too fast. The successful annealing of floating glass, like the successful annealing of all glass, is largely dependent upon the size and thickness of the finished piece, the process which is involved in the kilnforming process, the material used for inclusions, size of inclusions. The annealing process plays a very important role in the development of metal inclusion applications in glass as often the annealing processes of metal and glass are not complementary. This contradiction, which can also be seen in the production of window glass. Tempered glass, obtained by the rapid cooling is much stronger than annealed glass, but, as was explained in the previous section, even very small particles of NiS inclusions detained in the alpha-phase can cause the glass to break. The transformation from alpha to beta phase in temperature lower than 379°C it increases NiS in volume by 2-4% (Gromowski, 2010). The development of suitable firing programs was addressed in the research in the following chapter. The research has shown that the most effective method for application of metal inclusions is the hot glass being poured into the mould, so the window glass has not found many applications in this study. The main cause is its hardness and lack of flexibility. On the other hand, these features were useful for the application of nickel and lead (more in the relevant section) for the “Hempel Logo” commission (Figure 137, p.208; Figure 138, p.208 & Figure 139, p.208).

3.1.3. Borosilicate glass

Borosilicate glass, popularly known as Pyrex glass (COE between 3.5 and 5.5) is used mostly by lampworking artists. But in industry, the glass has many uses, and especially in combination with metal, to produce lamps, equipment for chemical laboratories or thermoresistant dishes. Based on some of these technologies, described by Partridge (1949) and Donald (2009), in their books, the phenomena that occur when glass is combined with metals at high temperatures can be understood. So, it was decided to carry out a preliminary experiment using this glass. This glass has one of the lowest COE due of the chemical composition, mainly because of the content of boric oxide (B_2O_3), in addition to quartz, sodium carbonate and aluminium oxide. The glass is more resistant to thermal shock, but due to the high melting temperature it is more difficult to work with, than traditional glass and it has several limitations: the possibility to make only relatively small size objects and because of the high melting temperature and difficulty to apply kiln cast techniques in artist studio environments). Preliminary experiments were conducted with several metals, by using borosilicate glass and lampworking techniques, because this method allows the researcher to yield immediate results and observe processes occurring during application of metal inclusions in the glass at high temperatures.

3.2. Properties of metals

The practical knowledge of the forming of metals was developed over thousands of years, but the understanding of the physical phenomena associated with deformation has only developed within the last seventy years. By the XIXth century the number of known metals was 23, by the beginning of the XXth century the number had risen to 65, in the second part of the century it had risen to 70, and now 81 metallic elements are known to science. Modern metallurgy, as does glass technology, has its roots in the ancient crafts of smelting, shaping and treatment of metal. In the contemporary world, the combination of metal and glass is nearly applied everywhere. This combination is so widespread that it is used by many artists, designers, craftsmen and architects in their artistic practice. They create objects in varying styles: both traditional and ultra-modern, they use: different types of metal and metallic patinas, a variety of glass, and diverse techniques to apply this combination of materials. However, the application of these two materials, especially by employing hot glass techniques (most suitable in this research), creates many problems, and as a consequence, often forces artisans to gain enormous empirical knowledge of working with these materials or/and application of advanced scientific knowledge in this field.

3.2.1. Definition of metals

“In glassmaking terms, the word “metal” refers to the molten glass in a furnace” (Bray, 2001). A term frequently used as a synonym for glass, it is misleading because glass is not a metallic substance, and its use is discouraged (Whitehouse, 1993). Physically, any of a class elementary substance, as gold, silver, or copper, all of which are crystalline when solid. A metal is a medium that is typically hard, opaque, shiny, and has good electrical ad thermal conductivity. It is an incredibly versatile material: from high-tech lightweight aluminium to air purifying titanium dioxide, and from crude and raw Corten steel used in marine transportation to gold leaf. These metals, as other chemicals, were arranged in order of atomic weight in Mendeleev’s periodic table (Table 8, p.114). The most obvious feature of such a table is that chemically similar elements form groups. metals comprise 81 percent of the elements occurring in the periodic table.

Metal | Metalloid | Nonmetal

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Table 8. Mendeleev’s Periodic Table of Elements.

The highlighted elements are considered the metal elements (Helmenstine, 2014)

3.2.2. Methods of selection of suitable materials and techniques

In the initial stages, the research undertaken was more focused and concentrated on the recognition of limitations involved in the use of different kinds of metal inclusions in glass. The research explored and experimented with a range of metals to try to determine possible alternatives with a view to applying the research findings in a new and innovative way. The results of the research into possible inclusions were to form the focus of the protocol that was tested and probed during the study.

The research was concentrated on investigating the compatibility of glass with metallic materials, mainly non-iron or non-ferrous metals such as lead, tin, nickel, titanium, cobalt, chromium, aluminium, gallium and a variety of alloys of these metals; because non-ferrous metals are more malleable, mostly non-magnetic with a higher resistance to rust and corrosion. Several of the metals which are difficult to produce in pure form, or can be more conveniently used when alloyed, are available as ferroalloys. These are used as addition to steel, for example molybdenum, vanadium, tungsten, titanium. But mostly pure metals will be examined in these studies, because it is easier to predict their behavior and they usually are softer than Ferroalloys. The most important property of solid materials is the “thermal expansion” or expansion-with-temperature relation. “This is the property that complicates sealing different materials together” (Schuler, Schuler, 1971, p.36). Consequently, the two materials will usually have their respective expansion-temperature relations differing during the heating and cooling process. If this problem occurs using two different metals bonded with each other, the metals would bend. But if we use the glass and metal, because glass is brittle, the glass may fracture from stress if the length difference is excessive. In the course of research, it has been found, to reduce the effects associated with this phenomenon, it is important to carry out an appropriate annealing for both materials. Glass artists and glass technicians focus only on the annealed glass, and they forget that they should also take into account in their calculations, relaxing metal at the same time. Heat expands all metals, which again contract in the cooling and no danger of fracture is caused even by rapid cooling (Pellatt, 2010, p.31) for this material, but if the metal is combined with glass it is a different matter. Metals annealing is a form of heat-treatment and is made use of when the metal is required for use in a soft but tough state (so most metals and their alloys selected in this study were annealed). Annealing may proceed in three separate stages depending upon the extent of the required treatment (Higgins, 2004, p.90). In this part of the research it was necessary to take an overview of the literature on metallurgy and annealing of metals, and have consultations with scientists in the field. In this way, it was possible to collect parameters of the annealing of metals and tailor to the research needs. On the basis of these results firing programs of cast glass with metal inclusions taking into account annealing for both materials have been established.

The aim of the research (aim2; section 1.3, p.36) was, that the metal inclusions used during the casting of glass (temperature approx. 830°C), will not adversely react with glass and will retain their original shape and retain silvery lustre. To get this it was necessary to seek information from engineering publications. Industries utilise the variety of metal alloys at elevated temperatures under severely corrosive conditions. For example, the development of the gas turbine drew attention to high temperature properties of metallic materials. The gas turbine demands materials operating in around 815°C, but at high stresses (Clark, 1950, p.1). However, for purposes of the research suitable metal to combine with glass should be soft, and therefore weak enough to allow the glass to brief during a cooling process, even if it has a bond to the surface of the metal due to the wetting action of the glass. Metals in high temperature will all oxidise to a certain extent with some exceptions for example gold.

Based on a review of literature and interviews with artists (Chapter Two, p.47), it has been deduced that most common metals used by artists in the past were: gold, silver, platinum, cooper, brass, bronze, and in the last few decades we can add to this list aluminium and zinc (Table 4, p.41 & Table 5, p.60). Artists justify their choice of metals because in their opinion these metals are the most compatible with glass. By comparing COE (Coefficient of Expansion) parameters of these metals has been noticed that the COE parameter is not fully correlated with the compatibility of these metals with glass. This is shown in Table 9 (p.117).

Casting Glass	Gold	Silver	Platinum	Cooper	Brass	Bronze	Aluminium	Zinc
9.6-9.9	14.0	19.5	9.0	16.6	18.7	18.0	22.2	29.7

Table 9. Comparison of the Linear Thermal Expansion Coefficient of most common metals and glass used by artists.

[In units 10^{-6}m/mK, most of values at 25°C (77°F)]; (The Engineering Tool Box, 2014)

For example, nickel (Figure 52, p.118) has COE 13, Kovar, which was designed to be used with borosilicate glass (Figure 78, p.145), is 1.5, when borosilicate glass is 5.5, and both metals are perfectly compatible with the glass.

Figure 51. Gallium inclusion applied in borosilicate glass by Lampworking.

The melted metal, has wetted the glass surface from the inside and the surface looks a shiny silver. 20g Ga was poured into a 1cm diameter tube and heated (Figure 51 left, p.117); effect after annealing (Figure 51, right, p.117). In this case, the bonding between the metal and glass is a positive phenomenon, because Gallium is in a liquid state during the entire heating and cooling process.

The review of literature and questionnaires sent out to artists also showed that the thickness of the metal inclusion has an effect during annealing, with the belief that any metal thicker than a foil 2-5 mil (= 0.0508-0.127mm) would cause the glass to crack (Walker 2010). However, having started experiments with metals of greater thickness than foil, up to 3mm = 118.11mil (Nickel 99.9, Figure 81, p.147, or Aluminium, Figure 67, p.136 or Gallium, Figure 65, p.135 or Lead alloys, Figure 63, p.132), it was decided to establish if thicker inclusions could be regularly produced effectively.

Figure 52. Nickel 99.9% (annealed) inclusion in borosilicate tube glass.

1 mm thick sheet of Nickel rolled with bare hands (probably that resulted in its yellow stains) and placed in 2cm diameter glass tube, embedded in glass in 1000ºC; it is compatible and stayed silvery effect. Small air bubbles are visible on the surface of the metal. probably thanks to this, glass does not wet the metal surface.

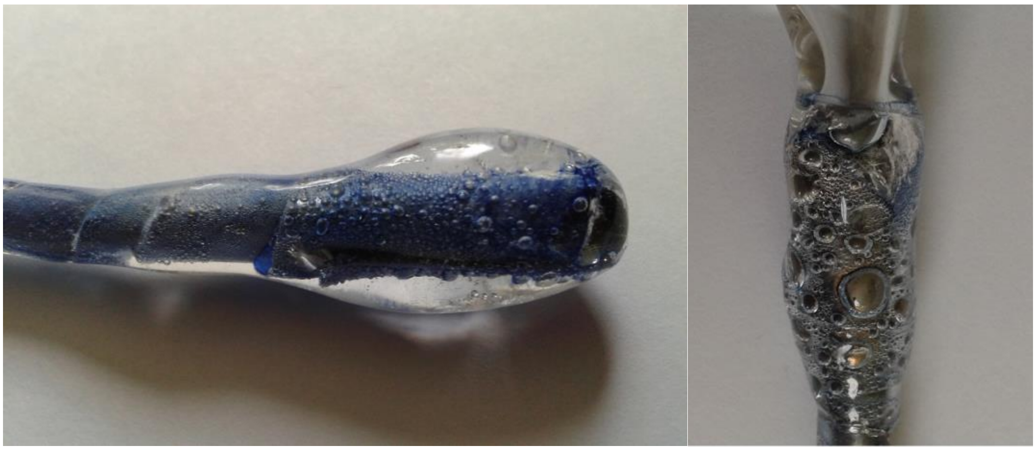

Figure 53. Nickel alloys inclusions in borosilicate tube glass.

0.5mm thick sheets formed in spiral shape to add even more tension to the glass. Left: nickel alloy with cobalt component; right with a higher proportion of chromium. Both alloys are compatible, but alloy with chromium produced bigger bubbles.

Figure 54. Stainless steel 410 inclusion in borosilicate glass.

0.5 mm thick sheet of stainless Steel in 3cm diameter tube and 3mm wall thickness. They are not compatible at all; the glass was wetted the surface of the metal and during the forming process, the glass bonded with metal had cracks all over the surface. During the cooling process, the glass shattered in kiln and has left exposed metal surfaces to heat.

Figure 55. Lead 50% Tin 50% inclusion in borosilicate glass.

Beads of the Lead 50% Tin 50% alloy in 2cm diameter tube and 2mm wall thickness. The alloy and glass are compatible. However, metal was exposed to long to heat and stained glass, but itself remained silver.

The conclusion is that a COE of metals can be different from glasses if there is not a strong bond between a metal inclusion and the glass. But if a chemical bond between the metal and the glass has been formed, probably through oxidation of the metal surface, then as the metal attempts to shrink away from the glass, stresses will be set up. Although these stresses could simply break the metal/ glass bond they might lead to other fracture problems, especially if surface roughness leads to some interlocking of the metal and the glass (Figure 56, p.120).

Figure 56. The metal/ glass bond caused the stress during cooling process.

As for the thickness of the inclusion then there are many variables in play. What the research has shown is that for softer metals, the thickness of the inclusion can be greater than that for harder metals which are more likely to cause the glass to crack but definitive results are difficult as the annealing process and any lubricant or separator will also have an effect.

The study showed that to avoid glass wetting in high temperatures, it is necessary to use a separator to coat metal surfaces or to find metal which can produce for itself such a coat during a process of heating (Chapter Four, p.155).

Further studies were focused on adjusting both materials: glass and metal, used in this research to minimalize differences of physical characteristics between them. To increase the COE of glass, sodium carbonate is frequently added but this should be done during the melting of the raw materials to manufacture glass (Holland, 1966). In Kenneth Svensson's, VD/Managing Director of Glasma AB opinion it is too late to add this ingredient to the melted glass nuggets in our furnices, it would cause blisters in the glass (Svensson, 2013). Of course, one can get around this problem in a different way, but since it was decided that this research should be approached using studio glass, this study focused on the choice of the most suitable metals and adapting them.

Initially the choice of metals considered in this study was made on the basis of the physical and chemical properties of these metals and preliminary experiments with these metals. It was noticed that the metals which can be used as inclusions in glass should meet a set of conditions. It means that it should conform some of general requirements listed below.

1. The thermal expansion of both metal and glass should be similar. This requirement was selected first, because it was mentioned in most publications for glass artists, as a central condition in the selection of materials for casting glass projects. But then again as has been noticed earlier, the COE parameter is not fully correlated with the compatibility of metal with glass. Professor Zasadziński, Krakow Academy of Technology, pointed out that the COE parameter mostly is measured between room temperature and 300°C, and the process of the application of metal inclusions is in a range 25°C to 1000°C. Though in this bracket the thermal expansion of materials often is not linear and does not change uniformly as the temperature increases, so it should be taken into account too.
2. If possible the curves of thermal expansions of the two materials, metal and glass, should be analogous during the process of cooling. With these limitations, appeared two problems; firstly, it is very difficult to find these parameters in literature (some of them are published by distributors of materials, but it is only about popular materials on the market) and secondly it is very rare that two materials have matching curves of thermal expansions. To get around these problems, from time to time, it was required to use empirical experience and intuition.

3. Metal melting point should be higher than highest casting point of the used glass. This condition was determined on the basis of information gathered from metals which have been used by artists as inclusions in the past. Melting temperature of common metals used by artist are indicated in the table below:

Gold	**Silver**	**Platinum**	**Copper**	**Brass**	**Bronze**	**Zinc**	**Casting Glass**
1063	961	1770	1084	905-1000	~980	419.5	~600

Table 10. Comparison of the melting points of metals and glass in °C. This data was collected from The Engineering Tool Box.

It was indicated in Table 10 (p.122), that most of these metals have a higher melting temperature than glass. Zinc was the only exception, but because this metal was not really that popular a choice in the past – only a few times it was mentioned by some artists and by Brad Walker in his book (2010) – so at this point of the research this exception can be omitted. On the other hand, it was noticed that if glass has a higher melting temperature than metal, it does not stick to metal surface during the cooling process. Therefore, it was decided to observe the characteristic, but not be guided by this feature when choosing metals.

4. Metal boiling point should be much higher than the highest casting point of the used glass (the boiling point is the temperature at which the liquid changes into a gas). This condition was placed because of safe working with metals at high temperatures, because of the emitted gases during the boiling process.

5. Low probability of oxidation. When metals are exposed to high temperatures, deposits often accumulate on the metal surfaces and initiate the oxidation processes. This process in literature is called high temperature hot corrosion (Petti, 2011).

For any metal, there exists a value of oxygen potential which is called the "free energy of formation" of the oxide (Crouse- Hinds series. 2016). Above this value the metal will be oxidised but below no oxidation will take place. This value is very much dependent upon temperature and usually increases with increasing temperature. For example, nickel, will undergo oxidation to nickel oxide (NiO) in an atmosphere with an oxygen potential greater than -60 kilocalories/mole at 1000°C (Crouse- Hinds series. 2016). Chromium has a greater attraction for oxygen than nickel. It would require -130 kilocalories/mole at 1000°C (Crouse- Hinds series. 2016) to prevent oxidation. Thus, a direct correspondence was found between the resistance to wetting and the resistance to oxidation, which means that more easily oxidised metals or alloys are more easily wetted. Although it was also noticed the great importance of the nature of the atmosphere surrounding the glass metals system, and the probability that the phenomena of wetting are related to the reactivity of the metals and alloys towards the gases in the atmosphere. These relations were visible in experiments, in the art practice of Sally Resnik Rockriver (Section 2.2; p.60) and a technology of using metal moulds with hot glass. For example, a major problem in glass container production is the sticking of the glass on metallic moulds. As a consequence, in glass moulding (not only metal moulds), the selection of process parameters such as mould temperature or cooling rate is strongly influenced by the requirement of non-sticking. In the literature, there is no satisfactory theory explaining the mechanism of glass sticking in such processes. Although several studies of mould material wetting by molten glass have been published, see for instance Angela Thwaites (2011) or Professor Cummings (2001) books. It appears that no theory exists relating sticking with wetting and glass-mould interfacial interaction. It is not possible to formulate such a theory at present because a divergence of experimental results exists concerning the effect on sticking of material parameters, such as the mould surface chemistry and roughness. “One main reason explaining this divergence is the lack of standard experimental techniques to quantify sticking” (Pech, Braccini, 2004, p.118).

6. Selected metal, preferably, should not react with the glass in the process of casting; it means that glass and metal should not stain each other.

The last condition was placed due to one of the aims of the research, that metal will not adversely react with glass. It would be very difficult to find metal which would satisfy all of these six conditions, this was the reason, that in some cases (to increase the list of the metal inclusions), the choice was made based on the empirical experience, or in some cases even randomly. Preliminary tests were conducted with different forms of metal, such as metal oxides or metals deposited by the thermal evaporation method, as it should be easier to apply as inclusions, nonetheless these attempts did not yield the expected results. But even if this part of the research was not successful, still it brought a better understanding of the metal and its application with the glass.

3.3. Preliminary experiments in search of materials as metal inclusions in glass

This section describes investigations for the appropriate metal medium for inclusions; practical tests in search of these inclusions, and finally it provides a theoretical and practical basis for understanding processes and properties of applying materials involved in this research. In order to apply the new inclusion materials and to exploit new methods creatively it was crucial to understand the technological problems from a scientific perspective. This phase of the research depended, to a great extent, on collaboration with scientists from Durham, Newcastle University, Krakow Academy of Technology, The Society of Glass Technology and Sheffield University. As the technological problems became better understood and were mostly overcome.

This part of the research was concentrated on searching for materials that would satisfy some conditions (section 3.2.2; p.114), mainly resistance to high temperatures, compatibility with glass, no chemical reactivity to glass and resistivity to oxidisation. Inclusions can be introduced into the glass by various methods such as: fusing, kiln casting and hot pouring glass. Each of these methods has its advantages and disadvantages if these methods are considered in terms of obtained results. But generally, it can be said that in the case of most materials employed in the application of inclusions in glass, the least satisfactory results for this study used the kiln casting method. Below, the technological problems that appeared during the application of these inclusions in high temperature were addressed. The review of literature for artists showed that using metals as inclusions is very limited due to the characteristics of this material, which is why pre-attempts were also carried out with other forms of metals, such as metal oxides or metals deposited by the thermal evaporation method, as it should be easier to apply them as inclusions, nonetheless these attempts did not yield the expected results. But even if this part of the research was not successful, it still brought a better understanding of the metal and its application with the glass. This is why it was included in the following section.

3.3.1. Experiments with metals deposited by the thermal evaporation method

Evaporation is a common method of thin film deposition. The source material is evaporated in a vacuum. The vacuum allows vapour particles to travel directly to the target object (substrate), where they condense back to a solid state. Evaporation is used in micro-fabrication, and to make macro-scale products such as metallized plastic film. Some metals (notably aluminium and copper) are seldom, or never, deposited by CVD (Chemical vapor deposition). As a commercially cost effective, viable CVD process for copper do not exist. Copper deposition of the metal has been done mostly by electroplating, in order to reduce the cost. However, CVD processes for molybdenum, tantalum, titanium, nickel, and tungsten are widely used. The most important target achieved by applying metals with this method is the possibility of controlling precisely the shapes of applications that they can form inclusions of programmed holograms, which were considered for application in future artworks. One of the aims of the research (Section 1.3; p.36) was to retain the original shape and colour of the metal inclusions. It means that the surface of metal will retain a silvery lustre.

Professor Wood and his assistant from Durham University were interested in the potential of this research and were collaborating in the process of the deposition of metals on glass and they assisted in adapting this technology to the research needs. The most important factor in this specific element of the research is to find the most suitable materials to produce the most reliable mask. A mask could be made in a different kind of metal. In this research the following were used; chrome (Figure 57, p.126), nickel (Figure 59, p.127 & Figure 60, p.127), titanium (Figure 58, p.126), as it appears that these metals are the strongest ones. The metal deposition was sandwiched between two pieces of Gaffer glass.

Figure 57. Chrome (99%) applied on Gaffer glass by evaporation method.

The left side before casting in kiln in 830ºC, the right side after firing.

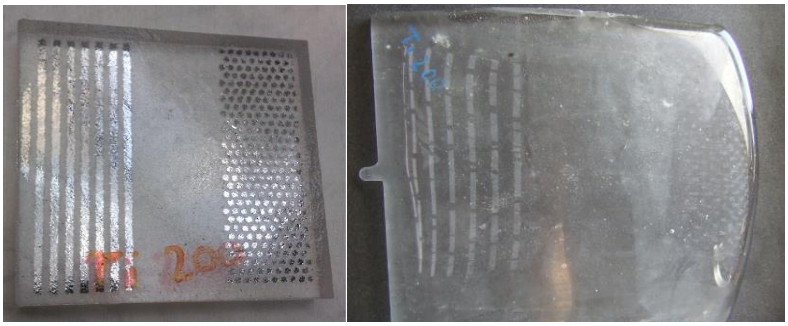

Figure 58. Titanium (99.99) on Gaffer glass; by evaporation method.

The left side before casting in kiln in 820ºC, the right side after firing.

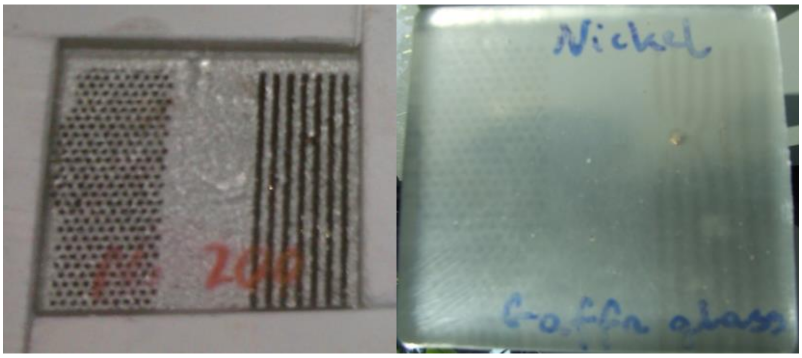

Figure 59. Nickel (99.99%) application on Gaffer glass.

Before (left) and after (right) the casting process in 820ºC

Tests with Gaffer glass were not successful. Deposits of metal during the heating process reacted with the glass and stained it: chromium to greenish; titanium to whitish and nickel to a greyish colour. Also, the shape of deposition was disturbed by melting glass and by air bubbles flowing to the surface of the glass during the casting process. In industry, this technology is generally used for Borosilicate glass. In this case, it was decided to use borosilicate glass in further tests to find the reason for the problems. The nickel (99.99%) applications on Borosilicate glass were; silver colour, mirror effect; two pieces of glass on top of each other with nickel layers face down. One layer of nickel faced to kiln shelf and the second layer was between plates of glass (Figure 60, the left side, p.127). Unfortunately, the silver layer of nickel disappeared too during the heating process and it turned to a light brown colour (Figure 60, the right side, p.127).

