

Leatherland, Eileen (2012) Possibilites for the use of Low Emissivity Glass by Surface Coating Manipulation Within a Creative Context. Doctoral thesis, University of Sunderland.

Downloaded from: http://sure.sunderland.ac.uk/id/eprint/3527/

Usage guidelines

Please refer to the usage guidelines at http://sure.sunderland.ac.uk/policies.html or alternatively contact sure@sunderland.ac.uk.

Contents

I.	List of Artworks Submitted in Partial Fulfilment of the Requirements for the University of Sunderland for the Degree of Doctor of Philosophy	viii
II.	List of Tables	xi
III.	List of Figures	xii
IV.	Author Declaration	xxxii
V.	Acknowledgements	xxxiii

1. Introduction

1.1	Background to the Initiation of the Research	1
1.2	Outline of the Research Field	2
1.3	Rationale for the Research and Research Questions	4
1.4	Aims and Objectives of the Research	5
1.5	Methodology and Methods Used	6
1.6	Components of Work which Constitute the Research Results	8

2. Contextual Review

2.1	Pilkington, Inventors of Float Glass	9
2.2	Creative Use of Float Glass	10
2.3	Development of Coated Flat Glass	13
2.4	Worldwide Energy Issues in Relation to Glass	16
2.5	Double Glazing	18

2.6	Low Emissivity Coating: Function and Heat Control	22
2.7	Coating Processes in Flat Glass Manufacturing	23
2.8	International Market of Flat Glass	25
2.8.1	Value Added Glass	25
2.8.2	Other Coatings Applied to Flat Glass	26
2.9	Interference Issue of Pilkington K Glass and its Resolution	26
2.9.1	Interference as it Relates to this Research	28
2.10	Creative Application of Coatings on Glass	32
2.10.1	Dichroic Coatings	35
2.10.2	2 Colour Surface Applications	38
2.11	The Iridescent Surface	41
2.12	Bubbles	46
2.13	The Influence of Science in Art Research	48
2.14	Summary	52

3. Practical Programme of Testing

3.1	Practical Programme of Testing	53
3.1.1	Identification of Visual Changes	55
3.1.2	Standardised Open Fired Testing	56
3.1.3	Standardised Fused Testing	58
3.1.4	Change of Form Testing	62
3.1.4.	1 Sagging	62
3.1.4.2	2 Bending	63
3.1.4.:	3 Moulding	64
3.1.4.4	4 Suspension	65
3.1.4.	5 Stretching	65

3.1.4.	6 Sliding	66
3.2	Evaluation of results	67
3.2.1	Categorisation of Visual Changes to Post-fired K Glass	67
3.2.1.	1 Colour	67
3.2.1.	2 Iridescence	68
3.2.1.	3 Bubbles	68
3.2.2	Microscopic Examination	68
3.3	Identification of Visual Changes Results	70
3.3.1	Colour	72
3.3.2	Iridescence	73
3.3.3	Bubbles	74
3.4	Standardised Open Tests Results	75
3.4.1	Colour Changes	75
3.4.2	Iridescence	78
3.4.3	Bubbles	80
3.4.4	Material Variable: Surface Coating Manipulation by Abrasion	80
3.4.4.	1 Scoring	81
3.4.4.	2 Scratching	82
3.4.4.	3 Sandblasting	83
3.4.4.	4 Engraving and Etching	84
3.4.5	Environmental Variable: Application of Heat	84
3.5	Standardised Fused Tests Results	89
3.5.1	Colour	89
3.5.2	Iridescence	96
3.5.3	Presence of Bubbles	99
3.6	Change of Form Testing Results	103
3.6.1	Sagging	103

3.7	Summary of Practical Programme of Testing	116
3.6.6	Sliding	115
3.6.5	Stretching	113
3.6.4	Suspension	109
3.6.3	Moulding	108
3.6.2	Bending	105

4. Evaluation of Post-fired K Glass Visual Effects

4.1	Pre-fired Structure of K Glass Low Emissivity Coating	118
4.2	Changes to Post-fired K Coating	119
4.2.1	Optical Microscope Examination of Open Fired K Coating	120
4.2.2	Optical Microscope Examination of Fuse Fired K Coating	121
4.3	Relationship of Bubbles and Ripples to Colouration	122
4.4	Energy Dispersive X-ray Spectroscopy	127
4.4.1	EDS Sample: Gold Coloured Coating	127
4.4.2	EDS Sample: Pink Coloured Coating	129
4.4.3	EDS Sample: Purple Coloured Coating	131
4.5	Contribution of Tin to the Colouration of the Fired Coating	133
4.6	Structure of the Fired Coating: Colouration and Iridescence	136
4.7	Contribution of Ripples to Iridescence and Reflectivity	139
4.8	Pilkington K Glass Coating: the Under Layer	143
4.8.1	Chemical Separation of K Coating Layers	145

5. Mirror Gap Technique

5.1	Exploratory Fusing Tests	148
5.2	Mirror Gap Technique	149
5.2.1	Colour Variations	150
5.2.2	Determination of Range of Colour	152
5.3	Depth of Gap Study	153
5.4	Repeatability for Artwork	158
5.4.1	Dimensional Limitations	158
5.4.2	Multiple Production Potential	160
5.4.3	Gap Volume	163
5.4.4	Reliability of Temperature	165
5.4.5	Degradation of Sandblasting Grit	166
5.4.6	Alternative Methods of Gap Creation	171
5.5	Alternative Low Emissivity Coated Glass	177
5.6	Summary	184