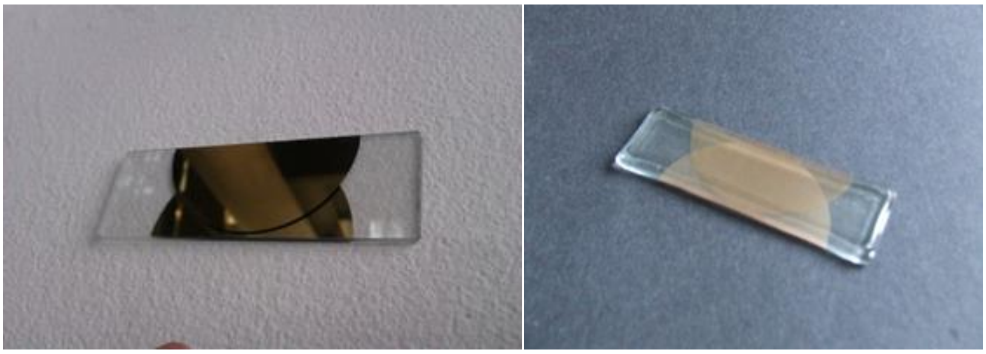

Figure 60. Nickel (99.99%) application on Borosilicate glass;

Before (left) and after (right) the fusing process in 820°C

Regrettably, frequent tests and experiments on this technology have not yet delivered expected results. The deposit of metal is very thin and it loses its lustre effect during the fusing process. During the heating between 730-830°C deposited metals, chemically reacted with the glass. It was found that more layers should be used to get a lustre effect. Usually there are up to two layers of metal, but as a request, Professor Wood tried to apply as many layers as possible and each layer thicker than usual. It meant that on each plate of glass were deposited alternately metals layers: nickel, titanium, nickel, titanium (Figure 61, p.128).

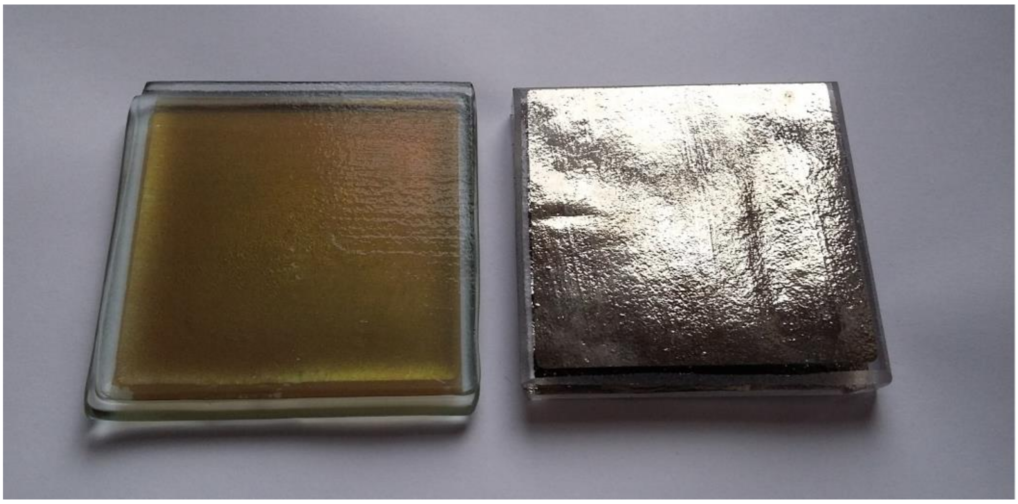

Figure 61. Deposition of four layers of metal: Ni, Ti, Ni, Ti on glass.

On the right: before firing and on the left: after firing at 820°C. there is an interesting result, the metal deposition changed colour to gold-pearly effect. However, the obtained results did not meet expectations, but it can be used in the design of jewellery (Chapter Six; p.192) or it can be used as a separator between solid metals inclusion and glass to stop the reaction between these materials, stopping the glass bonding to the surface of employed metals and reduce oxidation of surfaces of the metals during the heating process. This shows too many technological problems and on top of this is still too expensive in this kind of application.

3.3.2. Experiments with application of metal oxides in the form of Egyptian Paste

In search of a suitable material for shaping the metallic effect, screening inclusions was considered, also ceramic materials with metals coating.

The 19th century artists used porcelain objects - some of which were replicas of ancient metal coins or medals. These porcelain cameo inclusions in hot glass were called sulphides as they had a similar appearance to silver sulphide (Figure 15, p.52). This visual effect is created by a residual micro air layer between the ceramic cameo and the lead glass. It is caused by bad inlay of cameo porcelain. In this situation, the imperfection turns into a very unusual artistic design. The technique they used is described in Paul Jokelson's book (Jokelson, 1968). However, it was noticed that this interesting phenomenon also appears on surfaces of some metals which are employed in the research. It also helped in reducing stress between the glass and the inclusion during the cooling process. This topic is investigated further in the following chapter.

In this section Egyptian Paste was explored, which is a self-glazing, low-firing clay. It is mostly a mixture of sand, clay, potash feldspar and soda ash. It contains soluble salts that rise to the surface while the medium is drying. Therefore, this material was experimented with because it is suitable for hand building small pieces and is easy forming. Traditional ceramic oxides and body stains were used to get metallic effects, also some of the watersoluble metal salts were applied. Egyptian Paste is usually fired to a temperature range of 900 - 1000˚C.

Regrettably, this medium did not satisfy the research conditions. It was also noticed that metal coatings disappeared during firing at high temperatures and it is difficult to control the resulting colour. After firing, the coat of nickel lost a silvery colour, on the Gaffer glass leaving yellowish-red patches; right: the metallic coating burned, changed colour from silver to red (Figure 62, p.130).

Figure 62. Egyptian Paste with the metal coatings.

In this case, it was decided that further research would not continue in this direction. Moreover, full retrospectives of combination ceramic media with glass were investigated by Dr Jessamy Kelly (2009) in her PhD thesis.

3.3.3. Selection of pure metals and their alloys

In this stage of the research, considering the conditions established in Section 3.2.2 (p.114), the following metals were selected for further consideration: aluminium, chromium, stainless steel, titanium, iron, tin, lead, nickel and some alloys of these metals. The parameters for deciding the choice of considered metals in this investigation were collected in Table 11 (p.131). What was also taken into consideration was the ready availability of these metals and alloys. Metals that were scarce or requiring specialist handling were excluded on the grounds that their use in artistic practice would be exceptional.

Condition Materials	1 X 10^{-6}m/mK	2	3 In ºC	4 In ºC	5	6
Aluminium	22.2		660	2467	Yes	**Yes
Chromium	6.2		1860	2670	Yes	Yes
Cobalt	12.0-13.0		1495	2925	No	Yes
Gallium	1.8*	N/A	29.76	2400	No	No
Invar, Kovar	1.3 - 1.5	Stable	1449		Yes	**Yes
Iron pure	12.0	Stable	1127-1593	2870	Yes	Yes
Iron cast	10.4	Stable	~ 1270		No	Yes
Lead	28.0	N/A	327.5	1750	No	**Yes
Nickel	13.0	Stable	1453	2800	Yes	No
Steel Stainless (410)	9.9	Stable	~1510		Yes	**Yes
Tin	23.4	N/A	232	2600	No	**Yes
Titanium	8.6		1670	3290		Yes**
Lead-Tin, 50%-50%	24.0	N/A		~2000		Yes**

Table 11. Preliminary choice of metals made on the basis of physical and chemical properties of these metals.

Shows the Linear Thermal Expansion Coefficient in units 10^{-6}m/mK, most of values at 25°C; The coefficient of linear thermal expansion of the metals listed above ranges from 1.5 x 10^{-6} per degree C. for Invar to 28.0 x 10^{-6} per degree C for Lead.
*in units 10^{-5} [32] (Hampel, 1961)
** It depends on the process used and the temperature (Figure 63)

Primary experiment started with easy accessible, soft metals, as lead and tin.

3.3.4. Lead, tin and their alloys

The research commenced with lead as its properties suggested that it might fill the research expectations, even if not a fully complying with the conditions set out and mentioned at the beginning of this chapter. The main reason for this decision was that lead exhibits a high degree of resistance to atmospheric corrosion, attack by chemicals and subjected to a thermal process retains a silvery colour. On top of this lead was used by ancient civilization (Roman, c. 1st century B.C.E) as a writing medium which carried some information about the civilization even to our time.

Lead is a soft metal and one of the heaviest. Which is easy oxidised when exposed to air, but it has a shiny chrome silvery effect when it is melted into a liquid. Also, various oxidised forms of lead are easily reduced to the metal. Lead only oxidises on the surface and because of this characteristic it was selected for applications. A major disadvantage of lead is the evaporation of poisonous gases, but this takes place in very high temperatures. However, to work with lead, strict health and safety precautions must be in place. Hence when working with lead using glass hot pouring techniques or casting techniques a ventilation system needs to be in place and a suitable mask should be worn to prevent inhalation of lead fumes evaporated during experiments with this metal.

Initially lead was cast in a desired shape and then it was put in a previously prepared mould and covered with bits of glass to minimise contact with air. During the casting at 820°C lead, because it is much heavier than any studio glass, flowed through melted glass to the lowest points in the mould, nevertheless did not fully flow through the glass leaving a very thin glass layer between the mould and itself. This created an interesting effect. The metal stayed shiny. It did not react with the glass and did not create bubbles of gas, but unfortunately it lost its original shape. The reason for this disadvantage appeared to be, as lead has a relatively high density and if it has enough space it forms rounded objects (Figure 63, p.132).

Figure 63. Lead captured in hot pouring glass and recast in 820°C

With this technique were obtained interesting results. From the beginning, it was obvious that lead is compatible with glass as, despite a thin layer of glass padding on the lead surface, the glass did not break and the lead did not oxidise despite high temperatures. Even when the Linear Temperature Expansion Coefficient of lead is so high – 28 x 10^{-6} m/m K and used glass is around three times lower 9.6 – 9.8 x 10^{-6}. This phenomenon is due to lead's high parameter of wetness and high density of this metal. Unfortunately, at the same time lead is difficult to control due to its physical properties

Tin in contrast to lead is not that heavy, its density and wetness parameters are lower and it has low toxicity. These were the main reasons for considering tin in this research as also for the reason that it is silvery and, even better than lead, is not easily oxidised in air. As well as lead, tin is used in industries to coat other metals to prevent corrosion. The history of using tin is dates from 3000 BC. In modern times tin is used in many alloys, mostly tin/lead.

Tin has a very weak resistance to thermal processes, however even a small amount of lead added to an alloy with tin could stop this process. Additionally, in contrast to lead during evaporation tin does not produce harmful substances consequently it is considered in these studies as the alloy with lead. Tests were carried out in parallel with different alloys of these metals: 30% lead +70% tin, 50%-50% of both metals and 70% lead + 30% tin. It has been identified that in general most of these alloys behaved similarly, but because tin balanced lead, it was decided to focus in the final studies on the 50% tin and 50% lead alloy.

It was observed that these alloys have to be captured in glass during the whole casting process. At the point when the inclusion of this alloy has contact with the body of the mould it changed its consistency from metallic to white solid or to rusty-beige powder (Figure 64, p.134).

Figure 64. Lead & tin alloy inclusion cast in mould

Lead and tin were chosen for further research, because thanks to their softness, they are compatible with glass, giving opportunities for application of thick, silver inclusions.

3.3.5. Experiments with Gallium

Gallium was chosen mainly because of the non-toxic characteristic and very low melting temperature. It has the second largest liquid range of any element and is one of the few metals that is liquid near room temperature (m.pt. 29.76°C), melting in the hand. It means that it melts much below, the annealing points of the glass. Gallium also has the unusual property that, like water, it expands as it freezes. This characteristic allows it to avoid problems of compatibility. Gallium is a silvery, glass-like, soft metal, but its metallic properties aren't as obviously metallic as most other metals. The solid metal fractures conchoidally like glass, is brittle and is a poorer electrical conductor than lead. First experience with the metal (Figure 51, p.117) showed that Gallium liquid wets glass, which helps in the application of this metal as inclusions. Unfortunately, melted glass applied by the hot pouring method, displaces the metal because metal in its hot stage, is watery, and it is difficult to control its shape (Figure 65, p.135).

Figure 65. Gallium 99.9% inclusion in hot pouring Cristalica Glass.

It was noted that gallium keeps the silvery colour, even at very high temperatures (1,020°C) only if it is applied with hot glass pouring method. Another advantage of the metal, it does not emit gases during application. But if it is recast in glass in 830ºC it loses its lustre effect. Most of the metal turns to blackish bubbles formed around the initial shape of the inclusion, and a part of the gallium formed a goldish rounded shape circulated to the bottom of the mould (as lead does), but surrounded by the bubbles (Figure 66, p.135).

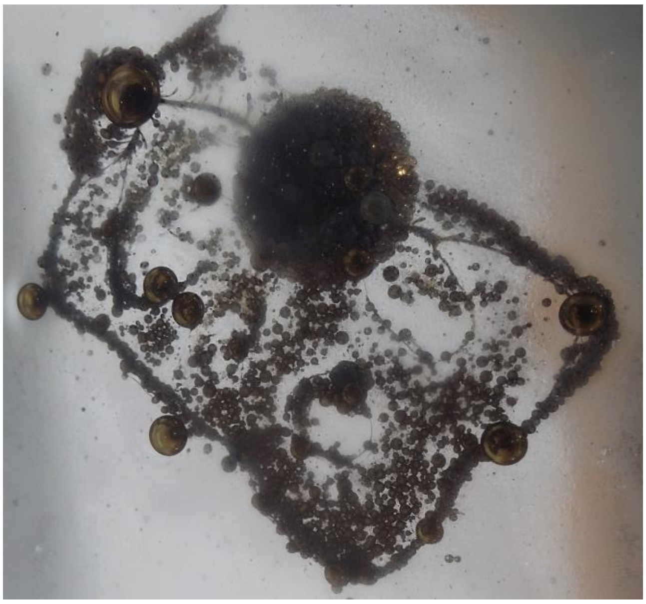

Figure 66. Gallium 99.9% recast in 830ºC.

However, because of the difficulty of controlling the shape during a hot glass pouring process and loss of the lustre effect during application of the metal by the casting methods, it was decided not to continue the experiments in this direction. Further attempts of using this metal have been carried out in order to apply it as a separator (Section 4.3, p.164).

3.3.6. Experiments with Aluminium

Initially aluminium (Al), was chosen for this study due its chemical and physical characteristics as it is: highly corrosion resistant, silvery effect even in powdered form, low density and its alloys are vital to the aerospace industry. Aluminium was used in the past by artists, but it was chosen in this research even due its high thermal expansion ($25x10^{-6}$m/mK), its highly reactive chemical nature and relatively low melting temperature of 660ºC, because properties of aluminium show us that metal, even with high resistance to corrosion, behaves completely different cast in glass at high temperatures.

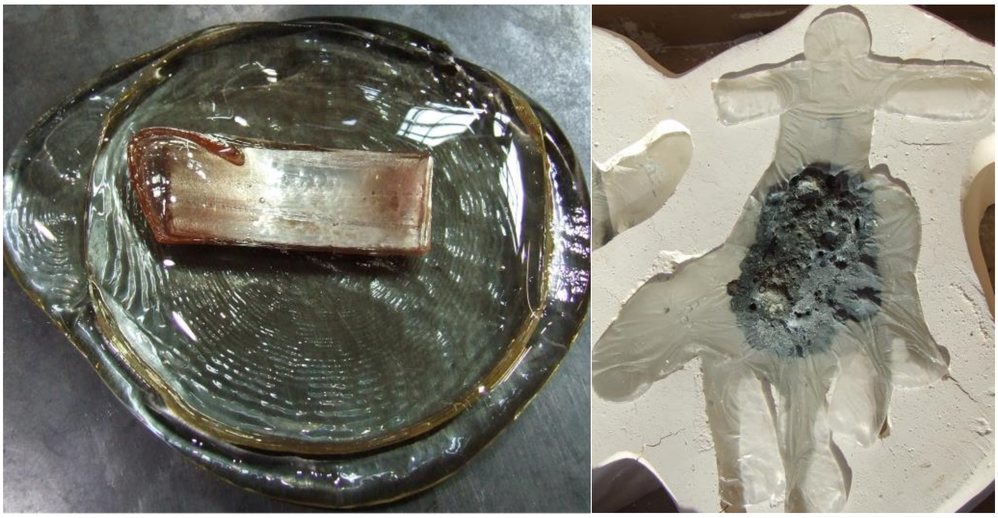

Figure 67. Aluminium captured in hot glass and kiln cast technique.

It is visible that if aluminium (3mm thick) is rapidly captured in hot glass, in an air free environment, even at 1015°C, it doesn’t react that strongly and retains the shiny, silver effect with a few black spots (Figure 67, on left, p.136), but if it is subjected to a gradual increase of temperature to 830°C in air for a longer period, it reacted strongly (Figure 67, on right, p.136).

Dr Bernadeta Procyk from the Technology Academy in Krakow did experiments with aluminium and glass casting (Procyk, 2012). From these experiments, she developed insulating material. Some aluminium alloys reacted with glass and in high temperature they form substances with a structure like volcanic rocks. Aluminium degrades and picks up harmful gases (particularly hydrogen) at high temperatures. The aluminium alloy should not be overheated. The investigation of using aluminium in casting glass demonstrates that aluminium can give quite interesting effects but unfortunately these effects are not appropriate to use in this research.

To avoid that, it was decided to employ the hot pouring technique to combine glass with aluminium, to get a lustre effect screen inside the body of the glass. Aluminium is notorious for difficult casting and welding because it picks up hydrogen from the atmosphere, but it is strong, corrosion-resistant, and comparatively lightweight (Figure 68, p.137). The metal expands more than the glass and may force it, but fortunately metal and glass have different points of melting and if aluminium is annealing well during the cooling process we can avoid the undesirable effects (Higgins, 2004, p.412-415).

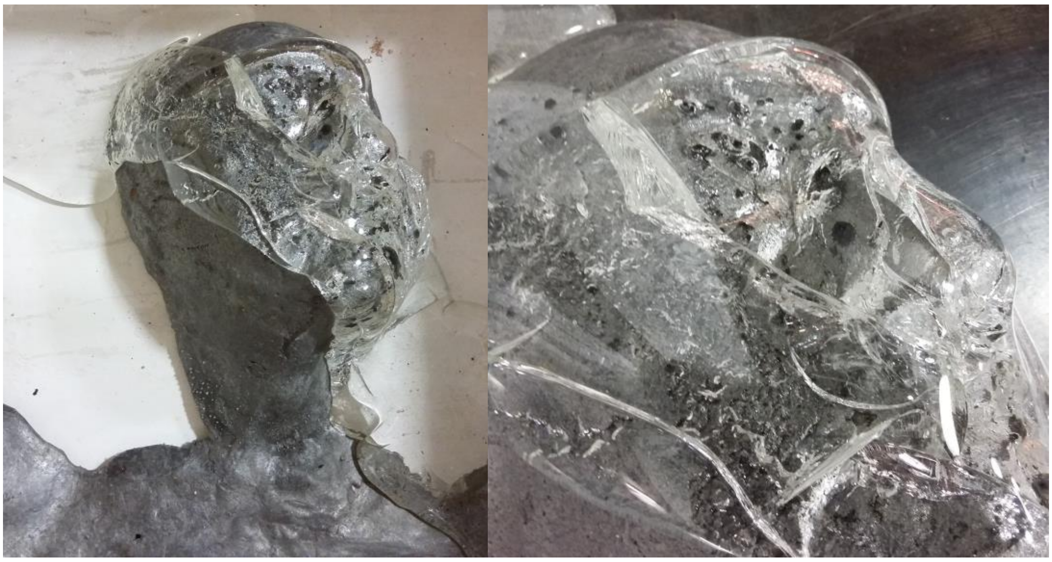

Figure 68. Hot poured Cristalica glass (1020°C) on the top of aluminium alloy.

The procedure of pouring glass on top of aluminium was repeated three times unsuccessfully, as successive layers of glass cracked. Initially the annealing point of aluminium was not considered in the firing program, second time it was too low a temperature during the pouring of the glass on the aluminium. The third attempt was also unsuccessful, even when the annealing was correctly done. It was thought that the porous surface and uneven shape of aluminium was the cause of the experiment failure, glass was trapped around the metal and as a result, stress arose. Besides this, the surface of aluminium reacted with the glass and lost its silvery colour, and this was the main cause, further experiments with this metal were not continued. It was noted, that the surface of the metal, not covered with glass, did not change colour. It means that aluminium is reacting with components of the glass at high temperature.

3.3.7. Experiments with Iron

Pure iron is relatively soft and is reactive to oxygen and water, but it is significantly hardened and strengthened by impurities, in particular carbon, from the smelting process. A certain proportion of carbon (between 0.002% and 2.1%) produces steel, which may be up to 1000 times harder than pure iron. Fresh iron surfaces appear a lustrous silvery-grey. Unlike the metals that form oxide layers, iron oxides flake off, exposing fresh surfaces to corrosion. It was decided to use this metal because of its extensive oxidation to understand how this oxidation affects the entire process, especially that many books mentioned that oxidation could be a reason of wetting metal and bonding with glass. This is why one of the condition was about oxidation. Pure iron nails: one rusty and one clean of rust, were cast in Gaffer glass in a mould.

Pure Iron COE (12) is not too far from COE of glass, it looks as though Iron is compatible with casting glass even if it is very rusty, but it reacted in glass and the glass lost its clarity (Figure 69, p.139).

Figure 69. Pure Iron nail cast in Gaffer glass in mould in 830°C.

From this experiment, it was understood that oxidation itself, is not a problem, if COE of both materials is similar and there is no strong bonding between them. As a result of iron corrosion, loose flakes worked as separators from the glass. This observation was used in the search for separators or lubricants eliminating glass bonding to the surface of the inclusions and is continued in next section.

3.3.8. Experiments with galvanized iron

Galvanisation, is the process of applying a protective zinc coating to steel or iron, to prevent rusting. Zinc is a chemical element with the symbol Zn and atomic number 30. It is a corrosion resistant metal, but when it is fired to fusing or casting temperature (around 800-830°C) zinc produces bubbles, even worse than aluminium (Figure 67, p.136). Upon firing the galvanization released toxic fumes and the metal flaked and caused contamination in the kiln (Figure 70, p.139).

Figure 70. Galvanised Iron nails casting to 830 °C temperature.

Galvanized Iron does not cause cracking of glass, because the emitted gases weaken the bonding between materials. On the basis of this phenomenon it was concluded that the gas also can act as a separator between the materials, so that they can shrink during cooling independently. Of course, in this case the result is too extreme, so this research did not continue studies with this material.

3.3.9. Experiments with titanium

Titanium (Ti) has a low density and is a strong, lustrous, metal with a silver colour, quite ductile especially in an oxygen-free environment. The relatively high melting point (Table 10, p.122) makes it useful as a refractory metal. This metal has found many applications in industry because of the two most useful properties: corrosion resistance and the highest strength-to-weight ratio. Pure titanium is as strong as some steels, but 45% lighter. Commercial grades of titanium (99.2% pure), which were investigated in the research, is 60% more dense than aluminium, but more than twice as strong. However, titanium loses strength when heated above 430°C and will soften if an appropriate cooling process is applied (Zasadzinski, 2012). The metal goes through transformations at 882°C from alpha into a form of beta and in forms of β remains constant regardless of temperature (Zasadzinski, 2013), which is a positive characteristic because casting is at a temperature around 830°C. These characteristics led to the choice of this metal and further tests on it to adapt it to the needs of the research (Figure 71, p.140).

Figure 71. Titanium 99.2% inclusion cast in glass in 820°C

Apart from excellent resistance to corrosion, unfortunately titanium is thermodynamically a very reactive metal and it is not compatible with most kinds of glass which were employed in the research. Even small amounts of this metal cause stress and cracks in glass (Figure 71, p.140).

3.3.10. Experiments with Chromium

Chromium (Cr) is a steely-grey, lustrous, hard metal that takes a high polish and has a high melting point. It is also odorless and malleable. Chromium oxide was used by the Chinese in the Qin dynasty over 2,000 years ago, and coated weapons found at the Terracotta Army site.

Chromium was regarded with great interest because of its high corrosion resistance and hardness. A major development was the discovery that steel could be made highly resistant to corrosion and discoloration by adding chromium to form stainless steel. This application, along with chrome plating (electroplating with chromium) are mostly the uses of the metal. Chromium 99.9% was chosen to be investigated in this research because of its high corrosion resistance. Regrettably, during the heating process, it turned to green, and produced gases. Even, when it was placed in an earlier drilled hole in the glass (left, Figure 72, p.141) or it was captured immediately in hot glass it still changes its colour, commonly to green.

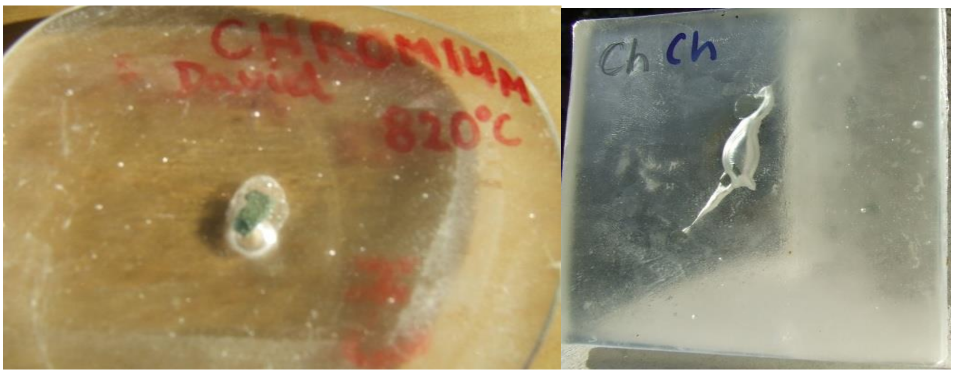

Figure 72. Chromium inclusion cast in Gaffer glass in temperature 830ºC.

The gases, evaporated during the heating process, creating a protection zone between glass and metal (Figure 72, p.141). Thanks to this there is no tension between these two materials. In this case experiments were conducted pouring hot glass to capture the metal. Before placing the metal in the glass, a recess was made with nickel alloy stamps (Section 4.4; p.171) in the shape of a lying man. While pouring a second layer of glass chromium turned a reddish- pink colour, but it is compatible with three types of casting glass and nicely settled without gas bubbles (Figure 73, p.142).

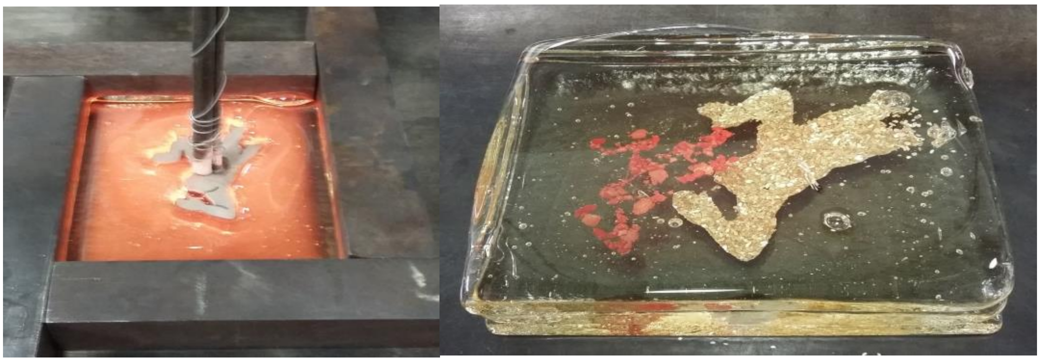

Figure 73. Chromium 99.9%; hot pouring Cristalica glass.

Though, further studies were not continued with chromium alloys because the pure chrome changes colour during the heating process.

3.3.11. Experiments with stainless steel

Stainless steel is notable for its corrosion resistance. It is a steel alloy with a minimum of 10% chromium and nickel. A typical composition of 18% chromium and 10% nickel, an austenitic alloy, commonly known as 18/20 stainless steel, is often used in cutlery and high-quality cookware (Figure 74, p.142).

Figure 74. Stainless steel 18/20, bowl filled with the Cristalica glass.

Stainless steel (410) is a typical ferritic alloy chosen in the research, as have better engineering properties than the 18/20 and it has COE 9.9 (similar to cast glass). Chemical content: Fe, 0.15% C, 11.5-13.5% Cr, 0.75% Ni, 1.0% Mn, 1.0% Si, 0.04% P, 0.03% S (AZO Materials, 2017). Unfortunately, it has lower corrosion resistance, because it has less chromium and nickel content than 18/20. The inclusion was cut by the Waterjet from a 0.2mm thick sheet (Figure 75, p.143).

Figure 75. Stainless Steel 410;

The studies have shown greater utility of Austenitic stainless steel (18/20) especially when was used as a container for hot glass (Figure 74, p.142), because these alloys exhibit superior corrosion resistance. Ferritic (410) completely failed to meet expectations in these studies. Firstly because of oxidation it changed colour from silver to blackish, greyish or brownish, but also it causes stress in the glass by bonding, probably because of oxidation changes and additionally the metal itself is not elastic enough to respond to differences of shrinkage between glass and metal during the cooling process (Figure 75, p.143).

3.3.12. Experiments with the cobalt

Cobalt is a hard, lustrous, silver greyish metal. It was used in ancient times as a pigment for jewellery, paints and a blue tint to glass. The pure metal has poor corrosion- resistance, but interestingly some of its alloys have excellent resistance, especially at high temperatures. Some cobalt-based alloys are used in orthopedic implants, because of its chemical inactivity (Higgins, 2004, p.459). It was decided to carry out experiments with some cobalt alloys (Figure 76, p.144 and Figure 77, p.144), because it appears that they should satisfy the conditions of the research. A shiny, silvery sheet 1.5cm wide and 0.1mm thick of the annealed cobalt alloy was applied between Gaffer bricks and cast in a mould at 830ºC. The alloy was exposed to air up to the moment when the glass was fully melted (above 650°C). It did not oxidise but its surface turned to a blue colour (Figure 76, p.144).

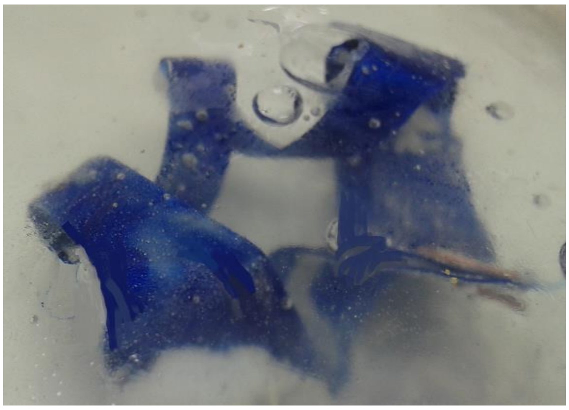

Figure 76. Cobalt Alloy 65% in Gaffer glass cast in plaster mould in 830°C.

The blue stain is so strong that even when it was cast immediately in hot poured glass it still turned to blue. Application of the metal gives very interesting effects (Figure 77, p.144).

Figure 77. Cobalt Alloy 65%; cast in hot pouring Gaffer glass

It was decided to carry out experiments with alloys with a smaller amount of cobalt or even none at all (next sections).

3.3.13. Experiments with the controlled expansion alloys; Invar and Kovar

Kovar and Invar were developed for applications where metals must form a hermetic seal with glass or ceramic, for example: lamps, power tubes, vacuum tubes, light bulbs, cathode ray tubes or applications where a specific expansion must be met over a certain temperature range.

Invar is a low expansion alloy, consisting of 36% nickel and balance. This alloy exhibits extremely low expansion around ambient temperatures. Kovar is a nickel–cobalt ferrous alloy consisting of 29% nickel, 17% cobalt and balance of iron. It was designed to have substantially the same thermal expansion characteristics as Borosilicate glass from room temperature to 800°C, in order to allow a tight mechanical joint between the two materials over a range of temperatures (Figure 78, p.145). Chemically, it bonds to glass via the intermediate oxide layer of nickel oxide and cobalt oxide; the proportion of iron oxide is low due to its reduction with cobalt. The bond strength is highly dependent on the oxide layer thickness. The presence of cobalt makes the oxide layer easier to melt and dissolve in the molten glass. A grey, grey-blue or grey-brown colour indicates a good seal. A metallic colour indicates lack of oxide, while a black colour indicates overly oxidized metal, in both cases leading to a weak joint (Carpenter Specialty Alloys, 1999, pp 5).

Figure 78. Kovar wire as an inclusion in Borosilicate tube glass.

To add even greater pressure on the glass, 1mm thick wire spring was put in 3cm diameter and 3mm wall thickness Borosilicate tubes (left Figure 78, p.145); (right Figure 78, p.145) right after gas lamp heating to around 1000°C. It is compatible with Borosilicate glass, but it reacted in flame and turned to blackish colour with a few blue spots. Next experiments were carried with Invar sheet in Glasma and Kovar wire in Gaffer glass. Regrettably both alloys are not compatible with the casting glass, as was expected, due to their large discrepancy in COE which is for Kovar 1.5 and for Invar even lower: 1.3, compared to that of casting glass 9.6; additionally, the glass wetted the metal and bonded to it (Figure 79 p.146).

Figure 79. Invar and Kovar inclusions.

Left, Sheet 0.2 mm thick Invar in Glasma; Right, the Kovar wire 0.5 mm thick in Gaffer glass. Both experiments were unsuccessful.

3.3.14. Experiments with Nickel – Silver

Nickel-Silver is a brass alloy containing 10% to 30% nickel and 5% to 50% zinc, the balance copper. The colour of these alloys is very similar to silver, hence the name. They were chosen, because of their shiny, silvery appearance, resistance to atmospheric corrosion and to acids. Experience conducted with this metal, have shown that at high temperatures the metal reacts with the glass, producing black-grey gas bubbles on the surface. Metal is compatible and does not cause cracking glass, but loses silvery colour (Figure 80, p.147).

Figure 80. Nickel-Silver inclusion in hot pouring Gaffer glass.

Because the metal lost its lustre effect, it was decided not to continue further research in this direction. This alloy in contact with the hot glass created a lubricant in the form of bubbles of gas, thanks to this, the glass did not wet the surface of metal and did not form a bond between materials. This phenomenon resulted in further exploration of metals that produce similar reactions without changing color.

3.3.15. Experiments with nickel and its alloys

Nickel was chosen because of its resistance to atmospheric and chemical corrosion, and because it can be highly polished. Additionally, the COE is quite close to cast glass, 13.0 x 10^{-6}m/mK. It has been recorded that pure nickel can keep silver surfaces, even at high temperatures (Figure 81, p.147),

Figure 81. Nickel 99.9% inclusion in Glasma glass applied in 1015°C.

The 0.5mm sheet thick inclusion, twisted into spiral to create greater stress in the glass.

On the surface of Ni inclusions tiny bubbles of gas were formed, such as the previously mentioned phenomenon with porcelain Cameo inclusions. So, it was assumed that the glass does not bond to the metal during the casting process because of the phenomenon and the characteristics of this metal it was decided to conduct further experiments on this material (Chapter Four, p.122). Two 99.5% nickel alloys were found: Nickel 200 and Nickel 201 (Table 12). They are solid, strengthened, commercially pure formed materials. Nickel 200/201 have exceptional resistance to caustic alkalis at various temperatures and concentrations. When operating temperatures are expected to exceed 315°C, carbon content becomes critical. The lower carbon content of Nickel 201 makes the material resistant to graphitization and brittleness. These alloys are fully resistant to corrosion for use up to 676°C. Both Nickel 200 and 201 offer corrosion resistance in reducing and neutral media as well as in oxidizing atmospheres provided that the oxidizing media allows the formation of an oxide film, which accounts for excellent resistance in corrosive environments (Corrosion Materials, 2015). Nickel 200 has been selected for the final investigation, because of its accessibility on the market.

	Ni	Fe	Cu	Cr	Mo
Nickel 200	99.5	0.15	0.05	-	-
Nickel 201	99.5	0.15	0.05	-	-

Table 12. Nickel 200 and Nickel 201.

But it was also decided to continue experiments with nickel alloys. It may be asked why in this situation only pure nickel was not considered in the further investigations. The answer is simple; because of the appallingly high price of this metal. But the exploration with pure nickel was continued because this gives the best expected results. In time, the price of the metal relatively might be reduced which would make it possible for artists to employ this metal in their projects in the future. The best results were obtained with sheets of metal which were given for further investigation by Professor Zasadzinski from Krakow Academy of Technology. He believed that this was pure nickel. During the application of this material into glass it was found that these sheets of metal behaved differently in similar or even the same circumstances. Advance investigation using Analytical Scanning Electron Microscope methods confirm that these metal sheets were a mixture of different nickel alloys and only some of these sheets were pure nickel. The description of alloys (Table 13, p.149; Table 14, p150. and Table 15, p.150) was obtained by analysis carried out using a Hitachi SU70. It should be noted that cobalt (Co) is typically included in nickel (Ni) alloys to improve high temperature workability, giving similar expansion properties to borosilicate glass. The SEM-EDS uses virtual standards and is a surface analysis method, only probing the upper few nanometers (nm) of the surface of the alloy. This means any segregation of the Ni/Co and any oxidation may lead to an overestimation of Co and oxygen (O) at the alloy surface (Table 13, p.149; Table 14, p150. and Table 15, p.150). In order to confirm this hypothesis, thin sections of the alloy would need to be taken and the full cross section probed (Greenwell, 2017).

1. The first nickel alloy contains about 19% of Cobalt (Table 13, p.149),

2. Element	App	Intensity	Weight%	Weight%	Atomic%
	Conc.	Corrn.		Sigma	
O K	29.45	1.0630	38.69	0.93	65.56
Na K	0.87	0.3777	3.21	0.45	3.78
Al K	0.30	0.5011	0.82	0.19	0.83
Si K	0.32	0.6243	0.72	0.17	0.69
S K	2.56	0.8225	4.35	0.22	3.68
Cl K	1.70	0.7390	3.22	0.20	2.46
K K	0.82	1.0398	1.10	0.14	0.76
Ca K	0.40	1.0151	0.55	0.13	0.37
Mn K	0.45	0.9978	0.63	0.17	0.31
Fe K	1.01	0.9518	1.49	0.21	0.72
Co K	18.61	0.8785	29.59	0.66	13.61
Ni K	10.18	0.9086	15.64	0.54	7.22
Totals			100.00		

Table 13. Nickel alloy with 11% Ni and 19% Co.

Because of content of cobalt the metal surface tinted the glass blue (Figure 82, p.150), but it is not that strong as the cobalt alloy shown in Figure 76 (p.144) and described in section 3.3.12 (p.143).

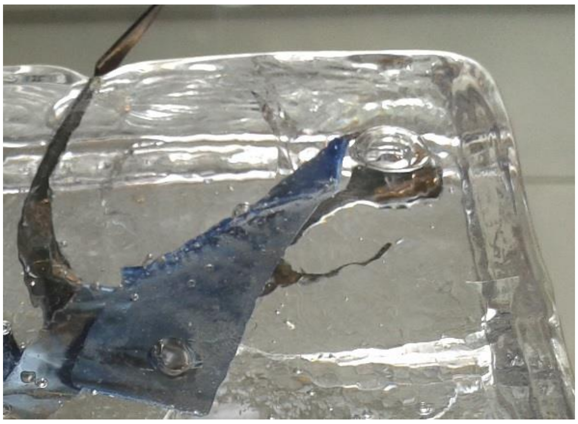

Figure 82. Nickel alloys containing cobalt (19%) cast in hot pouring Glasma glass.

2. The second alloy (Table 14, p.150) was with a higher dominance of cobalt and nickel than the previous one (Figure 76, p.144).

Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
O K	4.00	1.1077	3.31	0.31	11.17
Fe K	1.50	1.1151	1.23	0.10	1.19
Co K	65.37	0.9777	61.23	0.34	56.13
Ni K	37.90	1.0141	34.23	0.30	31.50
Totals			100.00		

Table 14. Nickel alloy with dominance of cobalt

3. The third nickel alloy (Table 15, p.150) considered in this research was with dominance of nickel with small amount of chromium, this is why visible green spots are on the metal surface (Figure 53, p.118).

Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
O K	24.31	1.1293	20.77	0.71	49.02
Cr K	0.48	1.0378	0.45	0.12	0.32
Ni K	77.97	0.9551	78.78	0.71	50.66
Totals			100.00		

Table 15. Nickel alloy with some elements of chromium

The three nickel alloys were compatible with all types of glass, which were used during the research. The only disadvantage of these alloys was that they stained glass. So, it was decided to consider more nickel alloys to try to get the silver effect of the inclusion. Taking all the above-mentioned conditions into account and conditions relating to other problems associated with the nickel alloys application, experiments were carried out on two nickel alloys:

1. Nickel Alloy 825 (sheet thickness 0.6mm) is a high performing nickel-iron-chromium alloy with additions of molybdenum, copper, and titanium. The nickel content is sufficient for resistance to chloride-ion stress-corrosion cracking. This has been successfully used in oil & gas, chemical processing and power generation markets.

Chemical components are shown in Table 16 (p.151):

	Ni	Cr	Fe	C	Mn	Si	Cu	Mo	Al	Ti	P	S
Min.	38.0	19.5	Bal.	0	0	0	1.5	2.5	0	0.6	0	0
Max.	46.0	23.5		0.05	1.0	0.5	3.0	3.5	0.2	1.2	0.02	0.01

Table 16. Nickel Alloy 825 (NeoNickel, 2013)

Properties of the alloy described by the producer are very suitable for the research: satisfactory resistance to pitting and crevice corrosion; good resistance to oxidising and non-oxidising hot acids; good mechanical properties at both room and elevated temperatures, up to approximately 550°C; Permission for pressure-vessel use at wall temperatures up to 425°C. One of the main attributes of alloy 825 is its high level of corrosion resistance. But attempts with the metal showed some problems with compatibilities, as well as loss of silver colour (Figure 83, p.151151).

Figure 83. Nickel 825 alloy

2. Cronifer 1925 hMo – Nickel Alloy 926 (sheet thickness 3mm) is a superaustenitic stainless steel developed by ThyssenKrupp VDM. By increasing the molybdenum and nitrogen contents of Cronifer 1925 LC, a material with markedly improved properties was obtained. In particular,

Cronifer 1925 hMo, shows significantly higher resistance to localized corrosion in halide media, with superior mechanical properties (ThyssenKrupp, 2012). It is in sheet, cold rolled, solution annealed, descaled, sheared, with an REA analysis RF=XRF show that it has some amount of S as a component (Table 17, p.152).

	C	S	N	Cr	Ni	Mn	Si	Mo	Cu	Fe	P
	0.012	0.001	0.20	20.55	24.64	0.76	0.32	6.43	0.88	45.83	0.021

Table 17. Cronifer 1925 hMo developed by ThyssenKrupp VDM.

Experiments carried out with the material, have shown that even a small part of the metal should be covered with some separator or lubricant to be successfully applied into the glass. Nevertheless, this metal was used to produce tools. the tools are necessary for the application of metal inclusions in the glass. Even long contact with the hot glass does not cause deformation of the material, as well as discoloration (Figure 84, p.152).

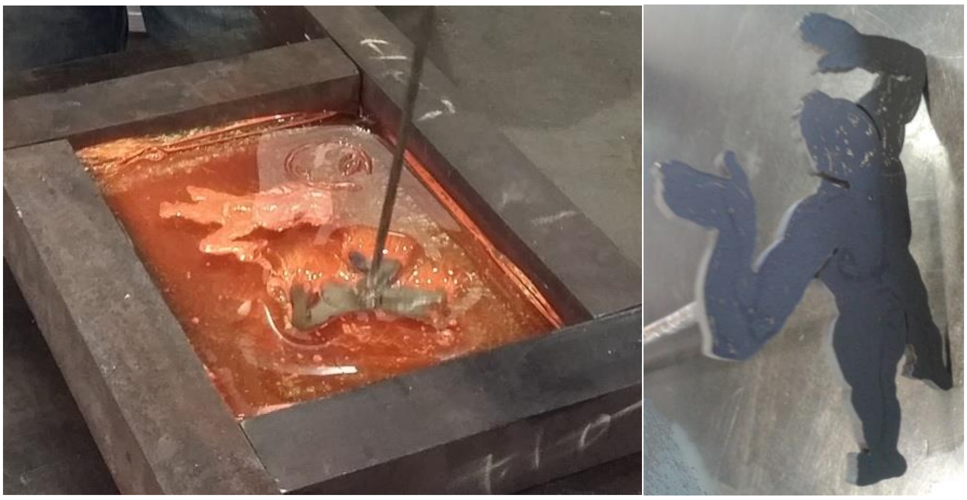

Figure 84. Stamp made from Cronifer 1925; Nickel alloy.

The disadvantage of both Nickel alloys 825 and 926 is that there is a discolouration and cracking when inserted in glass. This can be overcome by using a lubricant to coat the metal prior to insertion. However, it was decided not to use these alloys as part of the final selection, as a result of this lubricant requirement to meet the aim of keeping the inclusion in its original silver lustre.

3.4. Summary and final selection of metals for creative use in glass

This chapter has covered the context of the materials that was required to understand the challenges of selecting metals for inclusion in glass. This has included:

- Knowledge about metals, rationale;
- Determining of conditions during the choice of metal inclusions in the glass;
- Application of metals in combination with glass, especially in high temperatures, and recognition challenges that arise during the process;
- The choice of suitable metals for creative use in glass.

The preliminary experiments of combining glass with metals and their alloys have shown that the metal that best meets the conditions for research is 99% nickel, because it can keep its silver surfaces even at high temperatures (Figure 81, p.147). But it was also decided to continue studies on lead and its alloys (Chapter Five, p.183) as well. These metals were chosen because their chemical and physical properties are very different from each other (Table 11, p.131). The most important difference is their melting points: nickel's is above the melting point of glass, which is 600°C, while lead's is much below that temperature, and is even below the annealing point of glass. This was significant because, it shows that metals in their fluid stage are more flexible. In this case glass has space to shrink and is not stressed by the metal inclusions during the cooling process. But they also have common features, which are very important for this research. These metals are silver-lustre and corrosion resistant, even at high temperature. This means that they fulfill aim 2 (section 1.3, p.36). Additionally, thanks to their diversity it is possible to visualise more of the metal inclusions' potential in the application of art works and further our understanding of the problems which the application of metal inclusions can bring (aim 3, section 1.3, p.36). Nickel inclusions allow precise control of the shape and the lustre surface of the metal, whereas lead and tin inclusions allow a significant increase in the mass of inclusions, but at the expense of control over the shape of inclusions.

Moreover, some metals and their alloys, such as cobalt, chromium or their alloy stainless steel are compatible with glass, but they stain glass to different colours. These effects give more possibilities in artistic practice (Chapter Six, p.192).

Also, it was noted that some alloys, particularly nickel alloys, even if they are not entirely compatible with glass, can be adapted to the application as inclusions in glass, but this requires some additional actions, such as preventing sticking to the surface of the molten glass. Generally, hot glass wetted the surfaces of materials, which creates many problems during the inclusions application process. There are various possibilities to prevent these problems. The development of these methods is described in the next chapter.

4. Developments in processes in application of metal inclusion

This chapter is a continuation of the investigation into the compatibility of glass with metals and the possibility of developing new methods to apply these metals in glass in order to utilise the space inside sculpture.

This chapter will look at experiments and developments made during the research which make the process of inserting metal into glass more efficient and practical and in many cases possible the quite significant thickness of inclusion (even 3mm thick). The topics covered will include:

- Comparison between fusing, hot pouring and casting of glass during application of metals
- High temperature resistant moulds and their preparation
- Exploration to prevent metal oxidation during the heating process
- Development of tools
- Lubricants and separators
- Development of firing programmes
- Annealing of glass and metal inclusions

4.1. Comparison between three Kiln Forming techniques employed for application of metal inclusions in glass

Initially experiments with applying metal inclusion into the glass were carried out by hot pouring, the cast glass technique and the fusing technique. During the heating process, when the glass is still solid, the metal inclusions are exposed to air at high temperature. In many cases this causes deformation and discoloration of the metal surface. As a result, studies have been also directed to find better techniques to overcome these problems.

Technique Application	Cast kiln forming	Fusing	Hot pouring into mould
Glass	Furnace glass, cast glass	Window glass	Furnace glass
Lead & Tin alloys inclusions	Difficult to control the shape of the metal, because glass is too soft and metal gravitated to bottom of mould	Limited possibilities; Flat objects only	Possibility to control and manipulate the shape of inclusions; avoiding oxidation of metal
Nickel 99.9% and Nickel alloys	Most of inclusions lost silvery color, when they are exposed too long to air in high temperature	Window glass is stiff and it has to be annealing longer than the furnace glass	Pure Nickel is the best, but it is some other alloys, which with lubricants are compatible
Separators and Lubricants	Most of separators and lubricants reacted with glass during heating process, and glass lost its transparency	Window glass and inclusions are cut by WaterJet that inclusions covered with separators are not exposed to air	Some separators react with hot glass, producing gas bubbles. Only devitrification fluid, white and black graphite do not react
Disadvantages	More difficult to control oxidation and deformation of metal inclusions;	Limitation of shapes	It requires the assistance of hot glass technician; limitation of the size of the sculptures
Advantages	Easy to control clearness of the surface of glass;	Easy to control shape of inclusions;	meets most research conditions.

Table 18. Comparison of Hot Kiln techniques used in the research.

Preliminary investigation was concentrated on Bertil Vallien’s methods hot pouring glass into sand moulds. It was noted that the method also has some disadvantages, such as glass bond to beads of sand and its surface is no longer transparent. One of the conditions was to get a detailed, transparent surface, which is why it was decided in further studies to use the plaster moulds. To be able to get the expected results, it was necessary to obtain forms that will be resistant to thermal shock and high-temperature resistant (section 4.2, p.157).

4.2. High temperature resistant moulds and their preparation

This section will deal with the solution of problems which appeared during application of hot pouring glass method into refractory moulds. Proposed by specialists such as Angela Thwaites (2011), Boyce Lundstrom (1989), and Henry Halem (1996) and many others, so far recipes for refractory investment moulds that will withstand high temperatures over a long period of time do not meet the conditions for the research needs.

Based on a review of literature, numerous conversations with specialists in this field and preliminary experiments it was possible to draw up an accurate recipe for moulds which must be able in the same time:

- to take and retain an accurate fine detailed shape,
- it must be easily separated from the glass without sticking to the surface of the glass,
- to take thermal shock after applying very high temperatures such as 1150°C and continued firing for some time at a temperature of 830°C.

The results of these studies have been described in the subsequent sections of this chapter.

Also, a very important element in the deliberation on applications of metal inclusions in glass was to develop appropriate firing programmes for glass sculptures with these applications. Basically, it is known that metals have different melting and annealing points compared to each other, and also to glass. So, to reconcile the often-contradictory characteristics of these materials separate firing cycles have been programmed for the combination of different metals or metal alloys and glasses. Achievements in this area have been described in section 4.5 (p.172).

4.2.1. Manufacture of high temperature resistant moulds

Artists do not normally need, the expensive permanent moulds, which are used in factories, as they are rarely concerned with long production runs, so they tend to make their own moulds. Moulds produced in the artists' studios must be specifically adjusted each time to the requirements of the current projects which they run. The recognised requirement for this project is to manufacture high temperature resistant moulds. The literature review and numerous interviews with artists show that these kinds of moulds produced by the artists are resistant to change to 900°C.