6. Creation of Artwork with Low Emissivity K Glass

6.1	Rationale for the Development of Artwork	185
6.2	Creative Characteristics of Manipulated K Glass	186
6.2.1	The Nature and Interrelationship of Surface Characteristics	186
6.3	Creative Possibilities of Open Fired K Glass	187
6.4	Creative Possibilities of Fired Low Emissivity K Glass using the Mirror Gap Technique	205
6.5	Interferential Properties of the Post-fired K Glass	221
6.5.1	Angle of Viewing	221
6.5.2	Background	223

6.5.3	Light Source	224
6.5.4	Photography	226
6.6	Safety of Presentation	228
6.7	Summary	229

7. Conclusions and Areas for Further Research

7.1	Outcomes in relation to the Aims of the Research	230
7.1.1	In Relation to the First Objective	230
7.1.2	In Relation to the Second Objective:	231
7.1.3	In Relation to the Third Objective:	232
7.1.4	In Relation to the Fourth Objective:	233
7.1.5	In Relation to the Fifth Objective:	234
7.2	Originality of the Research and its Contribution to Knowledge	237
7.2.1	Patent Possibility	239
7.3	Areas for Further Research	241
7.3.1	Development of Artwork using Optiwhite	241
7.3.2	Extension of Developed Methods to Alternative Coatings	241
7.3.3	Commercial Feasibility of the Mirror Gap Technique	242
7.3.4	Investigation of Mirror Gap Technique Fusing Anomaly	242
7.3.5	Further Technical Enquiry	242
7.3.6	Intellectual Property Protection	243
7.4	Concluding Remarks: Dissemination of this Research	243

Appendices

Α.	The Industry of Flat Glass Manufacture	244
В.	Experimental Issues	253
C.	Equipment/Materials used during the Practical Research Process	265
D.	Kiln Specification, Kiln Tests, Firing Schedules	269
E.	SEM/EDS: Scanning Electron Microscopy/ Energy Dispersive X-ray Spectroscopy	280
F.	Additional Test Results	285
G.	Exhibitions Featuring Artworks Developed during this Research	296
Н.	Research Papers Published Relating to this Research	297

List of References

300

I. List of artworks submitted in partial fulfilment of the requirements of the University of Sunderland, for the Degree of Doctor of Philosophy.

Plate 1

6mm K Glass, 230mm x 230mm Geometric iridescent design, Sandblasted

Plate 2

6mm K Glass, 250mm x 250mm Geometric iridescent design Scored and sandblasted

Plate 3

6mm K Glass, 250mm x 250mm Ripple inspired design Scored and sandblasted

Plate 4

4mm K Glass 250mm x 250mm Bubble inspired design Scored and sandblasted

Plate 5

4mm K Glass rectangles 50mm x 15mm On 4mm float glass base 250mm x 250mm Geometric tile design

Plate 6

4mm Saint-Gobain Bioclean Coolite, 250mm x 250mm Double sided geometric design Sandblasted

Plate 7

4mm K Glass and 4mm float glass, 300mm x 300mm Geometric Islam inspired design Mirror Gap Technique

Plate 8

4mm K Glass and 4mm float glass, Blue compatible float, 250mm x 250mm Geometric Islam inspired design Mirror Gap Technique

Plate 9

4mm K Glass and 4mm float glass 250mm x 250mm Geometric iridescent design with Mirror Gap Technique

Plate 10

Saint-Gobain Bioclean Coolite and 4mm float glass, 280mm x 280mm Company Annual Award design Mirror Gap Technique

Plate 11

4mm K Glass and 4mm float glass 300mm x 300mm Washington Bowl 1 Fused

Plate 12

4mm K Glass and 4mm float glass 300mm x 300mm Washington Bowl 2 Fused

Morning Sunlight

Wall panel 4mm K Glass, 4mm float glass, 4mm float glass laminated with fabric inclusions, 950mm x 450mm Mirror Gap Technique

Triptych

Three wall panels 4mm K Glass and 4mm float glass Each 300mm x 250mm, Old English text design within each panel

Pyramid

4mm K Glass and 4mm float glass Stainless steel base 950mm x 300mm x 300mm Geometric design within each panel

ICCG7 Paperweight

4mm K Glass and 4mm float glass 100mm x 100mm Conference gift Screen printed enamel and Mirror Gap Technique

Laminated Panel

4mm K Glass and 4mm float glass Geometric design of iridescent rectangles Stainless steel frame

All Square

4mm K Glass rectangles 50mm x 15mm On 4mm float glass base 500mm x 500mm Concave plate Geometric tile design

Chequer Board

4mm K Glass and 3mm float glass 500mm x 500mm Geometric mosaic of 64 squares. Marble visual effect.