It has been identified on the basis of previously conducted experiments that the best technique of applying metal inclusions in glass is the hot pouring glass method because of the preservation properties of metal and the least damage to the structure of the material.

One of the artists who works with the hot pouring glass technique is Bertil Vallien. He is considered as the first artist to use sandcasting methods for hot pouring glass. Thanks to him, in the 1970's and 1980's there was a huge development of this technique. His method provided enough time for preparation of the moulds with control of details for design of internal space in the object before and during the process. Also, this method allows better utilization of inclusions, but does not allow the reproduction of fine detail and clarity of the surface of the whole sculpture. Usually a thin layer of sand adheres to the surface of the hot poured glass in the sandmould. The reason for this is the very high temperature of glass which is around 1015°C-1020°C.

In this research, what is very important is the utilization of metal inclusions and at the same time to obtain a visibly detailed surface of the final glass sculpture. To obtain these fine details a refractory investment mould should be employed, made from components which would enable the reproduction of these details.

Refractory investment moulds used by artists for kiln forming glass are manufactured from materials that are able to withstand quite a long time at high temperature between 780°C and 950°C (Thwaites, 2011; Lundstrom, 1989; Cummings, 1998), for example: alumina, grog, ludo and fine silica in the form of quartz and flint (Thwaites, 2011, p. 27). In the case of this research the mould has to be able to withstand a long time at high temperature and as well has to be able to handle thermal shock in 1015°C-1020°C temperature of pouring hot glass into it.

A refractory is a material that can withstand high temperatures and it would not melt. However, to comply with the research terms and conditions, it should not stick at all to glass too and on top of it should be able to reproduce the fine details of the final glass sculpture and strong enough not to crack during the casting and hot pouring glass process. Most experiments were carried out on small moulds. Nerveless it additional modifiers were considered for big moulds too.

Refractory investments moulds are composed of three basic components which have been given different names by different authors. In this study, the chosen classification of these components was as follow: binders, refractories and modifiers. The refractories occupied the most important part in these investigation, nevertheless it would not be possible to establish appropriate recipes suitable for this project without exploration other components and their proportion in these recipes, to best comply our needs.

Usual conditions and functions which must comply with refractory moulds for kiln-forming glass seem to contradict each other, and in the case of this research these terms function opposed to each other even more. As already mentioned none of the known recipes meet our expectations. Angela Thwaites in her book (2011) gives many recipes that have been explored in this study, unfortunately none of them fulfil our requirements and it was established that some of the recipes required improvements.

In addition, this research considered a ceramic shell process mostly used for metal casting explored by: Richard Rome and Hamish Young (2003), as well as crucible casting in Lundstrom's book (1989) and furnace maintenance by Henry Halem (1996).

Glass students from the University of Sunderland manufactured moulds mostly with a mixture of molochite – 120 (calcined kaolin) and Pottery plaster in proportions one to one in weight. Basically, it is known that the plaster and molachite -120 start to melt at fairly low temperatures, the plaster at ~700°C when malachite at ~900°C. Plaster unfortunately satisfies the very important binder role. Its principal properties are cohesion and adhesion to unite other materials in mould mixture. Therefore, deliberations have focused on minimizing plaster participation in the mixture, because it is not possible to eliminate plaster, to avoid the influence of melting the material on the surface of the glass. It was decided to develop an appropriate mix for the application of the first layer of moulds which would separate glass from the rest of the mould.

Preliminary experiments were carried out with applying kiln wash as refractory component, as a separator between glass and main body of mould, with very good results. Regrettably if it was applied by brush, spray or even high-pressure spray it covers the delicate surface of mould and the fine detail of the mould surface were lost during this process. It was decided that to keep the detail, a mixture of kiln wash with much less water than usual is added, and must be applied directly on to the master mould (Figure 85, p.160).

Figure 85. Kiln Wash as a separator and refractory component.

But it also did not bring the expected results because if the layer of kiln wash was left for some time to fully dry it started to crack, on the other hand if next the layer of the mould was put on the still wet layer of kiln wash that the kiln wash was not be able to dry out fully and some soft parts stick to the master mould (Figure 86, p.161). After putting back, the damaged parts of the mould in their place by hand, the mould was repaired and after firing, the surface of the glass was clear but lost the details of the human skin. This method was time consuming and still was not the perfect solution, especially in terms of larger forms or complicated patterns on surface of mould.

Figure 86. Hand repaired surface of mould made from 50% Kiln Wash separator.

To improve the performance of the first layer of separator, attempts were also made with other materials resistant to high temperatures, which were known for their greater flexibility than kiln wash. For the last two years, I was working in Moscow, Russia. I noticed that materials used in the University of Sunderland studio were not available there, but other powders were accessible, such as ready-mix Cristalcast 248 or Hydracast Crist. Most of these media contained components such as alumina and kaolin, only in different proportions. It has been found that each of these components brings some improvement but it’s still necessary to add kiln wash and some binder to unite and to increase adhesion between these components in the mixture of the first layer.

4.2.2. Investigation for high temperature resistant layers – a separator between glass and mould

To get around numerous contradictions that arise during the construction of moulds, the best way of bypassing these problems will be introducing additional layers – separators between the glass and the main body of the mould. Experiments showed the best material capable of this is the shelf wash and/or china clay with the addition of Nitride Boron on top of the surface of the mould (Figure 87, p.162 & Figure 89, p.163).

Figure 87. Three types of separators: Kiln Wash, Nitride Boron, and only 1% of Kiln Wash in usual mixture used by students in the University of Sunderland.

Figure 88. After firing three moulds are with very clear glass.

Figure 89. Boron Nitride – white graphite used as separator between glass and mould.

Best results were obtained from the separator Boron Nitride (white graphite) sprayed on the surface of the mould, where the first layer was made of Cristalcast 248 with addition of 1% the kiln wash and 10% Potter Plaster (Figure 89 left, p.163). Also, quite good results were gained with a first layer made from Hydracast Crist with the addition of 1% kiln wash and 10% Potter Plaster (Figure 89 right, p.163). Hydracast Crist was designed for casting metals and moulds made from this powder are quite inflexible. It was necessary to soften the mould so that cast glass had space to breathe during the hot pouring and cooling process.

4.2.3. Development of a pouring hot glass method into the mould

It was noted that during the pouring of the hot glass into plaster moulds arise numerous gas bubbles in the glass (Figure 90, p.163). Among glassmakers it is a known phenomenon, that caused the technique of pouring the hot glass into a mould be avoided.

Figure 90. An effect of the pouring hot glass (1020°C) into the plaster mould.

This problem was known, but it was not possible to find answers in the literature, if there's any way to prevent it. Experiments have been carried out with: mould components, separators between the mould and hot glass and firing programmes (Figure 87, p.162). These methods did not provide enough good results, bubbles were smaller, but still intensively formed in the glass. It turned out that the best method of controlling this phenomenon is the firing of the empty mould in the highest temperature, e.g. ~ 850°C for three hours before hot glass was poured into it. Even better results can be obtained by placing a small amount of glass in the cold mould, cast it to 840°C so that the melting glass will cover the surface of the mould (Figure 87, p.162). The glass layer is the separator, which reduces thermal shock during the pouring of the hot glass (Figure 88, p.162 and Figure 91, p.164).

Figure 91. The method of the hot pouring glass into plaster moulds.

4.3. Lubricants and Separators for metal and glass

The research has shown that two of the major challenges to inserting metal into glass are oxidation on the surface of the metal and the different coefficients of expansion can lead to the cracking of the glass. To avoid this happening, it was decided to attempt to form a barrier between the metal and the glass which would allow the metal and glass to move over each other without sticking or reacting.

A serious problem in the process of fusing metal in hot glass is accelerated oxidation of the material under the influence of high temperatures. The best method of preventing this process would be the opportunity to get rid of oxygen from the kiln during the glass kilnforming process. It would be possible to carry out this method in industrial conditions, but artists' studios do not have such capabilities. This why the research has been focused on finding other techniques of shielding metals surfaces to prevent them from oxidation. This can be achieved by using exact matching of the shape of the metal and glass surfaces so that they adhere tightly to each other. One way to succeed in this was the use of pouring hot glass that captured the metal immediately or using a Waterjet to cut out matching shapes in metal and in glass in their cold stage (Figure 92, p.165).

Figure 92. Metal inclusion and glass cut by WaterJet, before and after firing.

The third method is to hot pour metal into the Waterjet cut glass. This method is applicable with metals with low melting point, such as lead, tin and gallium (Figure 93, p.166).

These three techniques with their advantages and disadvantages are described below. But the use of these techniques is not always possible. Therefore, surrogate methods have been developed which protected the metal against penetration by oxygen during firing thorough applying a thin layer of coating material.

Figure 93. Hot pouring Lead alloy into Float glass cut by WaterJet.
Lead alloy inclusions were prepared in Harison & Harison Company workshops.

A very important element in achieving the expected effects was to protect the metal from oxidation during exposure it to thermal processes. Building on practices in metalsmiths' industries to achieve the best effects, the first step was to clean the metal of any impurities on the surface with special attention to the greasy ingredients, then cover the metal with a suitable layer. Methods used in industrial conditions are very expensive and very difficult to adopt by artists. So, it was necessary to find a surrogate method to allow artists applying metal inclusions in artists' studio conditions.

These methods should always be applied after metals sheet are cut to the wanted shape for an inclusion. It should be cleaned by washing with detergent and warm water and next it should be bathed in a pickle solution for about 20 minutes. This can be prepared from vinegar or lemon juice (EHow Contributor, 2009). After that process the metal, should not be touched with bare hands to prevent introducing any new grease back on the cleaned surface. Also, the surface should be kept dry.

To prevent oxidation of metals the following methods can be used: the pouring hot glass or the Waterjet cutting technique or coatings of metal with separators or lubricants, such as Borax, Flexi-glass medium, jewellery enamels, graphites, Overglaze, Silver Flakes, clear varnish or even transfers.

Clean metal shapes can be coated on both sides with a separator/lubricant, which are commercially available chemical compounds or similar metal-treating products. Alternately, a clear glass paint can be used to coat and protect the metal. The metal should be dry before it is placed into the kiln for the firing process.

In hot studios, craftsmen, to stop the glass sticking to plaster or metal moulds are using Graphite which is a black spray. It is a universal lubricant used in industries for lubrication of sliding mechanisms, conveyor belts or in glass studios as a release agent for different kinds of moulds. The graphite when dry leaves a black film on metal surfaces (Figure 94, p.167).

Figure 94. Nickel 825; one with layer of black graphite, one with white graphite.

Experiments have shown that the black graphite prevents glass sticking to surface of metal, but it leaves black residue (Figure 95, p.167).

Figure 95. Nickel 825 alloy with layer of the black graphite.

In glass industries to stop the glass sticking to stainless steel moulds Boron Nitride Spray is used, which is also known as white graphite (Figure 94, p.167), It is more expensive, but it gives better results than black graphite. Experiments showed that the spray gives better results for applications of nickel alloys in high temperatures. These metals inclusions during the heating process changed colour, they turned to gold-brown (Figure 96, p.168).

The metal inclusion covered with graphite lubricant should be placed on the first layer of the hot glass to give time for gases to escape, to avoid the bubbles in the second layer of glass.

Figure 96. Nickel 825 with coat of the white graphite.

The intention of the experiment was to show, how different nickel alloys, with different kinds of pre-treatment in similar circumstances will react. It is visible, that the best visual results were shown by the inclusion of pure nickel, after that with white graphite on Nickel 825 (Figure 97, p.168).

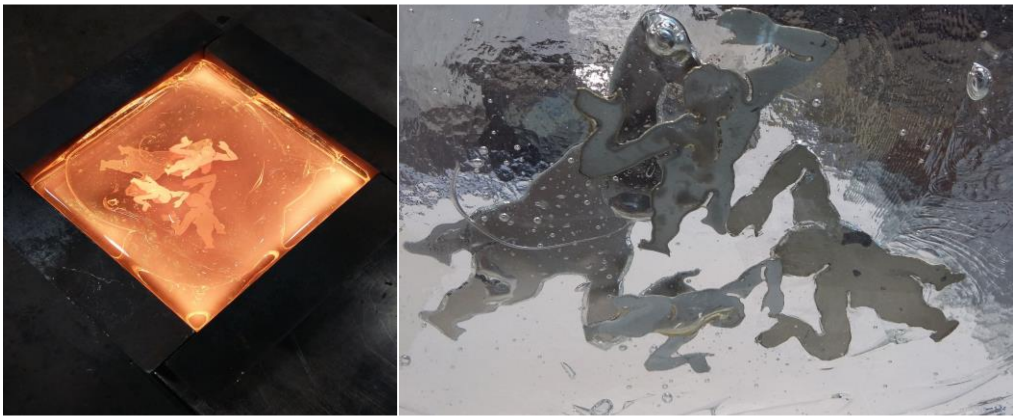

Figure 97. Nickel 99.9% annealed and variety of nickel alloys some with lubricants captured in Cristalica glass.

Experiments were also carried out using Borax as a lubricant/separator. Borax was effective from point of view regarding metal and glass compatibility. However, the results were unpredictable and the gas bubbles were difficult to control (Figure 98, p.169).

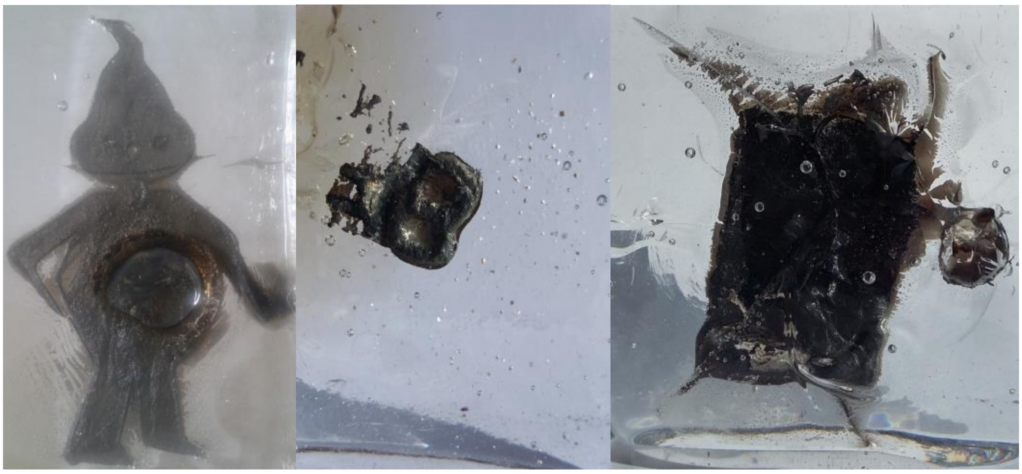

Figure 98. Using borax as a lubricant/separator on nickel alloys

Transfers and inks were also tried with the transfer patterns being introduced to the metal prior to the metal being used as an inclusion. These experiments followed my previous experience of the application of silk print images (Figure 5, p.24 and Figure 9, p.29). These images can act as lubricants as can be seen in Figure 99 (p.169).

Figure 99. Using ink transfer as lubricant.

Silver flakes can be used as separators too, (it is possible only by applying the hot pouring method), also it can be used as an inclusion itself and retains its appearance.

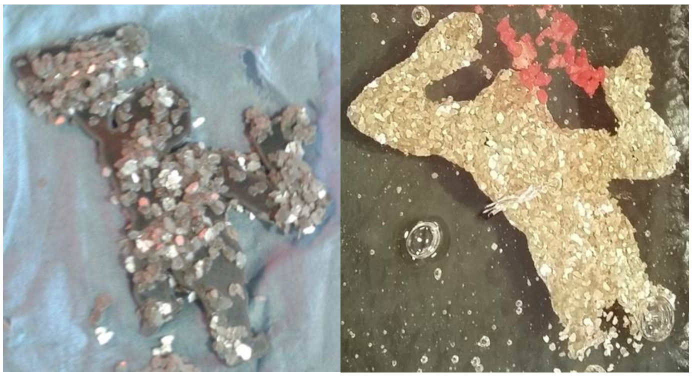

Figure 100. Silver Flake as separator (left) and as image itself.

Gallium can also be used as both a separator and in its own right to produce inclusions (Figure 65, p.135). But then gallium reacts with some materials during the heating process. For example, it turned nickel to powder (Figure 101, p.170).

Figure 101. Gallium and nickel 99.9% cast as inclusion in hot glass

Both Silver Flake and gallium only can be apply by the hot pouring method. If it is used in the cast glass process they lose the quality in appearance (Figure 66, p.135).

Separators/lubricants are useful materials in the process of application of metal in glass, however most of them change the surface appearances of the metal inclusions giving an additional textural aspect to the artistic practice.

4.4. Development of tools for applications of metal inclusions in the glass

As previously mentioned, the metal inclusions have carried many problems such as: bonding materials to each other, a difficulty to control the shape of inclusions, oxidation and rusting metal surface during the heating process. To solve these problems, it was necessary to develop new methods for applications available in the studio and the creation of tools for the needs of research. The best way to avoid oxidation of the metal inclusions during heating is to protect the metal from air. This can be achieved by the tight fit inclusions in the glass. The metal and glass have been cut by WaterJet, but only, if the applications will be by fusing, or cast glass processes (Figure 92, p.165). But if the hot glass pouring method was applied, it was necessary to develop stamps in the shape and size of the metal inclusions to make an indentation in the hot glass that the inclusion exactly fits into (Figure 102, p.171). These stamps, with frequent use at high temperatures, should maintain unchanged shape and surfaces. The Nickel alloy; Cronifer 1925, in the form of a 3-millimeter-thick sheet, has met these conditions (descriptions in Chapter Three, p.106), and therefore was selected for the production of stamps.

Figure 102. Stamp in shape GB to make indentation in hot glass.

Figure 103. Stamps and a Lead and Tin inclusions cut by WaterJet.

These stamps were cut out from the Nickel Cronifer 1925 alloy sheets using the WaterJet and Stainless-Steel handles were welded into it.

4.5. Firing programmes

In this section, the problems accompanying the firing process were considered. The annealing component of the firing process needs special consideration. Each object was treated separately, due to: the process used, combinations of types of glass and metal, the size of object.

4.5.1. Annealing of metals and glass

Annealing is a process for controlling a cooling temperature to release the tension created in the material during heat treatment or the mechanical treatment. This is a general definition from metallurgy technology books, which is not precise enough, if we consider the specific materials such as metals, when solids are crystalline in form, or a glass with its amorphous (a non-crystalline) structure, when is in its solid state.

Definition of annealing glass: "Annealing is the process of controlling the cooling of the glass, so that stress is removed and the glass won't crack once it cools to room temperature" (Walker, 2010, p.63).

Annealed window glass is much softer than the chemically similar toughened or tempered glass. One of the methods to get this glass is a process by quenching almost molten glass in a heated bath (Pilkington, 2010). But this type of glass carries with it the problem of nickel sulphide. This stone, if not properly annealed, can be a cause of cracking glass

Definition of annealing metals: "Annealing is a heat process whereby a metal is heated to a specific temperature and then allowed to cool slowly. This softens the metal which means it can be cut and shaped more easily" - from a dictionary for teaching of Design and Technology in schools (Ryan, 2005-2009).

Annealed metals usually have a lower hardness and good ductility. Nickel, like copper or silver does not tend to become as hard and brittle when it is deformed (for example bent), as do most other metals. Because of these attributes, it was decided to choose nickel in the research, but in its annealing stage.

In both cases annealing is a positive action, because the material softens and tones. It means that it should be easier to combine these materials. But how to define the annealing temperature for both materials in the same process, if they have different stress points temperatures (this is the temperature at which it begins to release internal stress of material). The glass manufacturers usually recommend an annealing temperature, but they change it regularly or it is not strictly defined. For example, Cristalica glass on their leaflet has 510°C, then in an interview with Mr Peter Kuchinke (2016), he is the expert, who developed the glass recipe, advised me to start the annealing from 515°C. Metals also require precise annealing, especially during a cooling, to switch from beta to alpha stage gently, especially, if they are used as inclusions, that it can be avoid further tensions in the glass. It involves heating a material to above its recrystallization temperature, maintaining a suitable temperature, and then cooling (Skrzypek, Przybylowicz, 2012, p.412). To define precisely the recrystallization is difficult, because the process is related to several other processes and it is very problematic to state the point at which one process begins and ends (Skrzypek, Przybylowicz, 2012). Furthermore, this recrystallization temperature decreases with annealing time.

Element (Alloy)	Lead	Tin	Zinc	Aluminum	Nickel	Chromium	Iron
Recrystallization Temperature ⁰C	**-4**	**-4**	**10**	**80-150**	**370-600**	**200**	**450**
Melting Point Temperature ⁰C	327	232	420	660	1453-1455	1085	1538

Table 19. Recrystallization temperatures.

Data was collected from different resources.

Lead, tin and zinc recrystallize below room temperature – so the recrystallization temperature was not considered in these cases, but only the melting point (it means that a metal is turning back from fluid to solid stage), because it is lower than the melting point of glass.

Metals require differentiated annealing programs, often incompatible with programmes for glass itself. In such situations, it was more important to concentrate on appropriate firing programmes for glass to reduce the tension caused by metal inclusions, because glass undergoes greater pressure during the process and it is less resistant to stress, particularly tensile stress.

4.5.2. Firing cycles suitable for applications of nickel and nickel alloys

A specific problem with nickel could arise if any sulphur is present in the glass - nickel sulphide forms low melting point inclusions (that are actually difficult to see) and which due to a phase change may cause fracture in specific circumstances - if the glass is fully annealed this should not be a major problem but could still cause interior cracking. This was by Professor Russell J Hand, President of Society of Glass Technology (2014). It is basically known that most of the leaflets which are attached to products by manufacturers and distributors often do not list all the chemical ingredients. In this case, further exploration using Analytical Scanning Electron

Microscope methods were used to make sure whether the nickel sulphide inclusions problem should be considered in the research. Unfortunately, both types of glass: Gaffer and Glasma used in the research showed the presence of sulphur, even if distributors and producers of these glasses did not mention this ingredient. Kenneth Svensson,VD/Managing Director of Glasma AB confirmed (2013) that their recipe contains sodium sulphate, also the Cristalica glass contains sodium sulphate, but it was not possible to get confirmation about it from the manufacturer of Gaffer glass. Information that this component occurs in the glass used in the study is very important, because it has been noted by Young (2008) that one of the metals which sulphidize faster than they oxidize at 800°C is nickel. He stated in his book that nickel sulphidation is extraordinarily rapid.

Nickel sulphide is an interesting compound that, like many compounds, exists in different phases at different temperatures. Relevant to this research are two specific phases of NiS, known as the alpha-phase and the beta-phase. At temperatures below 379ºC, nickel sulphide is stable in the beta-phase form (Jacob 1997). Above this temperature, it is stable in the alpha-phase. As a result, when glass is produced in the furnace, it is extremely likely that any NiS inclusions will be in the alpha-phase. In typical annealed glass, the slow cooling process provided by the annealing, allows the NiS to transform to its beta-phase as the glass cools. Nevertheless, in the fast cooling process there is insufficient time to complete the phase transition (which should be a rather slow process). The inclusions consequently are “trapped” in the glass in their high-temperature alpha-phase. This would have no effect on glass at all except that the NiS changes from alpha-phase to beta-phase, it increases in volume by 2-4%. This expansion creates localized tensile stresses that are estimated to be quite high at the glass-NiS Interaction surface (Jacob 1997). According to Jacob this may cause some micro cracking of the glass around the stone. In compression zones, even this large a stress is not a concern due to its extreme localization. However, in the core tension zone of the glass, these micro cracks are propagated by stress concentrations at the tip of the crack until the arrangement of the glass is undermined completely and the tempered glass starts its characteristic shattering, which causes the apparently unstructured failure (Jacob 1997).

Nickel sulphide is a compound that comes in various forms. Recently extensive research has been done into the ratio of different elements in compounds and how this could affect glass itself. The most common forms of NiS encountered are Ni_7S_6, NiS, $NiS_{1.03}$, Ni_3S_2 and Ni_3S_2+Ni. The first three types are non-magnetic and have been found to cause failure in tempered glass. Ni_3S_2 and Ni_3S_2+Ni are magnetic and have not been found to cause failure in tempered glass. Barry and Ford (2001) in their article discuss different types of NiS inclusions from the perspective of chemical composition and surface roughness and which ones are dangerous in the production of glass. Additionally, other metals components, particularly iron contamination in nickel sulphide inclusion can slow the transition process from alpha-phase to beta-phase compared with pure nickel sulphide (Jacob 2003). Each glass sheet is heat soaked to minimize the risk of spontaneous fracture due to the sulphide and nickel content. The heat soak process is carried out in accordance with DN 18516, Part 4, which specifies an 8h process at between 280°C and 300°C (Rice, Dutton, 1995, pp 100). Taking all the above-mentioned conditions into account and conditions relating to other problems associated with the nickel applications in glass suitable firing program was created (Chapter 5). However, the basis for that, constituted the general program-developed by the masters: Brychtová and Libensky to annealing glass (Figure 104, p.177).