II. List of Tables

Chapter 5

5.1.	Degradation of grit test results measured in mm.	169
Apper	ndix A	
A.1	Chronological summary of significant developments in flat glass production from the medieval period to 1952.	244
A.2	Constituents of float glass.	247
A.3	Types of coatings and their flat glass applications.	251
Apper	ndix B	
B.1	Experimental procedures used for artwork.	253
Apper	ndix D	
D.1	Kiln Test 2005. Temperature (°C) on indicator when reading 700°C on controller.	271
D.2	Kiln test August 2006. Vernier scale readings.	274
D.3	Kiln test 2006. Temperature variations plotted from the sag of glass readings as shown in	
	Table D.2.	274
D.4	Firing schedule fusing Key Numbers.	277
D.5	Firing schedule: Slow 1.	278
D.6	Firing schedule: Slow 2.	278
D.7	Firing schedule: Slow 3 (Slower firing above 520°C).	279

Appendix F

F.1	Gap depth study : dial guage readings.	289
F.2	Gap depth study: graph showing increase in depth of gap.	290

III List of Figures

Chapter 1

1.1	K Glass, pre-fired.	1
1.2	K Glass, manipulated and post-fired.	1
1.3	4mm K Glass, post-fired showing iridescent colouration to the surface.	2
1.4	Look Out', Cate Watkinson, Gateshead, UK, 2004, Height 7m.	4

2.1	Float glass bridge and balustrade, Co. Durham, UK, 2007.	10
2.2	John Hutton, Civic Centre, Newcastle upon Tyne, UK, 1958.	10
2.3	'Linear Fountain', John Gilbert Luebtow, San Francisco, USA.	11
2.4	Wall Panel, Jan Hein van Stiphout , 2002 float glass.	12
2.5	'Perpendicular', Jan Hein van Stiphout, 2007, float glass installation.	12
2.6	'Spinal Wave' (detail) Vanessa Cutler, 2005, 1180mm x 70mm, float glass.	12
2.7	'Frozen Form', Gavin Marshall, 2011, float glass.	13
2.8	Recycled float glass tableware.	13
2.9	Float glass trophy.	13
2.10	Fagus Factory, Alfeld, Germany, 1911.	14
2.11	Lever House, New York, USA,1951-2.	15
2.12	Seagram Building, New York, USA,1954-8.	15

2.13	Temperate House, Royal Botanical Gardens, Kew, London, UK, 1860.	19
2.14	Cite de Refuge, Paris, France, 1930-31.	20
2.15	St. George's School, Wallasey, Cheshire, UK, 1961.	20
2.16	Basic Double Glazed Unit.	21
2.17	Low emissivity heat reflecting coating.	23
2.18	European Market Structure Coated Glass Demand by Value, 1995 v 2006.	26
2.19	Float and K Glass colour comparison.	27
2.20	Film of oil on a puddle showing iridescence colouration.	28
2.21	Reflection and refraction of light.	29
2.22	Multiple reflections from two surfaces.	30
2.23	Interference.	30
2.24	Constructive interference.	31
2.25	Destructive interference.	31
2.26	'Cube', Marian Karel, 1998, glass panels, 3.5m x 2.4m x 1.85m.	32
2.27	'6x6x4-A,B', Larry Bell, 1995, Four 12mm glass panels coated with nickel- chrome each 6' x 6' x 1/2".	33
2.28	'My Body Your Body', Anish Kapoor, 1993. Fibreglass and pigment , 248cm x103cm x 205cm	34
2.29	'Glass Curtains', Robyn Smith, 2008, recycled glass.	35
2.30	Laura Johnston, ' Prismatic', 2003, dichroic coated glass and stainless steel.	36
2.31	'A Moment in Time', Peter Aldridge (1998), Height 3m. Steuben Starphire lead free glass and dichroic coated glass.	37

2.32	Al Faisaliah Centre, Brian Clarke, Riyadh, 1999, 79' x 265', enamel on float glass.	38
2.33	The Sage Balustrade, Kate Maestri, Gateshead, 2004, 100m, screen printed enamels on float glass.	39
2.34	'Eyefire', Michael Blayenberg, Bonn, 2000, 5m x 13m,, holographic film.	40
2.35	Photomicrograph of iridised surface.	42
2.36	SEM image of cross section of iridescent crust.	42
2.37	SEM image showing surface laminar distribution.	42
2.38	Iridised Bronze Glass vase, Thomas Webb, c.1878.	43
2.39	Tiffany Lustre Ware Vase, c.1900, Height 10".	44
2.40	'Test beaker' Frances Federer, 2008, Height 75 cm, blown glass, hot and cold gilded and painted.	45
2.41	Orrefors 'Ariel' Vase, Edvin Öhrström, 1937, Height 16.5cm.	46
2.42	'VR Tech', Raymond Flavell, 2001, blown glass vessel with encased voids.	47
2.43	'Seedy Glass' by Spectrum Glass, USA.	47
2.44	'ATP synthase' Colin Rennie, 2007, float glass, 1m x1m x 1m.	51
2.45	'Micro Macro 4', Katharine Dowson, Collaboration with Dr Gabriele Jordan, Acrylic, light reacting glass lenses, 23cm cubed.	52

3.1	Fused Glass format of fusing positions of K and float glass.	59
3.2	Enclosed Glass format of fusing positions of K and float glass between two pieces float glass.	60

3.3	Grid Format of fusing position of two sets of three strips of K at right angles to each other between two pieces of float glass.	60
3.4	Sagging, K and float glass pieces placed on metal form.	63
3.5	Bending, K and float glass pieces placed on metal form.	63
3.6	More severe bending, K Glass over steel tube.	64
3.7	Moulding, K Glass placed over brass waste.	64
3.8	Suspension, K and float glass pieces held in suspension.	65
3.9	Stretching, K and float glass pieces hung in suspension.	66
3.10	Sliding K pieces against metal form.	66
3.11	Studio microscope photography.	69
3.12	6mm K, post- fired at 740°C, 60% overall change to the surface.	71
3.13	4mm K, overall surface change from 680°C–820°C.	71
3.14	6mm K, overall surface change from 680°C–820°C.	71
3.15	6mm K, post-fired at 800°C, 100% colour change.	72
3.16	4mm K, colour change from 680°C–820°C.	72
3.17	6mm K, colour change from 680°C–820°C.	72
3.18	6mm K, post-fire at 780°C, 90% Iridescence change.	73
3.19	4mm K, Effect of iridescence from 680°C–820°C.	73
3.20	6mm K, Effect of iridescence from 680°C–820°C.	73
3.21	6mm K, post-fired at 790°C, presence of bubbles.	74
3.22	4mm K, presence of bubbles from 680°C–820°C.	74
3.23	6mm K, presence of bubbles from 680°C–820°C.	74
3.24	4mm K, post-fired 780°C.	76

3.25	4mm K, post-fired at 780°C, showing ripple linear formation.	76
3.26	4mm K, post-fired 790°C.	76
		10
3.27	4mm K, post-fired at 790°C, showing chaotic ripple formation.	76
3.28	4mm K, post-fired at 800°C.	77
3.29	4mm K, post-fired at 800°C, showing ripple and fold formation.	77
3.30	6mm K, post-fired at 775°C, coating fired down.	77
3.31	6mm K, post-fired at 775°C, coating fired down, micrograph.	77
3.32	6mm K, post-fired at 750°C.	79
3.33	750°C iridescence ripples.	79
3.34	6mm K, post-fired at 770°C.	79
3.35	770°C iridescence ripples.	79
3.36	6mm K, post-fired at 790°C.	79
3.37	790°C Iridescence ripples.	79
3.38	4mm K, post-fired at 800°C, showing bubble formation.	80
3.39	4mm K, scored surface, coating fired up showing bubbles along score lines.	81
3.40	4mm K, scored surface, coating fired down showing smaller bubbles along score lines.	81
3.41	4mm K, post-fired at 800°C, with scored surface.	81
3.42	4mm K, post-fired at 800°C, photograph of scored surface ripples.	81
3.43	6mm K, post fired at 775°C showing variation of scratching.	82
3.44	P100 wet and dry	82
3.45	Coarse wire wool.	82

3.46	Coarse sanding belt.	82
3.47	Diamond pad.	82
3.48	4mm K, post fired at 800°C, sandblasted, showing iridescence differences.	83
3.49	Micrograph showing edge of sandblasted area with linear ripple formation.	83
3.50	4mm K, post-fired at 775°C, showing sandblasting delineation.	83
3.51	Micrograph of top sandblasted area.	83
3.52	4mm K, post-fired at 775°C, using standardised test schedule showing 'patches' on surface.	85
3.53	6mm K, post-fired at 775°C using standardised test schedule showing 'patches' on surface.	85
3.54	4mm K, post-fired at 775°C with slow schedule 2, showing no patches.	85
3.55	6mm K, post-fired at 775°C with slow schedule 2, showing no patches.	85
3.56	4mm K, post-fired at 775°C, hold time test, fired from 10min to 60min showing change with length of hold.	86
3.57	6mm K, post-fired at 775°C, hold time test, fired from 10min to 60min showing change with length of hold.	86
3.58	4mm K, post-fired at775°C, 2hr hold test.	87
3.59	6mm K, post-fired at775°C, 2hr hold test.	87
3.60	4mm K, post-fired at 775°C, test for repeated firings.	88
3.61	6mm K, post-fired at 775°C, test for repeated firings.	88
3.62	4mm float over 4mm K, post-fired at 725°C, in Fused Format showing pink/gold colouration.	90
3.63	4mm float over 4mm K, post-fired at 775°C, in Fused Format showing pink/gold/blue/green colouration.	90
3.64	6mm float over 4mm K, post-fired at 775°C, in Fused Format showing stronger colouration.	90

3.65	3mm greenhouse glass over 4mm K, post-fired at 775°C, in Fused Format showing strong gold colouration and bubbles.	91
3.66	4mm float glass with non-tin side over 4mm K, post-fired at 775°C, in Fused Format showing strong gold colouration and bubbles.	91
3.67	4mm float over 4mm K, post-fired at 775°C with fusers glue showing reduction in colouration.	92
3.68	4mm K between 3mm float, post-fired at 800°C, showing gold colouration.	93
3.69	4mm K between 4mm float, post-fired at 800°C, showing pink/blue colouration.	93
3.70	4mm K between 6mm float, post-fired at 800°C, showing gold colouration.	93
3.71	4mm K strips enclosed in 4mm float, post-fired at 800°C, showing gold and pink/purple/blue colouration.	94
3.72	4mm K strips enclosed in 4mm float glass (end view), post-fired at 775°C, showing tiny gaps above.	95
3.73	4mm K strips enclosed in 4mm float glass (plan view), post-fired at 775 °C, showing pink and gold separate colouration.	95
3.74	4mm K, post-fired at 775°C, fused cut open sample showing gold iridescence.	96
3.75	4mm K, post-fired at 775°C, fused cut open sample showing peach/pink iridescence.	96
3.76	3mm float over 4mm K, post-fired at 775°C, in Fused Format showing iridescence pattern.	97
3.77	6mm K between 4mm float, post-fired at 800°C, in Enclosed Format showing gold and purple colouration.	97
3.78	4mm K strip between 4mm float (detail), post-fired at 775°C, fused in Grid Format showing pink colouration.	98
3.79	4mm K and 4mm float, post-fired at 775°C, in Fused Format showing bubbles.	99