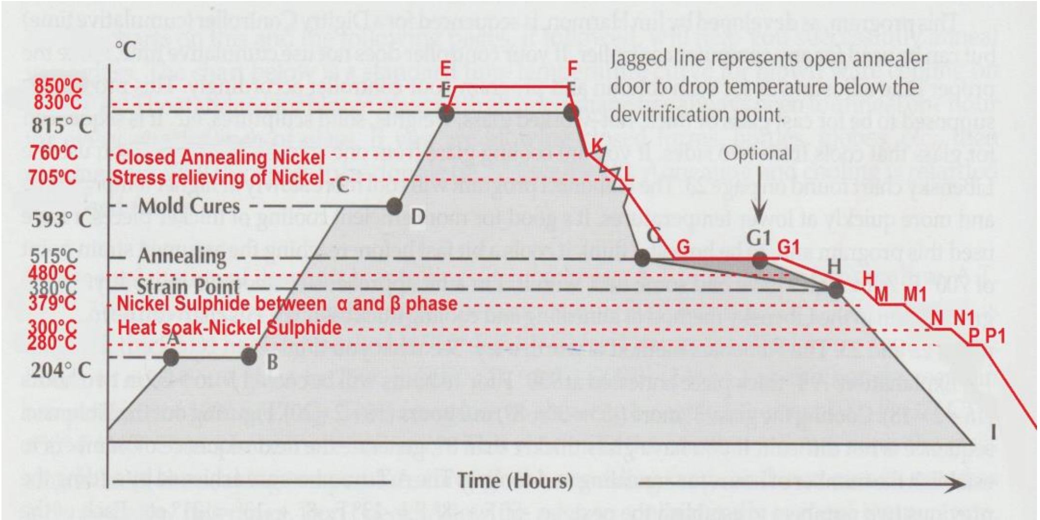

Figure 104. The Firing program for application of the nickel inclusion in glass

--- Brychtova and Libensky the annealing cast glass program (Halem, 1996, p. 22);

--- Nickel application in glass the firing program developed by researcher.

*The timing of the individual stages of the program depends on: type of glass; shape and thickness of glass object; the kind of metal used as an inclusion, shape, thickness and size of inclusion.

The time of annealing should be calculated for the thickest part of the object (see Appendix 1, p.238).

4.5.3. Firing cycles suitable for applications of tin and lead alloys

During the application of lead and tin alloys in glass by cast or fused method it was important to determine the appropriate program which would prevent gravitation of the metal to the bottom of the mould. In the case of Pilkington glass the firing program was developed from the research by Joanne Mitchell (2017), who solved problems in her research with air bubbles inclusions.

Joanne Mitchell's program (2014) is a variation on firing for test tiles up to 5 x layers of 4mm Pilkington's Float Glass (approx. size 7 x 10cm, with pierced cut-outs up to 20mm x 70mm) in the University of Sunderland Kiln 19 (Kilncare 9kw with FK4 Thermocouple). Developed programmes for the purposes of this research are different because experiments were carried out due to the applications of lead and tin alloys inclusions rather than air bubbles. During the fusing, air bubbles inclusions occur when the glass is soft enough flowing up, when lead and tin alloys behave opposite way than air. Lead is much heavier than glass and gravitation causes dropping of lead to the bottom of a mould. Correspondingly, the metal is a much denser material than air and it needs more annealing time than air, which means that it should be considered, and the corresponding cooling of the metal and glass adjusted at the same time. But lead alloy produced gases during the heating process and the gas bubbles are behaving as the air bubbles, this is why Joanne Mitchell's program (2014) considers this point. In experiments developing Mitchell's programme with 5 sheets 4mm glass with two layers of lead and tin inclusion with black ink marks on the surface of the metal and size of the object 20 cm x 15 cm x 2cm; no gas bubbles distorted the glass (Figure 105, p.178).

Figure 105. Fuse Pilkington glass with two layers of Lead and Tin inclusion.

Glass and metal was cut by WaterJet.

Then tests were carried out with 6 mm Pilkington glass with a size of 70cm x 30cm x 3.6cm (Figure 106, p.179). But unfortunately, the programme did not work for objects thicker than 2cm. It was necessary to develop a suitable programme for fusing the 6mm Pilkington optifloat glass with lead and tin inclusions in a cast kiln (Table 20, p.180).

Figure 106. Fusion of Pilkington Optifloat glass with Lead and Tin alloys inclusions.

Ramp	The fusing program Lead and Tin inclusions in 6 sheets 6mm thick of Pilkington optifloat glass	
1.	↑50°C →520°C 1h	
2.	↑30°C →671°C soak 4h	This slow ramp/soak between 520-670°C aims to even out the heat throughout glass, and 'bubble-squeeze' through the bending point up to the softening point of float glass, which is 715°C
3.	↑Full → 800°C 1h As fast as is possible, but minimum 150°C	800ºC maximum 1h to limit the time when glass would be too soft and Lead alloy could gravitate to bottom of glass (because Lead is much heavier than glass) and gas produced during heating process would not flow up through glass. But on the other hand, to give time to fuse glass properly
4.	↓Full→590 °C	As fast as possible
5.	↓8°C →548°C soak 10 hours	548°C - the annealing temp of Pilkington's 'optifloat' – was increased soak to 10h, because the thicker float glass plus metal inclusion, which should be cooling longer then glass.
6.	↓4°C →511°C soak 6 hours	this is strain point of Pilkington optifloat glass
7.	↓8°C →340°C soak 2hours	the ramp was added because of inclusion of Lead. It was decided that it is better to slow down

		cooling before lead melting point to stabilise temperature in whole object
8.	↓4ºC→330ºC soak 6 hours	327.5°C this is lead melting point temperature, it means that lead turn from liquid to solid. It was decided that it is better to increased soak in 330°C point to balance temperature inside and outside the glass
9.	↓4°C →230°C soak 6 hours	232°C this is tin melting point temperature. Inclusions are made from lead and tin alloys: 30%lead/70%tin, 50%lead/50%tin and 70%lead/30%tin
10.	↓6°C →210°C soak 6 hours	To stabilise temperature in whole object and to give time to tin alloy to turn from liquid to solid
11.	↓25°C →30°C	End

Table 20. Firing program - fusion of Pilkington Optifloat glass with lead and tin alloys inclusions.

This programme would not work for Gaffer, Glasma and Cristalica glass which have completely different properties to Pilkington’s Float Glass. General glass from the furnace is not suitable for fusing lead images between sheets of that glass, because is much softer and lead alloys gravitate to the bottom. At this point, it was decided that the best method to cast successfully lead in Glasma glass is employing hot glass pouring into moulds methods. In this case during the heating cycle a programme for heating empty moulds and cooling and annealing was specially crafted for lead and tin inclusion purposes.

Properties of Cristalica Glass are: the annealing point is 515°C and the strain point is 380°C and the lower strain point is 320°C, and the lead melting point is 327°C then these two points can be combined together in one ramp. It means that ramp from 7 to 11 (Table 20, p.180) are the same as for Pilkington glass (of course in both cases depend on thickness of the glass and the metal inclusion).

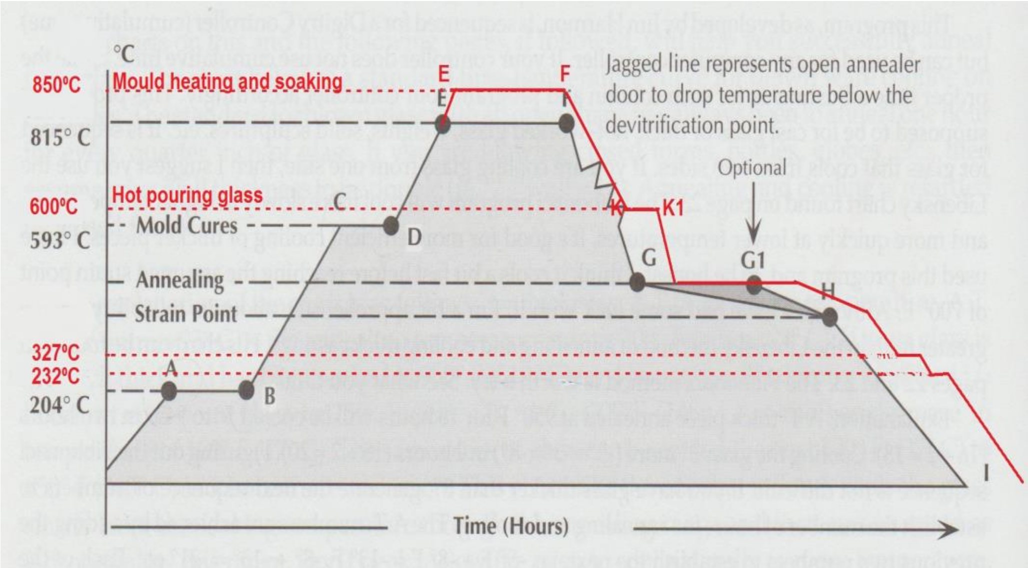

Figure 107, The Firing program for application of the Lead and Tin alloys inclusion in glass

--- Brychtova and Libensky the annealing cast glass program (Halem, 1996, p. 22);

--- Lead and Tin alloys application in glass the firing program developed by researcher.

*The timing of the individual stages of the program depends on: type of glass; shape and thickness of glass object; the kind of metal used as an inclusion, shape, thickness and size of inclusion. The time of annealing should be calculated for the thickest part of the object (see Appendix 1, p.238).

4.6. Summary of the new methods to apply the metal inclusions in the glass

This chapter describes experiments and developments made around the process of inserting metal into glass with the aim of making it more efficient and practical. Some of the findings have made a unique contribution to artistic practice. For example, the development of a technique for pouring hot glass into the plaster mould without producing glass distorting bubbles (Figure 90, p.163) that was previously thought impossible.

Experiments have also been carried out which have incorporated the heating and annealing processes of both glass and metal to produce bespoke casting processes for various combinations of metals and kinds of glass. These processes can then be used with high temperature resistant moulds (section 4.2, p.157), separators/lubricants (section 4.3, p,164) and metal stamps (section 4.4, p.171) to eliminate the sticking of glass to the moulds in a studio setting. By the application of different lubricants and separators, the experiments also addressed the major problem of oxidation and corrosion of metals.

By addressing these challenges with experts help and experimentation it has been possible to introduce industrial processes to creative practice and thus extend the options available to artists for working with metal and glass in the workshop.

5. Nickel 99,9% and lead and tin alloys inclusions in glass

The most promising results have emerged from the research with nickel, and lead and tin alloys. These are described in this chapter, along with the outcomes of investigations covered in Chapter Three (p.106) and Chapter Four (p.155). The chapter also explains the development of methods to control the application of these metals as inclusions in glass.

5.1. The application method of nickel 99.9% as inclusion in glass

The first step of the application of nickel 99.9% as an inclusion in a glass sculpture was to cut the 0.5 mm thick sheet of Nickel 99.9% inclusion by waterjet to an earlier designed shape (Figure 108).

Figure 108. Nickel 99.9% inclusions cut by WaterJet

The waterjet cutting leaves sharp edges of metal, which can cause stress in the glass during the casting process. Glass hooked on these edges will not be able to shrink independently of the metal during the cooling process. Therefore, the sharp edges of the metal should be filed, and then the surface of nickel should be washed, in order to avoid the glass sticking to the surface of the nickel. Metal inclusions were cleaned by washing them with detergent and warm water and next they were bathed in a warm vinegar solution for about 20 minutes to get rid of any impurities with special attention to the greasy ingredients, then the surface was dried. But at this stage inclusions cannot be touched with bare hands.

An illusion of a third dimension can be added with ink or engraving drawings to the flat surface of inclusion. In the case of engraving, a surface of inclusions should be re-cleaned and if the metal is less than 99.8% pure it would be worth covering it with devitrification spray to reduce stress between the glass and metal (Figure 109, p.184).

Figure 109. Applications on the Nickel inclusions.

Hot pouring glass process; The high temperature resistant moulds (section 4.2, p.157) preheated in a kiln (Figure 110, p.184). To obtain better results a small amount of glass should be placed in the cold mould and heated to 840ºC so that the glass will cover the surface of the mould. The mould is cast overnight at 840ºC and then soaked at this temperature for three hours (Figure 111, p.184).

Figure 110. The high temperature resistant moulds.

If the loaded mould is without glass it should be heated to a higher temperature, around 850°C and after that the temperature should be dropped to 830°C. In line with the bespoke heating programme described in Chapter Four (p.155).

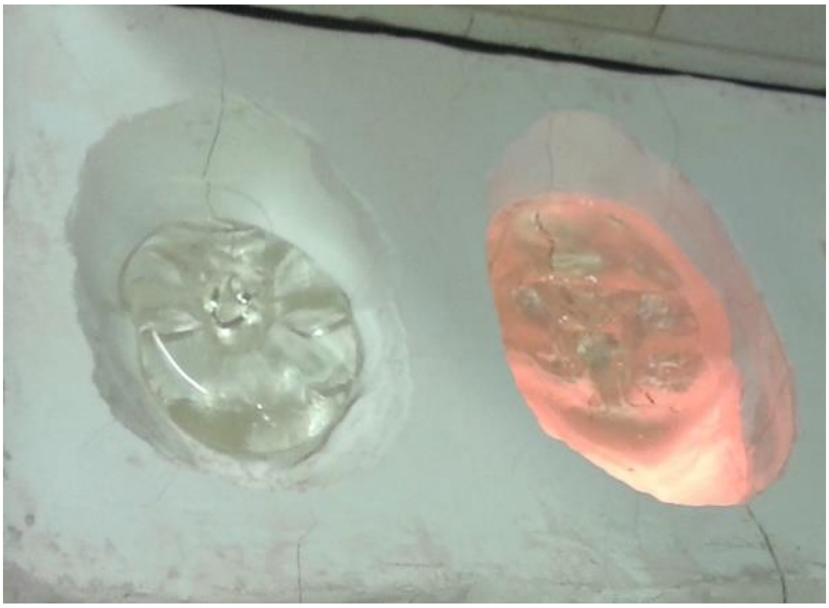

Figure 111. Moulds: left - with heated glass in and right - with poured hot glass during cast process (830°C)

Application of inclusions: nickel inclusions can be placed using long tongs directly in a hot kiln. But, it is safer, to prepare embedded metal in hot glass, in the shape of a brick and put it in a hot form (Figure 112, p.185).

Figure 112. Preparation of the glass brick with Nickel inclusion.

Some big gas bubbles produced during the application of metal inclusions in glass, can be reduced by heating the bubble with a gas lamp to realise gas from glass (Figure 113, p.186).

Figure 113. Process of releasing gas bubbles using gas lamp.

The brick is then placed on top of the first layer of glass in the mould. Then the mould is filled with hot glass (1020°C) using a ladle until the glass reaches the edges of the mould (Figure 114, p.186).

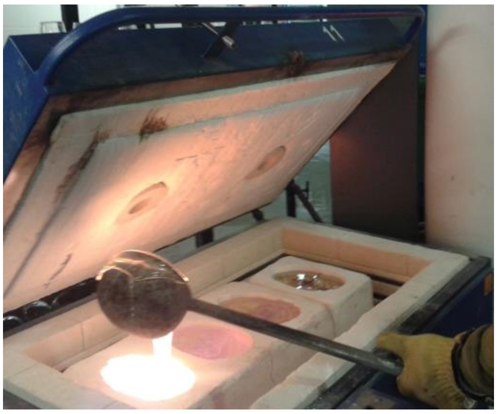

Figure 114. Mould is filled with hot glass (1020ºC)

The next stage involved ventilating the kiln to reduce the kiln temperature to 760ºC, just before beginning the annealing process of the metal (step 5 in Table 21 below).

Ramp	The hot pouring glass, cast and annealing program The Nickel inclusions in Cristalica glass	
1.	↑ 50°C →204°C 3h	This ramp/soak in 204°C aims to dry the moulds slowly.
2.	↑ 100°C →593°C soak 4h	Moulds cures in 593°C for 4hours. Chemical water evaporates slowly that moulds do not lose their strength.

3.	↑ 100°C → 850°C 3h	It is necessary to cast empty moulds in the temperature 850°C for three hours, that most of gases could evaporate.
4.	↓ 150°C →820°C	Hot pouring glass in moulds and application of nickel inclusions in glass.
5.	↓100°C →760°C ↓ 50°C →705°C	Nickel 99.8 must be annealed between 760ºC and 705ºC
6.	↓ 50°C →520°C soak 6 h ↓ 4°C →515°C soak 6 h	515ºC - the annealing temp of Cristalica glass – but it is necessary to start annealing earlier to be sure that glass and metal inclusion have the same temperature.
7.	↓ 4°C →480°C	To get equilibrium condition for metal during cooling
8.	↓ 4°C →380°C soak 6 h	380°C it is the Strain Point temperature of glass and additionally at temperatures below 379°C, nickel sulphide is stable in the beta-phase form
9.	↓ 8°C →320°C soak 6h	The Lower Strain Point temperature of glass; longer soaking to balance temperature inside and outside the glass
10.	↓ 8°C →300°C soak 6 h ↓ 2°C →280°C soak 6 h	16h process between280°C and 300°C to minimize the risk of spontaneous fracture due to the sulphide and nickel content
11.	↓ 8°C →200°C	
12.	↓ 16°C →100°C	
13.	↓ 25°C →30°C	End

Table 21. Firing program – Hot pouring Cristalica glass into moulds with nickel 99.9% inclusions.

Once cooled, after two days, the mould can be open (Figure 115, p.188).

Figure 115. Mould before and after opening.

5.2. The application method of a lead and tin alloy as inclusion in glass

For a lead and tin alloys, the process of mould making, heating and soaking are the same as for nickel (4 Ramps; Section 5.1, p.183). But the cooling process is different. The mould must be cooled to a lower temperature than with nickel - around 600°C (ramp 4 in Table 22, p.36), because if the consistency of the glass is not thick enough the metal will gravitate to the bottom of the mould.

With lead and tin alloys, the glass in the mould is allowed to get to a thicker consistency before the metal inclusion is added. This is because a stamp is used to put the alloy into the mould. If the consistency of the glass is too watery then the shape of the stamp will not be retained. Once the glass is stamped the metal can then be put into the indentation and immediately covered with hot glass which seals the metal. The glass needs to be added immediately before the metal melts to creamy consistence. If the hot poured glass is very hot it reduces the chances of a prominent seam forming between the two glass layers (Figure 116, p.189).

Figure 116. Lead and tin alloys inclusions in Cristalica glass.

Ramp	The program for application of lead and tin alloys inclusions in Cristalica glass; the hot pouring glass process.	
1.	↑ 50°C →204°C 3h	This ramp/soak in 204°C aims to dry the moulds slowly.
2.	↑ 100°C →593°C soak 4h	Moulds cures in 593°C for 4hours. Chemical water evaporates slowly that moulds do not lose their strength.
3.	↑ 100°C → 850°C 3h	It is necessary to cast empty moulds in the temperature 850°C for three hours, that most of gases could evaporate.
4.	↓ 50°C →600°C	At 600ºC hot pouring glass in moulds and application of lead and tin inclusions in glass; the temperature is when glass would not be too soft that the alloy could not gravitate to bottom of glass. But on the other hand, to fuse glass properly.
5.	↓Full→520°C	As fast as possible
6.	↓8ºC→515°C soak 10h	515°C - the annealing temp of Cristalica glass.
7.	↓4°C →380°C soak 6h	this is strain point of Cristalica glass.

8.	↓8°C →335°C soak 2h	the ramp was added because of inclusion of lead. It was decided that it is better to slow down cooling before Lead melting point (327°C) to stabilise temperature in whole object
9.	↓4°C →330°C soak 6h	327.5ºC this is lead melting point temperature, it means that lead turn from liquid to solid. It was decided that it is better to increased soak in 330°C point to balance temperature inside and outside the glass
10.	↓4°C →230°C soak 6h	232°C this is tin melting point temperature. Inclusions are made from lead and tin alloys: 30%Lead 70%Tin, 50%Lead 50% Tin and 70%Lead 30%Tin
11.	↓6°C →210°C soak 6h	To stabilise temperature in whole object and to give time to tin alloy to turn from liquid to solid
12.	↓25°C →30°C	End

Table 22. Firing program – Hot pouring Cristalica glass into mould with lead and tin alloys inclusions.

The process of opening the mould is the same as for nickel (Section 5.1). The process of working with nickel and lead and tin alloy is the same at the beginning, the only difference is in the process of application of the inclusion and annealing of metal.

5.3. Summary of the application of nickel and lead/tin alloys as inclusions in glass in artistic practice

This chapter has looked at the best approach to adding metal inclusions in glass according to the aims of the research (section 1.3, p.36). It has highlighted the processes that needed to be designed and improved in order that metal application is able to be used in the artistic practice of the researcher (see artistic applications of metal inclusions in Chapter Six, p.192).

The process of including different kinds of metal has meant that different methods have needed to be explored. Nickel with its higher melting point requires a less complex approach than lead and tin alloy, which has a lower melting point than glass. Both nickel and lead and tin alloys are compatible with glass for use as insertions but both have different challenges that have been addressed in this research.

6. Application of the Research Findings in Artistic Practice

This chapter will reflect how the findings of the research have given the researcher a grounding for developing tools that can further her artistic practice of including metal into the internal space in glass. The initial findings have enabled the production of pieces that show the potential for illusively including metal in glass and developing further visually aesthetic effects.

This chapter relates to the first aim of the research to create a body of combined glass and metal tests and their application in artworks, and to demonstrate and articulate the possible creative and practical benefits of the new potential processing routes. In the initial testing phase, three potential process routes were tested in order to map creative parameters of combining glass and metal in a hot state. Examples of these tests are shown in the following sections.

6.1. Experimenting with application of the metal inclusions in artistic practice.

This section describes research investigating the effects created during the preparation of 2D shapes cut from metals, which were prepared to be inclusions in glass sculpture. The experiments employed and explored in a creative way the internal space in objects through the use of glass and inclusion of metals. Experiments were also carried out into adapting the internal space to apply the metal inclusions through experimenting with 3D effects using a variety of metal shapes (Figure 117, p.193).

Figure 117. Experiments with 2D shapes cut from metal by the waterjet to produce 3D effects

6.1.1. Experimenting with multiply layers of 2D cut-outs shapes

Inserted between the layers of glass are the overlapping 2D images (of different sizes in their outline shape) of lying men (Figure 118, p.193). This creates perspective and a feeling of deeper internal space. The viewer can look around the object and see the floating men with different perspectives from each side (Figure 119, p.194). Elements of these effects were used in the application of metal inclusions.

Figure 118. Experimenting with 2D images with the application of perspective, thus using an object to create a false visual impression

The aim of these experiments was to introduce the illusion of depth in the sculpture by playing with perspective and manipulating the optics. The location and size of inserted images in the glass object were varied.

Figure 119. Objects creating illusionary perspective effects

6.1.2. Experimenting with applying the rules of drawing perspective in 3D objects

What interested me in these studies was the use of perspective in sculpture. Perspective is a drawing method that shows how things appear to get smaller as they get further away. It is a drawing of 3D objects upon a flat surface so that they look three-dimensional and realistic. And what happens if it is applied in 3D shapes.? Is it possible to convert a 3D into a 4D object by illusionary perspective effects?

Figure 120. Goshka Bialek, Illusion of space, 2016;

Lead grey glass and nickel alloys inclusions; H50cm x W40cm x D5cm; Photographed by Joanne Howell.

In this perspective (Figure 120, p.195), the figure looks out of proportion, but the proportions of the figures vary depending on the point of looking at it (Figure 121, p.195).

Figure 121. Goshka Bialek, *Illusion of space*, 2016;

Lead grey glass and nickel alloy inclusions; H50cm x W40cm x D5cm; Photographed by Joanne Howell

Inclusions, because they are cut out using perspectives (Figure 119, p.194), create the illusion of greater depths of the object. The work *Illusion* *of space* (Figure 121, p.195) was exhibited at the Stroganov Academy of Fine Arts Gallery, Moscow, Russia (2016).

6.1.3. Experimenting with 3D effects using 2D shapes.

In this section, internal space in objects is explored and employed in a creative way through the use of 2D inclusions cut from metals, through which it is possible to control the composition of the applications. The research investigated additional effects created during the preparation of 3D shapes assembled from 2D images cut from metals, which were prepared to be inclusions in glass sculpture. The main idea was to create a sense of movement inside the sculpture so that the viewer has an impression that the figure is moving (Figure 122, p.196). These effects have been applied in the work "*Self-Psychoanalysis*", which was exhibited at the Stroganov Academy of Fine Arts during the Moscow Biennale in 2015.

Figure 122. Experimenting with multiple layers of 2D cut-out shapes

Four 2D images of a dancing ballerina, linked to each other, give the impression of movement.

Figure 123. Goshka Bialek, *Self-Psychoanalysis II*, 2015;
Glasma glass with nickel inclusions; H 50cm x D 10cm x W 50cm;
Photographed by Joanne Howell

A sense of movement inside the sculpture can be created by applying metal inclusions. These effects were demonstrated by Patrick Hughes' development of reverse perspective, which he applied in his 3D paintings. Some elements of reverse perspective were used in this research for the implementation of 2D metal inclusions (Figure 124, p.197).

Figure 124. 2D metal inclusions assembled using reverse perspective.

The use of reverse perspective and 2D images makes it possible to visually manipulate the internal space of sculpture and the impression of movement.