3.80	4mm K and 4mm float, post-fired at 800°C, in Fused Format showing bubbles.	100
3.81	4mm K between 4mm float, at 800°C, Enclosed Format gold patch showing bubbles.	100
3.82	4mm K between 4mm float, at 800°C, Enclosed Format pink patch showing bubbles and ripples.	101
3.83	4mm K strips between 4mm float, post-fired at 800°C, in Grid Format showing bubble formation.	101
3.84	4mm float over 4mm K, post-fired at 775°C, in Fused Format with ceramic matting strips placed on top showing limitation of bubbles.	102
3.85	4mm float over 4mm K, post-fired at 775° in Fused Format showing channelling of bubbles.	103
3.86	6mm K, post-fired at 775°C, sagging, showing colour difference.	104
3.87	6mm K, post-fired at 775°C, bending, showing colour difference.	105
3.88	Bending curve diagram noting corresponding points of iridescence.	106
3.89	6mm K, post-fired at 775°C, bending curve, sections cut for microscopic examination.	106
3.90	Bending curve point 1.	107
3.91	Bending curve point 6.	107
3.92	Bending curve point 2.	107
3.93	Bending curve point 5.	107
3.94	Bending curve point 3.	107
3.95	Bending curve point 4.	107
3.96	6mm K, post-fired at 775°C, coating fired down, after moulding showing strong pink/purple colouration.	108

3.97	6mm K, post-fired at 775°C, coating fired up, after moulding showing split coating and multiple lines of bubbles.	109
3.98	6mm K, moulded, showing split coating and line of bubbles.	109
3.99	6mm K (higher magnification), moulded, showing edge of ripples.	109
3.100	4mm K, post-fired at 775°C, suspended, coating on under side showing cracks to coating.	110
3.101	4mm K, post-fired at 775°C, suspended, coating on upper side showing less defined cracks.	110
3.102	4mm K, post-fired at 775°C, suspended, coating under side – convex.	111
3.103	4mm K, post-fired at 775°C, suspended, coating under side – concave.	111
3.104	4mm float, post-fired at 775°C, suspended - flat.	111
3.105	4mm K, post-fired at 775°C, showing ripple formation.	112
3.106	6mm K, post-fired at 775°C, showing compact ripple formation.	112
3.107	6mm K and 6mm float, coating stability test, showing curve of glass supports.	113
3.108	4mm K, post-fired at c.775°C, stretching, showing cracking and spread coating.	113
3.109	6mm K, post-fired at c.775°C, stretching, showing cracking and spread coating.	114
3.110	6mm K (left) and 6mm float, post-fired at c.775°C, showing comparative stretching.	114
3.111	6mm K, at c.775°C, stretching, showing linear ripples and split coating.	115
3.112	4mm K post-fired, showing possible sliding of coating	115
3.113	6mm K post-fired, showing possible sliding of coating.	115

4.1	Pre-fired 6mm K – edge view showing coating.	119
4.2	6mm K, post-fired surface.	120
4.3	6mm K, post-fired surface, plan view showing ripples.	120
4.4.	6mm K, post-fired, edge view 1 showing surface ripples.	120
4.5	6mm K, post-fired, edge view 2 showing surface ripples.	120
4.6.	6mm K, post-fired, overhang - plan view showing surface ripples.	121
4.7	6mm K, post-fired, overhang, edge view showing ripples.	121
4.8.	Gap formation fused format – pre- firing diagram.	122
4.9.	Gap formation fused format – post- firing diagram.	122
4.10	Gap formation enclosed format – pre-firing diagram.	122
4.11	Gap formation enclosed format – post firing diagram.	122
4.12	Opened fused gold, pink and purple samples.	123
4.13.	Gold fused edge view showing dense bubbles.	123
4.14.	Gold fused plan view showing dense bubbles.	123
4.15	Gold fused plan view examined under angled light showing bubbles + presence of ripples.	123
4.16	'Photoshop' generated image of bubbles on top of ripples.	124
4.17	Pink fused edge view showing bubbles + ripples.	124
4.18	Pink fused plan view showing less dense bubbles + ripples.	125
4.19	Purple fused, edge view showing ripples only.	125
4.20	Purple fused, plan view showing ripples only.	126