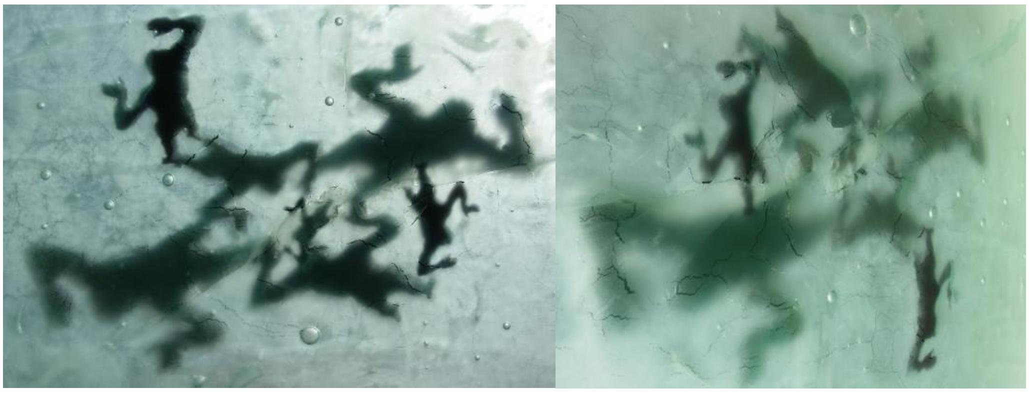

Figure 125. Goshka Bialek, *Flowing Memory*, 2017;

Float glass, 6 sheets 6mm thick, fused with inclusions: 0.5mm thick nickel with ink drawings on surface; in a wooden frame;

H 70cm x L 68cm x W 55cm;

If one moves around the object it can be noted that the flat surface of the glass with 2D inclusions underneath changes its visual appearance. Changes in relative position between the internal and external elements makes the impression of movement in the object.

6.2. Application of the research results in the artistic practice

It was important to make artwork to demonstrate the creative potential and practicality of the material testing phase (see Chapter 3). Key elements of the testing were created on a larger scale in the production of final exhibition artworks. By building on the tests which showed promise and trying out different production methods it was possible to make artworks that realised the visual qualities of the tests. The nature of the artwork produced reflects my personal interest in the visual relationship between glass and metal and the possibility of working with the internal space of produced objects. This interest is revealed through the visual language of the pieces which has been developed through the emerging tests. The artistic enquiry has been influenced by the process of experimentation and discovery that has inspired and driven the research forward. By working with key elements of the tests, such as the transparent effects of the material, it was possible to draw the processes together to create a synthesis of surface texture and form. The relation between the materials are echoed in the textures and forms which have helped me to develop a personal visual language.

6.2.1. The applications of metals in glass in sculpture

By using glass, it was possible to make space inside the sculpture visible and create within this space new forms. The main research was concentrated on inclusions of metals in glass, particularly nickel, and lead/tin alloys. The study engages the arts in an exploration of the internal space in sculpture to create works and methods of artistic expression. It explores and employs in an innovative and creative way the internal space in objects through the use of glass and metal inclusions, with prints and drawings (Figure 127, p.200) inside the sculpture having a relation with the outside surface of the sculpture (Figure 126, p.199).

Figure 126. Goshka Bialek, *Self-Psychoanalysis I, II & III*, 2017;
Glasma glass with metal inclusion with prints, ink drawings;
H 50cm x D 10cm x W 50cm; Photographed by Joanne Howell.

Figure 127. Goshka Bialek, *Self-Psychoanalysis I, II & III*, 2017;
Glasma glass with metal inclusion with prints, ink drawings;
H 50cm x D 10cm x W 50cm; Photographed by Joanne Howell.

In the work, *Self-Psychoanalysis I*, the main object is made in glass while opaque objects penetrate the internal space. This research was concentrated on the inner space in a relation with the outer shell of a sculpture (Figure 128, p.201).

Figure 128. Goshka Bialek, *Self-Psychoanalysis I*, 2014;
Glasma glass cast with lead and tin alloy inclusions; H 50cm x D 10cm x W 50cm;
Photographed by Tim Adams.

Another application of the research is explored in my work "Self-portrait in different environment" (Figure 129, p.202).

Figure 129. Goshka Bialek; *Self-portrait in different environment I*, 2017;

Inclusion of nickel, lead and tin alloy in Cristalica glass; hot pouring into the mould;

Another example of the application 3D effects using 2D shapes (Section 6.1.3, p.196) is explored in the work “Flowing Memory” (Figure 130, p.203).

Figure 130. Goshka Bialek, *Flowing memories*, 2017;

Float glass, 6 sheets 6mm thick, fused with inclusions: 0.5mm thick nickel with ink drawings on surface; in a wooden frame;

H 70cm x L 68cm x W 55cm;

Additionally, the study considered an application of the use of perspective in sculpture (section 6.1.2, p.194). In my work “Different interpretations from different perspectives” (Figure 131, p.204), I try to understand and explain why looking at the same object or problem can produce interpretations in different observers that are diametrically opposed.

Figure 131. Goshka Bialek, *Different interpretations from different perspectives*, 2017;

Inclusions of nickel cut by a waterjet, cast in lead Gaffer glass.

These studies require further development and will be continued in this direction.

6.2.2. The applications of metals with glass in the production of jewellery

As the study included tests based on the experience with evaporation of metals (Chapter Three, p.106) as used in the production of glass jewellery with metal applications. As previously mentioned, the evaporation process is quite expensive. Therefore, in the manufacture of the jewellery, the overlay metal on glass process was used by using lampworking techniques.

Figure 132. Application of a metal layer on a borosilicate glass;

Goshka Bialek, *Asterisk*, 2014. bracelet made from borosilicate glass with nickel coating by lampworking technique.

Many of the artworks were shown in exhibitions, which enabled the research results to be viewed professionally, and the impact of the emerging artworks on the field to be gauged. Shown below is a collection of jewellery that has been prepared for the future exhibition in the Middlesbrough Institute of Modern Art.

Figure 133. Goshka Bialek, *Rings*, 2013;

Borosilicate glass and metal coating; Photographed by Tim Adams.

Figure 134. Goshka Bialek, *Torment of Life*, 2014:
Borosilicate glass and metal coating; Photographed by Tim Adams.

Figure 135. Goshka Bialek, *Distillation*, 2015;
Borosilicate glass and metal coating; Photographed by Tim Adams.

Figure 136. Goshka Bialek, *Free Interpretation*, 2013;
Borosilicate glass and metal coating; Photographed by Tim Adams.

6.2.3. The applications of metal inclusions in glass in commercial use

The Hempel Company is a huge company that deals with the distribution of metals throughout Europe and beyond. The company has supplied many materials needed to carry out research on combining metal with glass. In return for their help they asked me to design a sculpture or logo for their company. The work was done using the experience gained during the study on inclusions the glass. The project also used findings of research on the effects created during the preparation of 3D shapes assembled from 2D images cut from metals, which were prepared as inclusions in glass sculpture. The main idea was to create a sense of additional depths in this work (Figure 137, p.208, Figure 138, p.208 and Figure 139, p.208).

Figure 137. Goshka Bialek, *Hempel Logo*, 2014;

Window glass 6mm, sheet of nickel alloy 3mm thick;

W 1000mm x H 350mm x D 36mm.

Figure 138. Goshka Bialek, *Hempel Logo*, Letters Details, 2014;

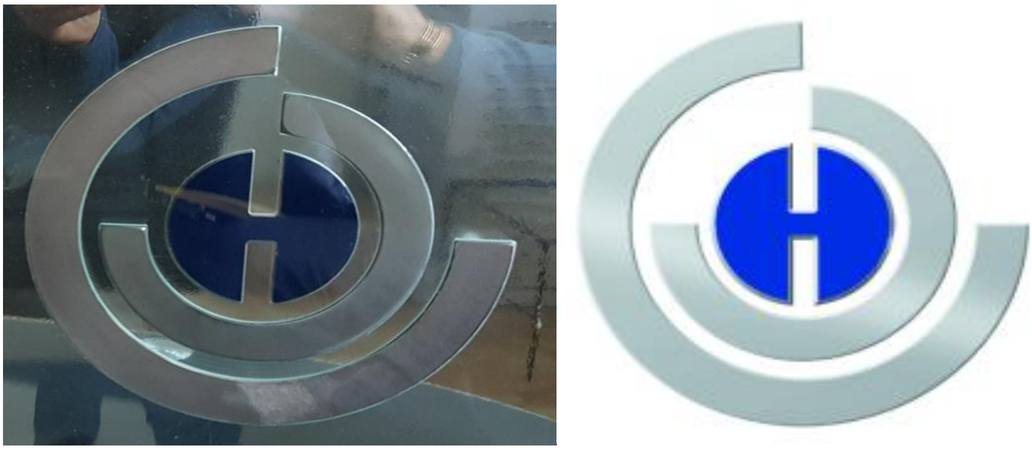

Figure 139. Goshka Bialek, *Hempel Logo* and the original image, 2014;

6.2.4. Assembly of the tests pieces produced during the research into an installation to be shown as the part of final PhD exhibition

The test pieces, which have been made in the course of the research, were designed in the shape of heads (author's self-portrait) or glass bricks, so that they could be employed in the production of the final exhibition artworks. By building on the tests which showed promise and trying out different production methods, it was possible to make artworks that realised the visual qualities achieved in the tests.

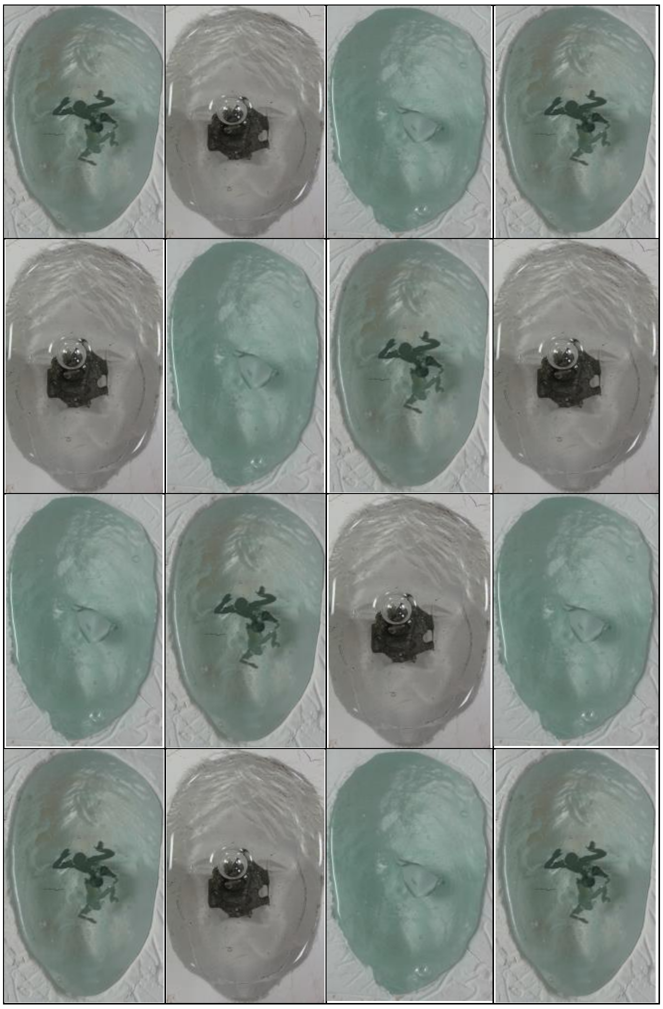

Figure 140. Goshka Bialek, *My way of thinking*, 2017;

The research test pieces in the shape of my face; glass and metal inclusions.

This installation is designed as part of the final exhibition to visualise my way of thinking during the whole research process. It will be finished and adjusted depending on the environment and exhibition space.

6.3. Summary of application of the research findings in artistic practice

The findings of the research were the base for starting a study of the application of the outcomes. Acquisition of the necessary tools allowed further development of the artistic practice.

Preliminary application of research achievements has been shown in this chapter. Of course, these are preliminary applications, which require the development and continuation of research in this direction.

In order to demonstrate and articulate the possible creative and practical benefits of the new processing routes, a few potential routes were tested:

- experiments with shapes of metal inclusions and adaptation of the internal space of objects in relation to them;
- experiments with application of the reverse perspective, based on Patrick Hughes' 3D paintings.
- the use of metal inclusions and glass in sculpture by using relations between the materials, textures, internal space and the surface of objects to develop a personal visual language.
- experiments with application of metals in production of jewellery
- application of research discoveries into commercial work

Each of these paths requires further research. These are only the preliminary uses of metal in combination with glass, but they show interesting possibilities for further development in artistic practice.

7. Summary, outcomes, conclusion, contribution to knowledge, and area for further research

This chapter will: summarise the research; state the conclusions and the outcomes of the research; show the contribution to knowledge that the research offers; identify and discuss possible areas for further research; and make some final comments about the research.

7.1. Summary of the research

Initially the research methods that were used throughout the research practice were identified, beginning with a literature review. The literature review identified and explored the historical, cultural and creative/artistic engagement, in both practice and conceptualisation, with the application of inclusions, particularly metal inclusions, and using internal space in sculpture, particularly glass sculpture.

The literature and contextual reviews include materials from a variety of sources, including PhDs in arts technology, in addition to the standard literature. Data has also been gathered from 59 artists, and 22 scientists in 119 interviews over a period of 20 years. This process also captured data that was collected from a range of other sources, including case studies, cooperation with chemists, engineers, experts from glass and metal industries and participation in conferences. Records were also collected in technical notebooks, journals, sketchbooks, models, photography and recorded on Dictaphone tapes

This variety of sources has been used to develop a framework to reflect the researcher's own personal experience as an artist and practitioner.

Secondly, the working definitions and techniques of glass inclusion have been drawn from these sources and perspectives as a means to present and describe the approaches used by current artists in their artistic practice.

Whilst working on these approaches, it was noted that an awareness of "internal space" is an important element in understanding why artists are intrigued by its use. It is significant how the notion of internal space in sculpture is used by artists who use glass in their artistic practice, and it is important to understand their use of internal space in their application of inclusions and to recognise its part in their artistic process.

Thirdly, as regards materials, the need to understand the challenges of selecting appropriate metals for inclusion in glass was addressed. In this context, the following are necessary:

- A knowledge about metals;
- An understanding of conditions during the choice of metal inclusions in glass;
- An appreciation of the effects of metals in combination with glass, especially at high temperatures, and of the challenges that arise during the inclusion process;
- A choice of suitable metals for creative use in glass.

The preliminary experiments of combining glass with metals and their alloys (Chapter Three, p.106) have shown that the metal that best meets the conditions for inclusion is 99% nickel, because it can keep silver surfaces, even at high temperatures. But it was also decided to continue studies on lead and its alloys. Nickel and lead and lead/tin alloys have common features, which are very important for this research; these metals are silver-lustre and corrosion-resistant, even at high temperature. This means that they fulfill Aim 2 (Section 1.3, p.36). Additionally, thanks to their diversity, it is possible to visualise more of the metal inclusions' potential in the application of artworks, and to achieve a better understanding of the problems which the application of metal inclusions can bring (Aim 3, Section 1.3, p.36).

Chapter Four (p.155) investigated the compatibility of glass with metals and the possibility of developing new methods of including metals in glass to utilise the space inside sculptures. Experimentation was used and the processes of including metal in glass were developed to make them more practical and efficient. Some of the findings have made a unique contribution to artistic practice, such as the development of a technique, previously thought impossible, of pouring hot glass into a mould without producing glass-distorting bubbles (Section 4.2, p.157).

Experiments were also carried out incorporating the heating and annealing processes of both glass and metal to produce bespoke casting processes for various combinations of metals and kinds of glass (Section 4.5, p.172). In an artist's studio setting these processes can then be used with high-temperature moulds and separators/lubricants to eliminate the sticking of glass to the moulds (Section 4.3, p.164), along with stamps to produce a tight-fitting silhouette for the inclusion (Section 4.4, p.171).

Next, the best approach to adding metal inclusions into glass that fit the requirements of the aims of the research was determined. This highlighted the processes that needed to be improved and designed in order that metal application could be used in the studio of the researcher.

The process of including different kinds of metal has meant that different methods have needed to be explored (Section 4.1, p.155). Nickel with its higher melting point requires a less complex approach than lead/tin alloy, which has a lower melting point than glass. Both nickel and lead and tin alloys are suitable for use as insertions but have different challenges that have been overcome in this research (Chapter Five, p.183).

Finally, the findings of the research were the preliminary basis for starting the study of the application of the outcomes (Chapter Six, p.192). The tools obtained allow further development of the researcher's artistic practice.

To demonstrate and articulate the possible creative and practical benefits of the new potential processing routes, the following potential routes were tested:

- experiments with the shapes of metal inclusions and adaptation of the internal space of the objects in relation to them (Section 6.1, p.192);
- experiments with the application of reverse perspective based on Patrick Hughes' 3D paintings (Section 6.1.2, p.194);
- use of metal inclusions and glass in sculpture by using relations between the materials, textures, internal space and the surface of the objects to develop a personal visual language (Section 6.2.1, p.1996.1.2);
- experiments with application of metals in the production of jewellery (Section 6.2.2, p.205);
- application of the research discoveries into commercial work (Section 6.2.3, p.207).

Each of these paths requires further research. These paths demonstrate only preliminary use of metal in combination with glass, but they suggest interesting possibilities for further development in artistic practice (Section 7.5, p.222).

7.2. Outcomes relating to this research

The following section deals with the outcomes of this research and is broken down by the Research Questions and Aims to provide clarity.

7.2.1. Research Questions

Q1. **How might internal space in sculpture and inclusions be used in artistic practice; and what are the potential creative benefits of metal inclusions in glass?**

Artists have many tools to penetrate the internal space of sculpture in artistic practice (Chapter Two, p.47). The control of the shape, form and texture of metal inclusions is now well understood (Section 6.1, p.192). In order to demonstrate and articulate the possible creative and practical benefits of the new potential processing routes, a few potential routes were tested (Chapter Six, p.192):

- The creative application of metals in glass sculpture (Section 6.2.1, p.199);
- The creative application of metals in the production of glass jewellery (Section 6.2.2, p.205);
- The creative application of metal inclusions in glass in commercial use (Section 6.2.3, p.207).

Q2. **What kind of problems and principles influence artists in the selection of metals to include in glass?**

The contextual review in Chapter Two shows that artists are challenged by the compatibility of materials, the expense and availability of materials and a lack of available specialised knowledge regarding the use of some materials. These difficulties were associated with the quality of glass and materials available to artists on the market, the lack of some information about chemical and physical parameters of these materials, the compatibility, strength and thickness of inclusion materials, oxidation, and the fusion of glass, moulds and inclusion surfaces due to the high wetting parameters of materials at high temperatures. Most of these problems were solved during the investigation for this research (Chapters Three, p.106 and Four, p.155).

Q3. How might problems of metal inclusions in glass be reduced in creative practice?

Chapters Four (p.155) and Five (p.183) discussed how the application of metal inclusions can be achieved by understanding the reactions of metal in different working conditions and during the cooling and annealing process, and by the development of appropriate, controlled processes to reduce the difficulties of the inclusion application with glass. This was possible to achieve through a review of specialist literature and through collaboration with materials engineers who specialise in metal or/and glass. On the basis of these experiences, it was concluded that to reduce the problems of applications of metals inclusions in glass in creative use it would be very helpful to widen the cooperation between scientists and artists and to encourage the publication of literature based on scientific knowledge, but expressed in a way that would be understandable by artists.

Q4. Is it possible to extend the range of metals that might be used with glass?

Being flexible and adaptive with the inclusion process widens the range of metals that can be used as is shown in Chapter Four. Chapter Two also deals with the technological use of metals that are used in industry (see an extended list of metals in Section 7.2.2, p.216, Aim 3).

7.2.2. Aims

Aim 1: to define, explore, evaluate and document potentially viable ways of utilising internal space and inclusions in glass sculpture (predominantly metal inclusions) as they have been used both in the past and in contemporary artistic practice

The research has shown the viability of using internal space in sculpture and applying inclusions of metal in glass by exploring how the topic has been approached in the literature and how artists and technologists themselves have anecdotally described their experiences in this field (Chapter Two, p.47). In addition to a traditional literature review of texts, data has been gathered from 59 artists in 89 interviews over 20 years. This has been used to develop a framework to reflect on my personal experience as an artist and practitioner. The working definitions and techniques of glass inclusion have been explored from these sources and perspectives to present and describe the approaches used by current artists in their artistic practice. The definitions can be found in Sections: 2.1, p.48, 3.1, p.107 and 3.2, p.113.

The cooperation between artists and technologists has also been discussed as this is an important area in the development of these techniques. This cooperation extends not only to successfully planned experimentation, but also to the understanding of how unexpected results, or “failures”, can be used to expand knowledge of the processes involved and even as a basis for artistic practice or new technological processes (Section 2.3, p.89and Chapter Four, p.155). The aim was to develop the range of processes that demonstrated the practical and creative parameters of the combination of glass and metal and displayed a variety of metal properties and surfaces from shiny, smooth and silver, to lustrous, oxidized, rusty and blackish, and including various other colours (Chapter Three, p.106).

One key element in the approaches to insertions is understanding why artists are intrigued by the concept and possibilities of “internal space” (dealt with in detail in Section 2.4, p.93). It is significant how the internal space in sculpture is used by artists who use glass in their artistic practice, because it is important to understand how to use the space through the application of inclusions and its demands in the artistic process.

The researcher’s own artistic practice has potentially shown how the preliminary findings can be explored further (Chapter Six, p.192).

Aim 2: **to develop the technology to enable the assembling of glass sculptures with the inclusion of metals, while keeping unchanged the shape and/or colour of the metal**

From the beginning the investigations gave an informative insight into what could be achieved when combining glass and metal in a hot state. Chapter

Three (p.106), from a metals and glass perspective, and Chapter Four (p.155), from the point of view of process, discuss the technological developments required to control the colour and shape of the metal inclusions. The manifestations of these developments can be seen in the artist's work in Chapter Six (p.192).

The investigations focused on materials suitable for the application of inclusions to develop illusion effects, such as programmed holograms or reverse perspective (Section1.1, p.21), and on the capabilities of controlling their shapes and surface lustre during the casting process (Chapters Four, p.155 and Five, p.183). The metal that best meets the conditions for research, is 99% nickel, because it can keep silver surfaces even at high temperatures. But studies were continued on lead and its alloys as well (Chapter Five, p.183). These metals were chosen because their chemical and physical properties are so different from each other. The most important difference is their melting points: nickel's is above the melting point of glass, which is 600ºC, while lead's is well below that temperature, and is even below the annealing temperature of glass. This was significant because it shows that metals in their fluid state are more flexible than in solid state. In this case glass has space to shrink and is not stressed by the metal inclusion during the cooling process. However, by following the application technique, developed during the study (Chapters Four, p.155 and Five, p.183), it is also possible to control the shape of lead and lead-alloy inclusions. But these metals also have common features, which are very important for this research: they are silver-lustre and corrosion resistant, even at high temperature. It means that in some circumstances they fulfill Aim 2. Nickel inclusions allow precise control of the shape and the surface lustre of the metal, whereas the inclusions of lead and tin allow significant increase in the mass of inclusions, but at the expense of less control over the shape of inclusions (Chapter Five, p.183).

The limitations of metal and glass in a hot state, as discussed in the Introduction and the Contextual Review, represent significant gaps in our knowledge of these materials. There is therefore a need to develop processes for combining them that could be transferred and used by others in the field. In this case, the investigation was continued on other metals than nickel and lead (Chapter Three, p.106). These metals, by application of the processes developed by the researcher, are compatible with glass and allow precise control of the shape, but they stain glass to different colours or their surfaces are oxidised during the heating process. These effects give additional possibilities in artistic practice. That is why these metals were also considered in this study, regardless of failing to keep their silver colour.

Aim 3: to develop of a list of metals, with their parameters, which are compatible with glass and can be used in artistic practice.

The palette of metals used by artists was restricted and the present technologies, widely drawn from the industrial sector and available to artists, have many limitations. Therefore, it was crucial to extend the range of systems for artists' other creative practices. In the research, it was also necessary to make an overview of the literature on metallurgy and the annealing of metals, and to have consultations with scientists in the field. In this way, it was possible to determine parameters of the annealing of metals and fit them to the research needs. On the basis of these results, firing programs of cast glass with metal inclusions, taking into account annealing for both materials, have been established. This allowed the list of compatible metals with glass to be increased. A list of metals and their alloys, which are or can be compatible if applied as inclusions in ways suggested by this research, includes the following:

Aluminium

Chromium

Cobalt

Gallium

Invar, Kovar

Iron pure

Iron cast

Lead

Nickel

Steel Stainless (18/20).

Tin and lead alloys

The research has developed a short, but not exhaustive, list of metals and the parameters under which they can be used as inclusions in glass sculpture (Chapter Three, p.106). The research has also provided affordable solutions which make the findings applicable for artists in their practice (Chapters Three, p.106 and Four, p.155). The benefits of the knowledge gained from the research project and the new processes have also been shared with 59 artists and 22 scientists, who were involved in the project and with students and staff of Wroclaw, Krakow and Warsaw Academies in Poland; Stroganov Academy Moscow and Irkuck University in Russia; and Durham and Sheffield Universities in the UK. The published thesis will be an accessible and permanent articulation of the outcome of this research project and its digital copy will be available on the internet to the wider public. Finally, this publication will be part of a textbook for Russian students and artists, which is planned to be published in 2019.