4.21	Fired surface structures diagram.	126
4.22	SEM gold sample, small piece of fuse fired K (opened) showing coating with gold colouration.	127
4.23	EDS gold sample x 300, showing general image of surface with unidentified holes.	128
4.24	EDS gold sample x 2000 showing presence of tin element as white beads.	128
4.25	SEM pink sample, small piece of fuse fired K (opened) showing coating with pink colouration.	130
4.26	SEM pink sample x 300 showing presence of ripples.	130
4.27	EDS pink sample x 2000, yellow/white grainy colouration representing tin element showing continuous layer.	131
4.28	SEM purple sample showing coating with purple colouration.	131
4.29	SEM purple sample x 300, showing ripples being more defined than those in pink sample.	132
4.30	EDS Purple sample x 2000, yellow/white grainy colouration representing tin element showing continuous layer.	133
4.31	Air annealing sprayed fluorine-doped tin oxide at 720°C.	134
4.32	Air annealing sprayed fluorine-doped tin oxide at 900°C.	134
4.33	Post-fired ITO showing iridescent pink surface.	135
4.34.	ITO fired coating showing ripples on surface.	135
4.35	Flat gold colouration showing bubbles.	137
4.36	Flat gold to iridescent gold colouration showing fewer bubbles.	137
4.37	Pink colouration showing fewer bubbles and underlying ripples.	138
4.38.	Purple colouration showing ripples and no bubbles.	138

4.39	Post-fired 6mm K showing dull and shiny areas.	140
4.40	Dull area with maze like ripples.	140
4.41	Diagram of scattered light resulting in dull areas.	140
4.42	Shiny area with elongated ripples.	141
4.43.	Diagram of evenly reflected light resulting in shiny areas.	141
4.44.	6mm K open fired, edge view showing ripples which will reflect light.	142
4.45	Diagram of light reflected of two surfaces.	142
4.46	6mm K and 6mm float showing fuse fired gap.	142
4.47	Spectrum of Silicon Dioxide (Si 0_2) at thicknesses from 1 to 1000 nm.	144
4.48	Spectrum of Silicon Nitride (Si $_3N_4$) at thicknesses from 1 to 1000 nm.	144
4.49	Silicon Dioxide (Si0 ₂) calculator.	145
4.50	Silicon Nitride (Si ₃ N ₄) calculator.	145
4.51	6mm K, post-fired at 775 °C, with half of coating removed.	146
4.52.	6mm K untreated surface showing ripple and bubble structure.	147
4.53	6mm K, post-fired, treated/untreated interface, showing removal of coating on treated surface.	147
4.54	6mm K, post-fired, treated surface, showing complete removal of coating.	147

5.1	Mirror Gap Technique pre-fired positions.	149
5.2	Mirror Gap Technique post-fired positions.	149

5.3	4mm K and 4mm float, post-fired at 775°C, in Mirror Gap Technique format.	150
5.4	Fused format showing variable effects of gold colouration.	151
5.5	Separation of colours in fused double layer test.	151
5.6	Gold colouration - 0.25mm.	152
5.7	Pink colouration - 0.50mm.	152
5.8	Purple colouration – 0.75mm.	152
5.9	Gap depth study – panel of sandblasted squares.	154
5.10	4mm K and 4mm float, post-fired at 825°C, gap depth study panel.	155
5.11	6mm K and 4mm float, post-fired at 775°C, gap depth study panel (detail).	155
5.12	Gap depth study selected photographs and micrographs.	156
5.13	Mercier dial gauge.	157
5.14	Mirror Gap Technique showing smooth coating.	158
5.15	Mirror Gap Technique showing sagged centre area.	158
5.16	Design templates for ICCG7 2008 Conference gift.	160
5.17	Pieces ready to sandblast at Creative Glass.	161
5.18	ICCG 7 Finished Gift.	161
5.19	Commission of finished gifts for ICCG7 Conference.	162
5.20	Volume test template (mm).	164
5.21	4mm K, post-fired at 775°C, volume test for gold colouration.	164
5.22	4mm K, post-fired at 775°C, volume test for pink colouration.	164
5.23	4mm K, post fired at 775°C, showing bands of colouration.	165
5.24	Arrangement for sandblasting grit study.	167

5.25	Grit study glass.	168
5.26	Grit study showing blasted gap.	168
5.27	New grit showing sharp edges.	169
5.28	Used grit showing rounded edges.	169
5.29	First Mirror Gap test with new grit showing purple colouration.	170
5.30	Fifth Mirror Gap test with used grit showing gold colouration.	170
5.31	First sandblasted gap showing purple colouration.	171
5.32	Third sandblasted gap showing gold colouration.	171
5.33	4mm K and 4mm float glass, post fired at 775°C, gaps made with 3mm float glass pieces between.	172
5.34	4mm K and 4mm float glass, post fired at 775°C, gaps made by with water jet cut 4mm float.	173
5.35	'Fireworks' Artwork test piece, 2007, 300mm x 250mm, 6mm K and 6mm float, engraved by Claudia Phipps.	173
5.36	4mmK and 4mm float, post-fired at 775°C, gaps made with 3 thickness of 0.7mm BullseyeThinfire.	174
5.37	4mmK and 4mm float, post-fired at 775°, gaps made with 1 thickness of 3mm ceramic matting.	174
5.38.	Design cut out of 3mm ceramic matting.	175
5.39	4mm K, post-fired image.	175
5.40	4mm K with double Thinfire 'frame'	176
5.41	4mm K and Thinfire 'frame' covered with kiln shelf.	176
5.42.	4mm K, post-fired K at 775°, showing a very pale pink iridescence.	176
5.43	4mm Optitherm, post-fired at 775°C.	177
5.44	4mm Optitherm and 4mm float, post-fired at 775°C, Mirror Gap Technique.	177