7.3. Conclusions

The research, by achieving its three initial aims, through a combination of anecdotal evidence from artists themselves, and scientific research and experimentation, has shown that there are affordable and appropriate ways for contemporary artists to include a wider variety of metal inclusions within glass sculpture. This research aims to contribute to advancing glass sculpture including research into methods, technology, materials and processes. Generally, it is a vehicle for extending collaboration between technologists and artists, and the exchange of information, resulting in widening the techniques and materials available for artists.

7.4. Original Contribution to Knowledge

This project has developed and documented new possibilities for the application of metal inclusions in creative practice. Experiments to identify creative parameters for combining glass and metal, especially in a hot state, and process routes for combining these two materials, have been developed and tested. Some of these processes were previously thought impossible or unlikely to produce the desired effects. The review of literature and questionnaires sent out to artists also showed that the thickness of the metal inclusion has an effect during annealing, and that many held the belief that any metal thicker than a foil 2-5 mil (= 0.0508-0.127mm) would cause the glass to crack (Walker 2010). However, having started experiments with metals of greater thickness than foil (up to 3mm = 118.11mil), it has been established that thicker inclusions could be regularly produced effectively. The processes described are listed below.

Finally, the original contribution to knowledge was to create techniques for applying nickel and lead/tin alloys in glass in the hot stage for creative practice with the solution of many problems accompanying these processes. For instance:

▪ building affordable high-temperature resistant moulds with a very finely textured surface, which would not be not responsive to the glass even when poured into the mould at 1000°C (Section 4.2, p.157);

▪ developing appropriate firing cycles to control the applications of the inclusions and annealing of both metal and glass (Section 4.5, p.172 and Chapter Five, p.183);

▪ adapting “lubricants” and developing affordable, appropriate methods to apply them to prevent reaction and compatibility problems between the applied materials (Section 4.3, p.164);

▪ developing the application of nickel (up to 3mm = 118.11mil) and lead/tin (up to 5mm = 196.85mil) alloys with hot pouring glass using the mould method (Chapter Five, p.183).

A further original contribution of this research relates to the assemblage and interpretation of views concerning the perception of inner space in glass sculpture occupied by inclusions.

7.5. Areas for further research

Further experimentation with other metals for inclusion would be helpful to expand the palette of affordable and accessible metals for inclusion. In particular, it would be useful to expand the list of metals and metal alloys which, during the casting of glass (temperature approx. 830°C), will not adversely react with the glass and will retain its original colour (e.g. will not oxidise) and/or shape. Following the research results it would be thought-provoking to continue experiments with other nickel alloys (mostly stainless-steel metals). Very good results were obtained with pure nickel but because of the high price of this metal it was impossible to explore this area as far as could be wished.

It has been identified, on the basis of previously conducted experiments, that the best technique of applying metal inclusions in glass is the hot pouring glass method. This method preserves the properties of metal and does least damage to the structure of the materials. However, because it requires teamwork, it is difficult to fully control this process in the artist’s studio. Consequently, it is still in need of development and improvement.

To obtain better results for metal surfaces and of the final glass sculpture, further experiments could be conducted. These would include experimentation with better developed heat resistant moulds to improve control of gas bubbles during the hot glass pouring process. It would also be useful to experiment with specialised lubricants available to artists as a means to eliminate bonding of glass to inclusions and moulds and to increase the variety of practical and affordable materials that artists might use.

As well as researching the general areas mentioned above, on a personal level I would also be keen to research the following areas: the lenticular lens print method and programmed holograms and their applications.

I would also like to develop the use of internal space in glass sculpture in my artistic practice by searching for other optical illusions and improving on the effects studied in this research. For example, it would be possible to apply a three-dimensional twist to a two-dimensional drawing, or to include a two-dimensional drawing on or in a three-dimensional object. Both of these could be achieved by using: linear perspective, 2D metal inclusions assembled using the reverse perspective, overlapping objects, placement in the glass object, distant objects with more details, or multiple layers of 2D cut-out shapes. Also, it would be desirable to improve lenticular lenses (prints) method and the application of programmed holograms in the internal space of glass objects.

I am particularly interested in Computer Generated Holography (CGH). These holographic patterns can be printed onto a mask using metal coatings or cut from a sheet of metal. Currently it is possible to produce only simple shapes. However, I am co-operating with scientists at Durham University to produce more complex designs that are 3D and cross lines of perspective inside glass objects.

Computer Generated Holography (CGH) can be generated by digitally computing a holographic interference pattern. It can then be printed onto a mask. Normally only a highly stable and planar mask substrate can hold the hologram information, since any stretching or deviations from planarity would degrade the hologram image. Usually plates of glass which are used in this process to make the mask are very expensive and not compatible with casting glass.

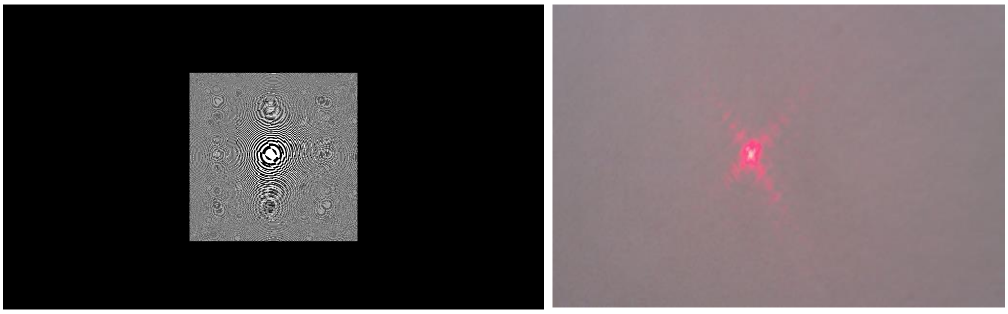

Figure 141. Programmed hologram and its projection after firing as inclusion in glass;

However, scientists and engineers from Durham University are interested in this research and are trying to resolve these problems. It is particularly important to find suitable materials to produce the most reliable mask. Approachable and not too expensive glass includes Gaffer glass, Pilkington glass, Bullseye glass or Cristalica glass. The surface of glass samples was prepared to be as smooth as possible and was measured by Professor David Wood of Durham University. The most appropriate sample that could be used in terms of flatness was the typical Pilkington window glass. Unfortunately, Pilkington glass is not very suitable for kiln casting and is not compatible with other types of casting glass. An inclusion of holographic mask glass (in this case Pilkington glass) and the rest of the glass used in a project have to be compatible with each other, and both glass fabrics have to be of even tension and without any distortion of foreign materials and bubbles. Some suggestions for further research in the area of developing programmed holograph applications in glass are as follows:

My first suggestion would be to look into laser engraving post-cast. Laser engravers can be set to burn at a specific depth, and a series of small dots can combine to create a three-dimensional image inside another object. This method is commonly used in the awards industry to burn company logos into plexi-glass awards. But cast pieces may possibly be too large to fit into most commercial engravers.

Another suggestion is to use some type of glass treatment to give the glass a lighting effect. For example, the glass could be treated with a three-layer photo-resist with different grades of blasting media to give layer one a light etch, layer two a heavier etch, and layer three a hard etch. This essentially mimics the way in which holograms are created and how they bend light. Each layer could be separated, to help with the three-dimension visual.

The last idea is to consider making a hologram-like effect by stamping a lenticular lens into the glass. It would be possible to have a fine lenticular die produced in metal, and then press that die into the glass while it is still hot. This would create the ridged effect of a lenticular lens.

The research included in this PhD was undertaken in order to find and develop processes and materials that could be used to enhance her own artistic practice. The processes and range of materials available to her before the research was undertaken were impractical. As a result of this research more opportunities have been discovered and a greater understanding of the options available to artists within their own studios has been developed.

The aims and objectives that were anticipated at the beginning of this research have been achieved, and in some ways, have been developed even further than anticipated. The contribution to knowledge consists of a wide range of benefits that other craftsmen may find interesting and of benefit to their practice. This could also be extended to wider audiences such as sculptors, technologists and materials suppliers. As the research has evolved, further areas for research have been recognized, which suggests that this is an interesting subject within the field of Crafts, Fine Art and Science; that still has research possibilities to be studied. In this further research, the future of combining glass and metal in studio practice can continue to be advanced and made accessible to wider audiences, thus developing creativity and encouraging knowledge transfer within and beyond the field.

List of References

Agilent Technologies, 2002. *Laser and Optics*. *User's Manual*. [Online] Available at: http://psec.uchicago.edu/thermal_coefficients/cte_metals_05517-90143.pdf [Accessed 12 January 2017].

Albrecht, J., Šenk, P., 1999. *Vladimir Kopecký*. Praha: Galerie Hlavniho Města Prahy.

Almeida, T., 2010. *Luminescent Glass-art Works. In Creativity and Innovation in Glass.* Proceedings of the International Glass Symposium. Wolverhampton: University of Wolverhampton.

AMES, 2013-2017. *Linear Thermal Expansion Coefficient for metals*. [Online] Available at: http://www.amesweb.info/Materials/Linear-Thermal-Expansion-Coefficient-Metals.aspx [Accessed 15 November 2016].

Anderson, H., 1997. *Kiln-Fired Glass*, 2nd ed. McLean Publisher.

Antonio, J., 2009. *The development of new methods of working to create a greater integration of form and image in glass through the exploration of applied and residual surface coatings*. Sunderland: PhD Thesis. University of Sunderland.

Auping, M., 2007. *Declaring space*. Fort Worth TX: Modern Art Museum of Fort Worth in assoc. with Prestel.

AZO Materials, 2017. *Stainless Steel – Grade 410*. AZoNetwork. [Online] Available at: http://www.azom.com/article.aspx?ArticleID=970#5 [Accressed 28 January 2017]

Barasch, M., 1985. *Theories of Art, from Plato to Winckelmann*. New York, London: New York University Press.

Barry, J.C. and Ford, S. (2001). *An electron microscopic study of nickel sulfide inclusions in toughened glass*. Journal of Materials Science, 36(15), 3721-3730.

Bayley, J., 2014. A historian from The Museum Portable Antiquities Scheme; *Telephone conversations with Goshka Bialek.* 14 January 2014.

Berdyszak, J., 1999. *O obrazie /Jan Berdyszak.* Olsztyn: Muzeum Warmii i Mazur.

Berdyszak, J., 2011. Artist. *Interview with Goshka Bialek*. 21 November 2011.

Billen, N., 2009. The shape of things to come. Royal Academy of Arts Magazine, 104 Autumn, pp.10.

Bowler-Reed, J., 2002. *The disintegration of thermally toughened glass by nickel sulphide inclusions.* March, Glass Technology [Online] Available at: http://www.aisglass.com/heat-soaking/AIS-365.pdf [Accessed 14 November 2010]

Bray, Ch., 2001. *Dictionary of Glass; Materials and techniques.* Second edition. London: A & C Black.

Brill, R. H.; Moll, S., 1963. Electron Beam Probe Microanalysis of Ancient Glass." Advances in Glass Technology, part 2. New York: Plenum Press, © Springer. Rakow Research Library, The Corning Museum of Glass. pp.293-302.

Button, V., 1997. *The Turner Prize Catalogue 1997*. London: Tate Gallery Publishing

Carpenter Specialty Alloys, 1999. *Controlled Expansion Alloys*. Wyomissing, PA: CRS Holdings, Inc.

Castle Metals, 2011. *Nickel Alloys, Materials Data Sheet*. Available at: http://www.castlemetalsuk.com/nickel-alloys/alloy-825-uns-n08825-2-4858-sheet-plate-bar/ [Accessed 16, 18, June 2013]

Celant, G., 1996. *Anish Kapoor*. London: Thames and Hudson.

Chrysopoulo, A., 2014. *Cast Glass; The course description delivered by Anna Chrysopoulo*; Westminster Adult College.

Clark-Monks, C., Parker, J.M., 1980. Stones and Cord in Glass; Sheffield: Society of Glass Technology.

Clough, Rosa T., 1969. *Futurism, The Story of a Modern Art Movement, a New Appraisal*. New York: Greenwood Press, Publishers. Collier, G., 1965. *Form, Space, and Vision, discovering design through drawing*, London: Prentice-Hall International, INC.

Corrosion Materials, 2015. *Nickel 200 and 201; Data Sheet.* [Online]; Available at: http://www.corrosionmaterials.com/ [Accessed 14 January 2011]

Creswell, John W., 1998. *Qualitative Inquiry and Research Desing, Choosing Among Five Traditions*. Thousand Oaks, CA, London, New Delhi: Sage.

Crouse-Hinds series, 2016. *Oxygen Potential Measurements in Metal Heat Treatment Processes*, Technical note MTL gas analysers & systems; TN05 520-1004 Rev3. Luton, UK; Eaton Electric Limited.

Cummings, K., 1998. *Contemporary Kiln-Formed Glass*. London: A&C Black.

Cummings, K., 2001. *Techniques of Kiln-Formed Glass*, London: A&C Black.

Cummings, K., 2002. *A History of Glassforming*, London: A&C Black.

Cummings, K., 2007. *Techniques of Kiln-Formed Glass*, London: A&C Black.

Cummings, K., 2009. Artist. *Interview with Goshka Bialek*. 20 April 2009.

Cummings, K., 2009. *Contemporary Kiln-Formed Glass*. London: A&C Black.

Curtis, P., 2003. *Sculpture in 20th- century Britain*. Volume 1, Leeds: Henry Moore Institute.

Curtis, P., 2003. *Sculpture in 20th- century Britain*. Volume 2, Leeds: Henry Moore Institute.

Deer, W. A., Howie, R. A. and Zussman, J., 1966. *An Introduction to the Rock Forming Minerals*, Logman.

De La Torre, E., 2014. Artists. *Interview with Goshka Bialek*. 18 June 2014

De La Torre, E., 2014. Artist’s e-mails. *Conversation by internet with Goshka Bialek, unpublished information.*

De La Torre, E., 2014. Workshop with artists, University Sunderland, *Interviewed by Goshka Bialek.*

De Wilde, F., 2013. Artist. *Interview with Goshka Bialek by telephone*. 28 November 2013.

Donald, I.W., 2009, *Glass-to-Metal* Sheffield: Society of Glass Technology.

Dorigato, A., Klein, D., 1996. *Venezia Aperto Vetro; International New Glass*, San Polo, Venezia: Arsenale editrice.

Dowson, J., 2000. *Swedish Glass*. Sunderland: Institute for International Research in Glass, University of Sunderland.

Dowson, J., 1996. *Finish Post War Glass, 1945-1996*. Sunderland: University of Sunderland.

Dreyfus, H.L Dreyfus, S.E., 1986. *Mind over Machine: the power of human intuition and expertise in the age of the computer*, Oxford, Basil Blackwell.

Eberle, B., 1997. *Creative Glass Techniques; Fusing, Painting, Lampworking*. London: A&C Black

EHow Contributor, 2009. *How to Keep Copper Inclusions from Oxidizing in Fused Glass*. [Online]; Available at: http://www.ehow.com/how_5496506_keep-inclusions-oxidizing-fused-glass.html#ixzz33fKQ7lBx [Accessed 29 Maj 2013]

Esaak, S., 2014. *What is the Definition of Space in Art?* [Online]; Available at: http://arthistory.about.com/cs/glossaries/g/s_space.htm [Accessed: 20September 2014]

Flavell, R., Smale, C., 1974. *Studio Glassmaking*. London: Van Nostrand Reinhold Company Ltd.

Flynn, B., 2006. *Patrick Hughes, Superduperspective*. Birmingham: Birmingham Museums & Art Gallery.

Folga-Januszewska, D., Christo, 1997. *Christo and Jeanne-Claude in Warsaw*. Warsaw: National Museum in Warsaw.

Frost, A., 2010. *Knowledge Management*. KMT, An Educational Site; [Online]; Available at: http://www.knowledge-management-tools.net/ [Accessed 18 June 2015]

Garrett, A., 1972. *On Space and Time in Art.* The MIT Press Leonardo, Vol. 5. No 4 (Autumn, pp.329-331.

George, H., 2014. *The elements of Sculpture*. New York: Phaidon Press Inc.

Giubilei, F., 2012. *Bertil Vallien, 9 Rooms*. Venice: Marsilio Editori.

Glasstress, 2009,2011, 2015. *Exhibition of contemporary artworks using glass as medium*. Venice; Instituto Veneto di Scienze Lettere ed Arti. [Online]. Available at: http://www.glasstress.org/home [Accessed 14 March 2017]

Golding, J., 1988. *Cubism; A History and an Analysis 1907-1914*. 3rd ed. London, Boston: Faber and Faber Limited.

Gordon, Arthur, E., 1983. *Illustrated Introduction to Latin Epigraphy*, Berkeley, Los Angeles, London; University of California Press.

Gormley, A., 2009. Artist. *Interview with Goshka Bialek*. 18 September 2009

Gormley, A., 2013. *Antony Gormley, Sculpture*. The Japan Art Association; [Online]. Available at: http://www.praemiumimperiale.org/en/laureate/sculpture/item/296-gormley [Accessed 20 June 2014]

Gormley, A., 2012. *Sculpted space, within and without, Antony Gormley*. TEDGlobal, June 2012. [Online]; Available at: http://www.ted.com/talks/antony_gormley_sculpted_space_within_and_without.html [Accessed 10 January 2014]

Greiner-Wrona, E., 2013; 2014; 2015. Scientist. *Interviews with Goshka Bialek by telephone*, internet and meetings.

Gromowski, K., 2010. *Glass Breakage – Nickel Sulfide Inclusions*. BAE/MAE, Penn State. [Online]; Available at:

https://failures.wikispaces.com/Glass+Breakage+-+Nickel+Sulfide+Inclusions [Accessed 26 January 2014]

Grose, D.F., 1989. *The Toledo Museum of Art, Early Ancient Glass. 1600 BC to A.D. 50*. 1st ed. New York, Hudson Hill Press in Association with the Toledo Museum of Art.

Halem, H., 1996. *Glass Notes, A reference for the glass artist*, 3rd ed. Kent, OH: Franklin Mills Press.

Hammacher, A., 1987. *Barbara Hepworth*. Revised ed. London: Thames and Hudson.

Hampel, C., 1961. *Rare Metals Handbook*. London: Chapman & Hall, Ltd.

Hand, R., 2014, 2015. Scientist. *Interviews with Goshka Bialek by telephone*.

Hartwig, J., 2014. *Art of Cameo Sulphides*. Hartwig Jean- Meilleur Ouvrier de France (M.O.F); [Online]; Available at: http://paperweights.cristallerie-hartwig.com/history.html [Accessed 4 March 2014]

Helkama, I., 1997. *Dogs, bottles and life itself*. Form Function Finland No 65

Helmenstine, T., 2014. *Mendeleev's Periodic Table of Elements*. [Online]; Available at: https://sciencenotes.org/list-metals/metals/ [Accessed:03 January 2016]

Holland, L., 1966. *The properties of Glass Surfaces*. London: Chapman and Hall.

Hurst, S., 1996. *Metal Casting; Appropriate technology in the small foundry*, London: Intermediate Technology Publications Ltd.

Ivins, William M., Jr. 1964. *Art and Geometry: A Study in Space Intuition*. New York. Dover.

Jacisin, M., 2011. *Interview with artist by Goshka Bialek* [Online]; at: group-digests@linkedin.com

Jacop, L., 1997. *Factors that influence Spontaneous Failure in Thermally Treated Glass – Nickel Sulphide.* Glass Processing Days, September, 333-327

Jokelson, P., 1968. *Sulphides, The Art of Cameo incrustation*; New Edition; Galahad Books.

Kapoor, A., 2003. *Anish Kapoor, Artist's Talk.* Tate Modern. [Online]; Available at: http://www.tate.org.uk/context-comment/video/anish-kapoor-artists-talk [Accessed 29 December 2013]]

Kapoor, A., 2015. *Interview with Goshka Bialek; Moscow Biennale 2015.*

Kehlmann, R., ca.2001. *The Inner Light, Sculpture by Stanislav Libensky and Stanislava Brychtova*, Seatle and London: Museum of Glass; International Center for Contemporary Art, Tacoma, Washington in association with University of Washington Press.

Kelly, J., 2009. *The combination of glass and Ceramics as a Means of Artistic Expression in Studio Practice*. Sunderland: PhD Thesis. University of Sunderland.

Kelly, J., 2012-2014. Artist's e-mails. *Conversation by internet with Goshka Bialek, unpublished information.*

Kolb, D., 1984. *Experiential Learning as the Science of Learning and Development*. Englewood Cliffs, NJ: Prentice Hall.

Ksiazek, T., 2002. *Jan Berdyszak, Tworczosc z lat 1960-2002*. Oronsko. Centrum Rzezby Polskiej w Oronsku.

Kuchinke, P., 2016. Technologist's e-mails. *Conversation by internet with Goshka Bialek, unpublished information.*

Lambert, J-C., 1993. *Naraha and Diabase. Translated by Brian Holmen*. Takashi Naraha Mandala, pp.2-6.

Laursen, L., 2013. *Data for the 31st Century*. Spectrum IEEE Org. for the Technology Insider, International, November pp 12.

Leatherland, E.M., 2012. *The manipulation of coatings on specialist float glass with particular reference to low-emissivity glass for creative application in architectural contexts*. Sunderland: PhD Thesis. University of Sunderland.

Lechaczynski, S., 2013. *Visit in Gallery; interview with Goshka Bialek*

Lechaczynski, S., 2011-2014. *Interviews with Goshka Bialek*

Leperier, A., 2002- 2014. Artists. *Telephone conversations with Goshka Bialek*

Leperier, A., 2002- 2014. Artist's e-mails. *Conversation by internet with Goshka Bialek, unpublished information*

Leperier, A., 2002. Workshop with artist, University Sunderland, *Interview with Goshka Bialek*

Lodermeyer, P., 2005. *Takashi Naraha, A Solid Frame*. Sculpture Magazine, Vol 24, no.9, November, pp.38-43.

Lundstrom, B., 1989. *Glass Casting and Moldmaking, Glass Fusing Book Three* Colton: Vitreous Publications.

Machiels, G., 2011. *Glass Canvas.* Lommel, Belgium; Glass Canvas Exhibition Catalogue.

Majmudar, U., 2014. Artist. *Telephone conversations with Goshka Bialek*

Majmudar, U., 2014. Artist's e-mails. *Conversation by internet with Goshka Bialek, unpublished information*.

Matsuo, K., 1998. *The Art and Technique of Pate de Verre*. Tokyo: Tokyo Glass Institute.

McGregor, L., 1997. *Bertil Vallien at Bullseye Glass*. Portland, Bullseye Glass. Co.

McKay, C., Strachan, J., 2013. *Their Colours and their Forms*. Cumbria: Art Editions North and the Wordsworth Trust.

Merrill, R. 2001. *Anacronistas Jamex & Einar DeLaTorre Grand Arts*. Kansas City Review, 1st April 2001.

Meyjes, T., 2017. *Rare glass penny made during World War II sells for £57,300*; Metro.co.uk, Sunday, 8th January 2017. [Online];

Available at: http://metro.co.uk/2017/01/08/rare-glass-penny-made-during-world-war-ii-sells-for-57300-6368892/ [Accessed 16th January 2017]

Mitchell, J., 2014. Artist's e-mails. *Conversation by internet with Goshka Bialek, unpublished information*

Mitchell, J., 2017. *Precision Air Entrapment through Applied Digital and Kiln Technologies*: Sunderland: PhD Thesis. University of Sunderland.

Murray, R., 2002. *How to write a thesis*. Buckingham, Philadelphia. Open University Press.

NeoNickel, 2013. *Nickel Alloy 825*. The NeoNickel. [Online];
Available at: http://www.neonickel.com/ [Accessed 5 January 2017]

Nowotny, W., 1963. *Podstawy Technologii szkla,* Vol. 1, Second Edition. Warszawa. Panstwowe Wydawnictwo Szkolenia Zawodowego.

Ojovan. M.I., Lee, W., 2010. *Connectivity and glass transition in disordered oxide systems*. Journal of Non-Crystaline Solids. Volume 356, Issue 44-49: pp. 2534-2540

Oldknow, T., 2010. *Michael Glancy: Molecular Aesthetics*. An interview with Michael Glancy and commentary by Tina Oldknow; For Barry Friedman Ltd.

Oppenheim, A.N., 2000. *Questionnarire Design, Interviewing and Attitude Measurment*. New Edition. London, New York. Continuum.

Oxford Advanced Learner's Dictionary, 2014. *Definitions*. Oxford University Press. [Online];
Available at: http://www.oxforddictionaries.com/definition/english/inclusion [Accessed 6 April 2014]

Palazzoli, D., 1967. *Interview with Lucio Fontana*, Bit, no.5, Milan, Oct – Nov **1967**. [Online]; Available at: http://www.speronewestwater.com/exhibitions/lucio-fontana [Accessed 12 May 2009]

Panting, J., 1972. *Sculpture in Glass*-fibre, London and Bradford: Lund Humphries in association with the Royal College of Art

Park, Y.S., 2005, *Defining video space art within video installations in the context of space and spectators*. Ph.D., University of the Arts London

Parsaye, K., Chignell, M., 1988. *Expert systems for experts*, Hoboken, NJ: Wiley, ISBN 978-0-471-60175-3

Pech, J., Braccini, M., Mortensen, A., Eustathopoulos, N., 2004. *Wetting, interfacial interactions and sticking in glass/steel systems*. Lausanne, Switzerland. Materials Science and Engineering; pp 117–128 [Online]; Available at: https://infoscience.epfl.ch/record/90688/files/PechJ-2004.pdf [Accessed 10 June 2014]

Percy, H.M., 1970. *New Materials in sculpture*, London: Alec Tiranti Ltd.

Petrie, K., 2006. *Glass and Print*, London. A&C Black/American Ceramic Society.

Petrie, K., 2011. *Ceramic Transfer Printing*; A&C Black/American Ceramic Society.

Pettit, F., 2011. *Hot Corrosion of metals and Alloys*. Journal, Oxidation of Metals. 01August, Volume 76, Issue 1-2, pp 1-21.

Philips Design News. 2009. *Getting emotional- integrating biometric sensors into textiles and apparel*. [Online] (Updated on November 2009). Available at: http://www.design.philips.com/philips/shared/assets/design_assets/pdf/nvbD/november2009/Getting_emotional1.pdf [Accessed 13 November 2009]

Pilkington, 2007. *Student Information Pack*. St. Helens Merseyside; Pilkington Group Limited. [Online] (Updated on March 2007). Available at: https://www.pilkington.com/resources/studentpackversionmar2007.pdf [Accessed 24 February 2017].

Pilkington North America, 2013. Technical Bulletin. Toledo, Ohio; NSG Group. [Online] (Updated on 14 January 2013). Available at:

https://www.pilkington.com/resources/ats129propertiesofglass20130114.pdf [Accessed 24 February 2017].

Pilkington UK, 2010. *UK Technical Bulletin*. Pilkington NSG Group, *Conversation by internet with Goshka Bialek*.

Procyk, B., 2012. Technologist from the Technology Academy in Krakow. *Intervies with Goshka Bialek*.

Read, H., 1998. *Modern Sculpture*, London: Thames and Hudson.

Reid, C., 2014. Artist. *Telephone conversations with Goshka Bialek*

Reid, C., 2014. Artist's e-mails. *Conversation by internet with Goshka Bialek, unpublished information*

Retro Glass Dictionary, 2014 *Art Glass Terminology, Definitions*. [Online] (Updated on 2014). Available at: http://www.retroartglass.com/page/14wn1/Glass_info/Glass_Definitions.html [Accessed 13 November 2009]

Reynolds, G., 1990. *The Fused Glass, Handbook*. Revised Edition, Scottsdale, Arizona. Hidden Valley Books.

Rice, P., Dutton, H., 1995. *Structural Glass*. Second Edition, London, New York. Spon Press Taylor & Francis Group.

Robbin, T., 2006. *Shadows of Reality: The Fourth Dimension in Relativity, Cubism, and Modern Art*. New Haven, Conn. Yale University Press.

Rome, R., Young, H., 2003. *Fine Art metal casting; an illustrated guide to mould making and lost wax processes*, London: Robert Hale Limited

Rhody, A., Ross, F., 1999. *Holography Marketplace*, Eighth Edition. Berkeley: Ross Books Ltd.

Ryan, V., 2005-2009. *Annealing Metals*. Teaching of design and technology; TechnologyStudent.com. [Online] Available:

http://www.technologystudent.com/equip1/heat3.htm [Accessed 10 January 2017]

Thwaites, A., 2011. *Mould Making for Glass*. London: Bloomsbury Publishing Plc.

Salo, M., 2013, 2014, Artist's e-mails. *Conversation by internet with Goshka Bialek, unpublished information*.

Sarmiento, J., 2011. *Graphic: Development of creative approaches to expressions of ethnicity*. Sunderland; PhD the University of Sunderland.

Sarmiento, J., 2012. *Artist, interview with Goshka Bialek, unpublished information.*

Schön, D.A., 1983. *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books.

Schuler, F., Schuler, L., 1971. *Glassforming, Glassmaking for the Craftsman*. Pitman Publishing, London.

Shaughnessy, J., Zechmeister, E., Jeanne, Z., 2011. *Research Methods in Psychology*. 9th ed. New York, NY: McGraw.

Shaffer, M., 2014. Artist. *Telephone conversations with Goshka Bialek*

Shaffer, M., 2014. Artist's e-mails. *Conversation by internet with Goshka Bialek, unpublished information.*

Skrzypek, S.J., Przybylowicz, K., 2012. *Inzynieria metali i ich stopow*. Krakow; Wydawnistwa AGH.

Stake, R., 1995. *The art of case study research.* Thousand Oaks, CA, London, New Delhi; Sage.

Stanicky, P., 2014. Artists. *Telephone conversations with Goshka Bialek*

Stanicky, P., 2014. Workshops with artists, University Sunderland, *Interview with Goshka Bialek*

Stanicky, P., 2014. Artist’s e-mails. *Conversation by internet with Goshka Bialek, unpublished information*

Stankard, P., 2014. Artist’s e-mails. *Conversation by internet with Goshka Bialek, unpublished information*

Stephens, C., 2005. *Barbara Hepworth: Centenary*. Tate magazine [Online]; Issue 5, 2005. Available at: http://www.tate.org.uk/magazine/issue5/hepworth.htm [Accessed 20 May 2010]

Svensson, K., 2013. VD/Managing Director of Glasma AB. *Telephone conversations with Goshka Bialek*

Sybart, K., 2006. Workshop with artist, University Sunderland, *Interview with Goshka Bialek*

Tomaszewski, T., 2006, Przestrzen Realna i Iluzoryczna jako Motyw Dziela Rzezbiarskiego. Ph.D., Wroclaw Academy of Fine Arts.

The Engineering Toolbox, 2014. *Coefficients of Linear Thermal Expansion. Resources, Tools and Basic Information for Engineering and Design of Technical Applications* [Online] Available at: http://www.engineeringtoolbox.com/linear-expansion-coefficients-d95.html [Accessed 24 November 2016]

Thwaites, A., 2011. *Mould Making for Glass, Glass Handbook*. London, New Delhi, New York, Sydney; Bloomsbury.

Thwaites, A., 2010. Workshops with artists, University Sunderland, *Interview with Goshka Bialek*

ThyssenKrupp, 2012. *Metals, Material Data Sheet.* ThyssenKrupp VDM (February Edition); Available at: http://www.outokumpu.com/SiteCollectionDocuments/VDM%20Data%20Sheet%20Cronifer%201925%20hMo_e.pdf (Accessed 19 June 2013)

Vallien, B., 2009 - 2014. Artists. *Telephone conversations with Goshka Bialek*

Vallien, B., 2013, 2014. Artist's e-mails. *Conversation by internet with Goshka Bialek, unpublished information*

Vallien, B., 1999. Workshops with artists, University Sunderland, *Interview with Goshka Bialek*

Vallien, B., 2012. *Artist Statement; Bertil Vallien exhibition catalogue.* Number Nine the Gallery; [Online] (updated on 2012); Available at: http://www.numberninethegallery.com/index_numbernine.php?artistinfo=bertilvallien [Accessed 28 May 2012]

Viney, J., 2009. *Sculptor Jill Viney*. Yaddo Corporation, The Artists Voice, [Online]; (updated on September 2009]; Available at: http://www.yaddo.org/yaddo/TheArtistsVoice.shtml [Accessed 20 January 2010]

Walker, B., 2010. *Contemporary Fused Glass*. Clemmons, North Carolina, Four Corners International, Inc.,

Warmus, W., 2016. Curator's e-mails. *Conversation by internet with Goshka Bialek, unpublished information.*

Whitehouse, D., 1993. *Glass: A Pocket Dictionary of Terms Commonly Used to Describe Glass and Glassmaking*. Corning, New York, The Corning Museum of Glass.

Wikipedia, 2014. *Metal.* Wikipedia, The Artists Voice, [Online]; [updated on 23 September 2014]; Available at: http://en.wikipedia.org/wiki/Metall [Accessed 28 September 2014]

Yoshimizu, T., 1998. The Art and Technique of Pâte de Verre. Tokyo, Tokyo Glass Art Institute.

Young, D., 2008. *High Temperature Oxidation and Corrosion of Metals,* Oxford; Elsevier Ltd.

Zasadzinski, J., 2012; 2013; 2014; 2015. Scientist. *Interview with Goshka Bialek by telephone*, internet and meetings.

Zieba,B., 1987. *Technologia Szkla*, Vol. 1. Third Edition, Warszawa. Wydawnictwo Arkady.

IV.1. Appendix: Cast and annealing program examples; the nickel, lead and tin alloys inclusions in different types of glass

1. The hot pouring glass, cast and annealing program
The Nickel inclusions in Cristalica glass
- thickness of glass 5cm

Ramp	Rate of temperature change in °C/hour	Target temperature	Time of soaking	Additional notes
1.	↑50°C	→ 204°C	3h	This ramp/soak in 204°C aims to dry the moulds slowly.
2.	↑100°C	→593°C	4h	Moulds cures in 593°C for 4hours. Chemical water evaporates slowly that moulds do not lose their strength.
3.	↑100°C	→ 850°C	3h	It is necessary to cast moulds with small amount of glass in the higher temperature than usually, it means 850°C for three hours, that most of gases could evaporate.
4.	↓ 150°C	→820°C		Hot pouring glass in moulds with small amount of glass and application of nickel inclusions in glass.
5.	↓150°C ↓5°C ↓6°C	→770°C →760°C →705°C	 6h 	Nickel 99.8 must be annealed between 760ºC and 705ºC, to be soft.

1. The hot pouring glass, cast and annealing program The Nickel inclusions in Cristalica glass - thickness of glass 5cm				
Ramp	**Rate of temperature change in °C/hour**	**Target temperature**	**Time of soaking**	**Additional notes**
6.	↓50°C ↓4°C	→520°C →515°C	6 h 6 h	515ºC - the annealing temp of Cristalica glass – but it is necessary to start annealing earlier to be sure that glass and metal inclusion have the same temperature.
7.	↓4°C	→480°C		To get equilibrium condition for metal during cooling
8.	↓4°C h ↓4°C h	→380°C →375°C	6 6	380°C it is the Strain Point temperature of glass and additionally at temperatures below 379°C, nickel sulphide is stable in the beta-phase form
9.	↓8°C	→320°C	6h	The Lower Strain Point temperature of glass; longer soaking to balance temperature inside and outside the glass
10.	↓8°C h ↓1°C h	→300°C →280°C	6 6	Minimum 8h process between 280°C and 300°C to minimize the risk of spontaneous fracture due to the sulphide and nickel content
11.	↓8°C	→200°C		
12.	↓16°C	→100°C		
13.	↓25°C	→30°C		End

2. The hot pouring glass, cast and annealing program The Nickel inclusions in Cristalica glass - thickness of glass 10 cm				
Ramp	**Rate of temperature change in °C/hour**	**Target temperature**	**Time of soaking**	**Additional notes**
1.	↑50°C	→204°C	3h	This ramp/soak in 204°C aims to dry the moulds slowly.
2.	↑100°C	→593°C	4h	Moulds cures in 593°C for 4hours. Chemical water evaporates slowly that moulds do not lose their strength.
3.	↑100°C	→ 850°C	3h	It is necessary to cast moulds with small amount of glass in the higher temperature than usually, it means 850°C for three hours, that most of gases could evaporate.
4.	↓150°C	→820°C		Hot pouring glass in moulds with small amount of glass and application of nickel inclusions in glass.
5.	↓150°C ↓5°C ↓5°C	→770°C →760°C →705°C	 6h 6h	Nickel 99.8 must be annealed between 760ºC and 705ºC, to be soft.
6.	↓50°C ↓2°C	→520°C →515°C	6h 8h	515ºC - the annealing temp of Cristalica glass – but it is necessary to start annealing earlier to be sure that glass and metal inclusion have the same temperature.
7.	↓1°C	→480°C		To get equilibrium condition for metal during cooling

2. The hot pouring glass, cast and annealing program The Nickel inclusions in Cristalica glass - thickness of glass 10 cm				
Ramp	**Rate of temperature change in °C/hour**	**Target temperature**	**Time of soaking**	**Additional notes**
8.	↓1°C ↓1°C	→380°C →375°C	8h 8h	380°C it is the Strain Point temperature of glass and additionally at temperatures below 379°C, nickel sulphide is stable in the beta-phase form
9.	↓2°C	→320°C	6h	The Lower Strain Point temperature of glass; longer soaking to balance temperature inside and outside the glass
10.	↓4°C ↓1°C	→300°C →280°C	10h 10h	Minimum 8h process between 280°C and 300°C to minimize the risk of spontaneous fracture due to the sulphide and nickel content
11.	↓2°C	→200°C		
12.	↓4°C	→100°C		
13.	↓8°C	→ 30°C		End

3. The cast and annealing program The Nickel inclusions in Cast Colour Gaffer glass - thickness of glass 10 cm (Figure 142, p.246)				
Ramp	**Rate of temperature change in °C/hour**	**Target temperature**	**Time of soaking**	**Additional notes**
1.	↑50°C	→204°C	3h	This ramp/soak in 204°C aims to dry the moulds slowly.
2.	↑100°C	→593°C	4h	Moulds cures in 593°C for 4hours. Chemical water evaporates slowly that moulds do not lose their strength.
3.	↑100°C	→ 830°C	4h	The cast process
5.	↓150°C ↓5°C ↓5°C	→770°C →760°C →705°C	 6h 6h	Nickel 99.8 must be annealed between 760ºC and 705ºC, to be soft.
6.	↓20°C ↓2°C	→490°C →480°C	6h 8h	*480ºC - the annealing temp of the Cast Gaffer glass – but it is necessary to start annealing earlier to be sure that glass and metal inclusion have the same temperature.
7.	↓1°C	→430°C	8h	*430ºC the second annealing temp of the Cast Gaffer glass. Also, to get equilibrium condition for metal during cooling
8.	↓1°C ↓1°C	→380°C →375°C	8h 8h	380°C it is the Strain Point temperature of glass and additionally at temperatures below 379°C, nickel sulphide is stable in the beta-phase form
9.	↓1°C	→330°C	6h	The Lower Strain Point temperature of glass;

3. The cast and annealing program The Nickel inclusions in Cast Colour Gaffer glass - thickness of glass 10 cm (Figure 142, p.246)				
Ramp	**Rate of temperature change in °C/hour**	**Target temperature**	**Time of soaking**	**Additional notes**
				longer soaking to balance temperature inside and outside the glass
10.	↓2°C ↓1°C	→300°C →280°C	10h 10h	Minimum 8h process between 280°C and 300°C to minimize the risk of spontaneous fracture due to the sulphide and nickel content
11.	↓2°C	→200°C		
12.	↓4°C	→100°C		
13.	↓8°C	→ 30°C		End

* It was not clear, exactly which temperature is the annealing temperature for the glass.

Figure 142. Goshka Bialek; Diverse points of view from different perspectives, 2017;

Inclusions of nickel cut by a waterjet, cast in lead Gaffer glass;

W50cm x L120cm x D10cm;

4. The hot pouring glass; cast and annealing program; The nickel, lead and tin alloys inclusions in Cristalica glass - thickness of glass 5cm (Figure 143, p.249)				
Ramp	**Rate of temperature change in °C/hour**	**Target temperature**	**Time of soaking**	**Additional notes**
1.	↑50°C	→ 204°C	3h	This ramp/soak in 204°C aims to dry the moulds slowly.
2.	↑100°C	→593°C	4h	Moulds cures in 593°C for 4hours. Chemical water evaporates slowly that moulds do not lose their strength.
3.	↑100°C	→ 850°C	3h	It is necessary to cast moulds with small amount of glass in the higher temperature than usually, it means 850°C for three hours, that most of gases could evaporate.
4.	↓ 150°C	→820°C		Hot pouring glass in moulds with small amount of glass and application of nickel inclusions in glass.
5.	↓150°C ↓5°C ↓6°C	→770°C →760°C →705°C	 6h	Nickel 99.8 must be annealed between 760ºC and 705ºC, to be soft.
6.	↓50°C ↓4°C	→520°C →515°C	6 h 6 h	515ºC - the annealing temp of Cristalica glass – but it is necessary to start annealing earlier to be sure that glass and metal inclusion have the same temperature.
7.	↓4°C	→480°C		To get equilibrium condition for metal during cooling

4. The hot pouring glass; cast and annealing program; The nickel, lead and tin alloys inclusions in Cristalica glass - thickness of glass 5cm (Figure 143, p.249)				
Ramp	**Rate of temperature change in °C/hour**	**Target temperature**	**Time of soaking**	**Additional notes**
8.	↓4°C ↓4°C	→380°C →375°C	6h 6h	380°C it is the Strain Point temperature of glass and additionally at temperatures below 379°C, nickel sulphide is stable in the beta-phase form
9.	↓4°C	→335°C	6h	the ramp was added because of inclusion of lead. It was decided that it is better to slow down cooling before Lead melting point (327°C) to steady temperature in whole object
10.	↓4°C	→325°C	6h	327.5ºC this is lead melting point temperature, it means that lead turn from liquid to solid. It was decided that it is better to increased soak in 330°C point to balance temperature inside and outside the glass
11.	↓8°C	→320°C	6h	The Lower Strain Point temperature of glass; longer soaking to balance temperature inside and outside the glass

4. The hot pouring glass; cast and annealing program; The nickel, lead and tin alloys inclusions in Cristalica glass - thickness of glass 5cm (Figure 143, p.249)				
Ramp	**Rate of temperature change in °C/hour**	**Target temperature**	**Time of soaking**	**Additional notes**
12.	↓8°C ↓1°C	→300°C →280°C	6h 6h	Minimum 8h process between 280°C and 300°C to minimize the risk of spontaneous fracture due to the sulphide and nickel content
13.	↓4°C	→230°C	6h	232°C this is tin melting point temperature. Inclusions are made from lead and tin alloys: 30%Lead 70%Tin, 50%Lead 50% Tin and 70%Lead 30%Tin
14.	↓8°C	→200°C		
15.	↓16°C	→100°C		
16.	↓25°C	→30°C		End

Figure 143. Goshka Bialek; Self-portrait, 2017;

Inclusion of nickel, lead and tin alloy in Cristalica glass; hot pouring into the mould;

IV.2. Appendix: Interviews, consultations, discussions, workshops with artists, art historians and scientists.

Artists:

Almeida, T., 2010. Artist. Interview and discussions about luminescent glass inclusions;

Berdyszak, J., 2011. Artist. *Interviews about internal space in sculpture*.

Bray, Ch., 2004. Artist, art educator. *Interview about inclusions and adaptation of them in glass*.

Bretcanu, O., 2016-2017. Expert, Newcastle University. Consultation metal and glass application (particularly gallium).

Brychtova, S. and Libensky, S., 1999. Artists and educators*, Interview about the internal space in sculpture and inclusions.*

Chrysopoulo, A., 2014. Artist and instructor; interview about *cast glass and inclusions*.

Cummings, K., 2009. Artist, writer and educator. *Interview about inclusions in glass*.

De La Torre, E., 2014. Artists (two). *Interview about inclusions in transparent materials.* Artist's e-mails. *Conversation by internet.* Workshop with artists, University Sunderland.

De Wilde, F., 2013. Artist. *Interview about a role of technology in art and inclusions.*

Flavell, R., 1999-2010. Artists and educator. Discussion about glass and inclusions.

Glancy, M., 2013-2016. Artists and educator*. Interviews and conversation about his work.*

Glass Artist Group (LinkedIn) 14 artists. *Discussions about application of inclusions, particularly metal inclusions*.

Glass Secessionism Group (Facebook), 39 Artists. *Consultations, discussions, questioners*.

Gormley, A., 2009-2010. Artist. *Interview about internal space.*

Jacisin, M., 2009-2012. Artist, Glass Artists Group Member, *Interview about space in transparent sculptures*.

Kapoor, A., 2003, 2015. Artist, *Discussion during Artist's Talk in* Tate Modern; *Interview about transparent materials, internal space and inclusions; Moscow Biennale 2015.*

Kelly, J., 2008-2016. Artist and educator. *Conversations about combination of glass and ceramic and ceramic inclusions in glass.*

Lhotsky, Z., 1999-2005. Artist, owner of studio Pelechov. Workshops, conversations, consultations about. moulds and cast glass technology.

Majmudar, U., 2013-2015. Artist. *Conversations and Interviews about her work, combination of metal and glass.*

Marinkova, L., 2014. Artist. *Interviews about her work*.

Mitchell, J., 2009-2017. Artist. *Conversation about air bubble inclusions.*

Morrell, R., 2014-2015. Artist. Interviews about his works and application of metal and glass.

Nawa, K., 2015. Artist, SCAI Gallery. Interview about internal space in sculpture.

Nowotny, J., 2011. Artist, Corning Museum. *Interview and consultations about glass and firing programs*.

Petrie, K., 2000-2017. Artist, educator, writer. *Workshops, consultations about glass and print inclusions.*

Prisse. C., 2011. Artist. Interview about her work.

Reid, C., 2001-2017. Artist. C*onversations about his work and metal application.*

Renni, C., 2005-2014. Artist. *Workshops, conversations, consultations about his work and application of metal and glass*.

Resnik Rickriver, S., 2014-2017. Artist. Conversation and Consultation about application of inclusion in glass.

Sculpture Group (Linkedin), 12 artists. *Interviews: using glass as a sculpture medium*.

Salo, M., 2013, 2014, Artist. *Conversation about internal space in glass sculpture, and combination of metal and glass*.

Sarmiento, J., 2012. Artist. Workshops, *conversations, interviews about his work and application of print inclusions in glass and glass cut with WaterJet.*

Shaffer, M., 2013-2016. Artist. *Interviews and conversations.*

Stanicky, P., 2014-2016. Artists. *Conversations about his work and glass and metal combination. Workshop in* University of Sunderland*.*

Stankard, P., 2014-2015. Artist. *Conversation about his works and inclusions in glass.*

Sybart, K., 2006. Artist. *Interview and workshop*, University of Sunderland.

Tate, T., 2009-2017. Artist. Glass Secessionism. *Conversations and images of artists' works*.

Thompson, B., 1997-2014. Artist. Workshops, consultations, interview about his work.

Thwaites, A., 2002, 2010, 2016, 2017. Artist, writer, educator. *Workshop and conversations about cast glass moulds technology.*

Tomaszewski, T., 2006, Artist. *Interview about his work and internal space in sculpture,* Wroclaw Academy of Fine Arts.

Vallien, B., 1999 - 2017. Artist. *Workshop and conversations about his work, internal space in sculpture and inclusions in glass.*

Walentynowicz, J., 2015-2016. Artist. Conversation about internal space in sculpture.

Walker, B., 2010. Artist and writer. *Conversation about combination of glass and metal*.

Historian and curators:

Bayley, J., 2013-2014. A historian from The Museum Portable Antiquities Scheme; *Telephone conversations about metal inclusion in glass history*.

Dowson, J., 2000-2013. Historian. Conversations about *Scandinavian Glass artists working with glass and metal*.

Eremeeva, A., 2014-2015. Curator, The Hermitage Museum, St. Petersburg, Russia. Consultations.

Hylen. B., 2012-2014. Reference and Education Librarian, the Rakow Research Library. Consultations about artists who works with glass and metal.

Kaplan, J., 2002, 2007. Curator and owner of Kaplan Gallery in New York. *Interviews about artists who employs glass and metal* (Chicago, New York).

Klein, D., 1997-2007. Historian, writer. Interviews, discussions about glass artists who employed inclusions in glass.

Lechaczynski, S., 2011-2014. Owner and curator of La Verrerie de Biot Gallery. *Interviews about artists who works with inclusions (particularly metal inclusions).*

Makarewicz, Z., 2010-2014. Historian of art, Wroclaw Academy of Fine Art. Consultation about internal space in sculpture.

Petrova, S., 1998-2013. Historian, writer and curator. *Discussions, consultations about artists who works with transparent materials and inclusions (particularly metal inclusions)*.

Warmus, W., 2016. Curator. *Conversations about glass, internal space and inclusions.*

Scientists:

Brookes, B., 2013-2014. Technologist, Society of Glass Technology. Consultation about metal and glass application.

Crozier, D., Expert, SGT. *Consultation about glass and metal*.

Gill, C., 2009. Expert, University of Sunderland. *Consultation in application of metal and glass.*

Greenwell, C., 2010-2017. Professor, Durham University. *Consultation and Workshops analyses of materials as metal and glass*.

Greiner-Wrona, E., 2013; 2014; 2015. Expert from the Technology Academy in Krakow. *Interviews about glass and corrosion of inclusions.*

Hand, R. 2013-2015. Expert in metal and glass, *Chairman of SGT;* Sheffield University. *Conversations about metals application in glass*.

Kuchinke, P., 2016. Technologist from Cristalica glass. *Conversations about properties of Cristalica glass.*

Martlew, D., 2014. Expert, SGT. *Consultation about inclusion in glass*.

McWilliam, R., 2009-2011. Expert, Durham University. *Consultation and workshops application of programmed Holography on glass*.

Moore, D., 2013-2014. Managing Editor, Society of Glass Technology. Consultation about application of metal and glass.

Pilkington UK, 2010. *UK Technical Bulletin*. Pilkington NSG Group, *Conversations.*

Procyk, B., 2012. Technologist from the Technology Academy in Krakow. *Interviews.*

Rzadkosz, Z., 2011-2014. Expert from Technology Academy in Krakow. *Consultations about metals.*

Svensson, K., 2013. VD/Managing Director of Glasma AB. *Telephone conversations about properties of Glasma glass.*

Wood, D., 2009-2014. Expert, Durham University. *Consultation and workshops coating glass with metals.*

Zasadzinski, J., 2012-2015. Expert from the Technology Academy in Krakow. *Consultations about metals (particularly non-iron metals) and their properties.*