5.45.	4mm ST150, post-fired at 775°C.	178
5.46	ST 150 solar coated side, post-fired at 775°C.	179
5.47	ST150 low e coated side post-fired at 775°C.	179
5.48	4mm ST150, post-fired at 775°C, bending test.	180
5.49	ST150, Mirror Gap Technique commission application panel.	180
5.50	AGC Planibel G, pre-fired and post-fired at 775°C.	181
5.51	AGC Sunergy Blue, pre-fired and post-fired at 775°C.	182
5.52	Guardian SunGuard Solar Silver 08, pre-fired and post-fired at 775°C.	182
5.53	Sunergy Dark Blue Mirror Gap Technique test.	183
5.54	Stopray Vision Mirror Gap Technique test.	183

6.1	'Plate 1', Eileen Leatherland, 2011, 230mm x 230mm, 6mm K, detail showing blue border colouration.	188
6.2	'Plate 2', Eileen Leatherland, 2011, 250mm x 250mm, 6mm K, detail showing scoring and sandblasting design.	189
6.3	'Plate 3', Eileen Leatherland, 2011, 250mm x 250mm, 6mm K, detail showing interferential colouration and iridescence.	190
6.4	Microscope image of bubbles.	191
6.5	'Plate 4', (detail) after first firing showing 'bubble' relief.	191
6.6	'Plate 4' after second firing showing debris in mounds and poor surface marking.	192

6.7	'Plate 4' Eileen Leatherland, 2011, 250mm x 250mm, 6mm K, showing improved relief 'bubble' design.	192
6.8	'Plate 5', Eileen Leatherland, 2011, 250mm x 250mm 6mm K, pieces in tile formation.	193
6.9	'Plate 6', Eileen Leatherland, 2011, 250mm x 250mm, ST150, showing double sided design. Detail showing 'unpolished' sandblasted surface.	194
6.10	4mm K fired 'face to face'.	195
6. 11	4mm K, post-fired face to face test piece, after sandblasting and bending.	196
6.12	4mm K, post-fired face to face, test piece showing cut and fused to blue painted float.	197
6.13	Test for 'Chequer Board', Eileen Leatherland, 2011, 4mm K Glass fired 'face to face' cut and fused between float.	198
6.14	Test for 'Chequer Board (2)' Eileen Leatherland, 2011, 4mm K Glass fired 'face to face', on blue enamelled float glass.	198
6.15	Laminated wall panel, Eileen Leatherland, 2011, 4mm K between 4mm float glass.	199
6.16	4mm K and 6mm K, flat abrasion test squares.	200
6.17	4mm K and 6mm K, curved abrasion test pieces.	200
6.18	4mm K curved diagonal strips showing interferential response to light source.	201
6.19	4mm K curved diagonal bent over copper pipe.	202
6.20	4mm K, sandblasted bubble and ripple test design bent over copper pipe.	202
6.21	'To Nowhere', Eileen Leatherland, 2011, 6mm K scored text design.	203
6.22	'Necklace', Eileen Leatherland, 2011 4mm K.	204

6.23	Small pyramid, 100mm x 100mm x 60mm 6mm K.	205
6.24	Washington Bowls', Eileen Leatherland, 2008 300mm x 300mm 4mm K and 4mm float glass.	206
6.25	'Plate 7', Eileen Leatherland, 2007, 300mm x 300mm, 4mm K and 4mm float glass. Mirror Gap Technique.	208
6.26	'Plate 8', Mirror Gap Technique, Eileen Leatherland, 2007, 250mm x 250mm, 4mm K, 4mm float and blue float. Detail showing bubbles formed between fused layers.	209
6.27	'Plate 9', Test plate, 4mm K and 4mm float, Mirror Gap Technique with scored upper layer.	210
6.28	'Plate 9' Eileen Leatherland 2011, 250m x 250mm 4mm K and float glass. Mirror Gap Technique.	211
6.29	'Plate 10' Eileen Leatherland 2009, 280mm x 280mm, 4mm K and float glass, Mirror Gap Technique.	212
6.30	Dubai stencil, 270mm x 200mm, 4mm K and 4mm float, Mirror Gap Technique.	213
6.31	'Falcon', 330mm x 270mm, 4mm K and 4mm float, Mirror Gap Technique.	214
6.32	'Faces 1 and 2', 300mm x 210mm and 220mm x 160mm, 4mmK and 4mm float, Mirror Gap Technique. Positive and negative versions of photographic image.	215
6.33	'Triptytch' (detail), Eileen Leatherland, 2006, One of 3 Panels each 300mm x 250mm, 4mm K and 4mm float, Mirror Gap Technique.	216
6.34	'Pyramid', Eileen Leatherland, 2006, Height 950mm, 4mm K and 4mm float glass, stainless steel base, Mirror Gap Technique.	217
6.35	'Squares', 165mm x 165mm x 23mm, 6mm K and 6mm float, Mirror Gap Technique.	218
6.36	KOW fused test piece, 100mm x 100mm x 23mm, 2011, KOW and Optiwhite square, Mirror Gap Technique.	219

6.37	'Dhow' and detail, Eileen Leatherland, 2007, Height 900mm. 4mm K and 4mm float, Mirror Gap Technique.	220
6.38	Angle of viewing of flat glass showing colour seen at all angles through 160°.	222
6.39	Angle of viewing of curved glass showing colour seen at all angles of reflection of light through 160°.	223
6.40	4mmK moulded test on dark background.	224
6.41	4mmK moulded test on light background.	224
6.42	Light background. No additional lighting.	225
6.43	Light background. Additional front lighting.	225
6.44	Dark background. No additional lighting.	225
6.45	Dark background. Additional front lighting.	225
6.46	Morning Sunlight ', Eileen Leatherland, 2009, Design by Manny Ling, 950mm x 450mm, 4mm K and 4mm float glass.	227

Appendix A

A.1.	The basic float glass process.	248
A.2.	Off line Coating process.	249
A.3.	Online Coating process.	250

Appendix B

B.1	Effect of coloured base to surface changes.	256
B.2	AGC Glass coatings open fired (1).	258
B.3.	AGC Glass coatings open fired (2).	259
B.4	AGC Glass coatings open fired (3).	260
B.5	AGC Glass coatings open fired (4).	261
B.6	AGC Glass coatings – Mirror Gap Technique.	262
B.7	Guardian Glass coatings open fired (1).	263
B.8	Guardian Glass coatings open fired (2).	264

Appendix C

C.1	Littlefuse Blade Fuse Tester.	265
C.2	DIG Coatings Detector.	265
C.3	Tin side detector.	266
C.4.	Detector showing tin side.	266
C.5	Detector showing non-tin side.	266

Appendix D

D.1	Author's Kilncare FK-5 Kiln.	269
D.2	Controller. Stafford Instruments ST105.	270
D.3	Kiln test 2006, bridge of 6mm float glass.	272
D.4	Kiln test 2006, pre-fired.	272
D.5	Kiln Test 2006, post-fired.	273
D.6	Measurement of sag with Vernier Scale.	273

Appendix E

E.1	Scanning electron microscope (SEM).	280
E.2	SEM images – gold sample.	282
E.3	SEM images – pink sample.	283
E.4	SEM images – purple sample.	284

Appendix F

F.1	4mm K at 850°C for 30min and micrograph.	285
F.2	4mm K at 875°C for 30min and micrograph.	285
F.3	4mm K at 900°C for 30min and micrograph.	286
F.4	4mm K at 925°C for 30min and micrograph.	286
F.5	4mm K at 950°C for 30min and micrograph.	286
F.6	6mm K at 850°C for 30min and micrograph.	287
F.7	6mm K at 875°C for 30min and micrograph.	287
F.8	6mm K at 900°C for 30min and micrograph.	287
F.9	6mm K at 925°C for 30min and micrograph.	288
F.10	6mm K at 925°C for 30 min and micrograph.	288

F.11.	6mm K at 925°C for 1hour and micrograph.	288
F.12	Sandblasted squares 1-7.	291
F.13	Sandblasted squares 8-14.	292
F.14	Sandblasted squares 15-21.	293
F.15	Sandblasted squares 22-28.	294
F.16	Sandblasted squares 28-35.	295

III. Author declaration

According to the regulations I declare that during my registration I was not registered for any other degree. Material in this thesis has not been used by me for any other academic award.

IV. Acknowledgements

I would like to thank my director of studies, Professor Kevin Petrie and my supervisor, Cate Watkinson for their support and guidance throughout the research, also Sylvie Vandenhouke for her enthusiasm during her short period of supervision.

I wish also to express my sincere gratitude to Dr. Douglas Crozier for his expertise and patience in helping to interpret the scientific information relating to this project; to David Gelder, formerly of Pilkington Group Limited, for his time and technical knowledge and to Professor Andrew Monkman of Durham University for the facilitating of the SEM imaging and his specialist interest. Appreciation must also be given to Professor Stephanie Atkinson and Faculty of Education for technical support and the provision of microscopy facilities by Professor Mark Davies.

Although he sadly died before my research began, I could not omit the inspiration of Dr. Collin Gill, without whom this project would not have been initiated or the support of his widow, Dr. Margaret Gill, who has maintained a close interest in my work.

Throughout my study at the University of Sunderland I have benefitted from the most outstanding assistance from the staff at Ashburne Library. Jan Dodshon and her team, provide a highly professional, efficient and exceptionally friendly service which I found to be invaluable. I must also include Tim Betterton and his technical team for their help with the production and presentation of artwork. I wish most sincerely to thank them all.

I would also like to extend my appreciation to Ken Armstrong of Clayton Glass for the provision of some of the glass used within this research and, latterly, Dr. Kevin Sanderson of Pilkington UK Limited who has provided K coated Optiwhite glass for further research.

Finally, my inestimable gratitude is owed to my family who will no longer have to share me with my research. To Lincoln for his experience, patience and unfailing confidence in my ability to achieve my goal, to Joanne for her encouragement and understanding and, especially, to my long suffering husband Mike, for his tolerance and technical support throughout my years of study.