Trusting the body.
Colour pattern making in glass inspired by Lithyalin glass formula.

Technical Appendix.

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1.1.1. KILN CASTING

1.1.2. Kiln specification:

A basic ceramic kiln was employed with maximum design temperature of 1350°C.
The kiln used for almost all firings was a front loader - Kilns & Furnaces Ltd with the dimensions of 38 / 38 / 42 cm. The Kiln Temperature Controller is a Stafford Instruments ST314A with nine ramps per program that allow annealing glass. The kiln has two vents that face air extraction provided in the RCA kiln room.

1.1.3. Refractory Mould:

Different formulas for refractory moulds were tested. A receipt chosen for most of the moulds was the one formulated through analysis and adaptation of Almeric Walter's speculated refractory mix.[1]

The refractory mix of Almeric Walter:		The refractory mix employed:	
Plaster	28%	Pottery basic plaster:	20%
Calcined kaolin	22%	Crystalcast Plaster:	40%
Kaolin	3%	UK's kaolin[2]:	20%
Ground sand	10%	Quartz:	20%
Sand in grains	37%		

[1] Cummings K., Contemporary Kiln-Formed Glass, A World Survey, A & C Black, London: 2009, p. 36
[2] https://www.bgs.ac.uk/downloads/start.cfm?id=1362

A hand built outer layer of the refractory mould, following the same formula, consisted of extra glass fiber, talc and sometimes chicken wire.

- Materials:

- Plasters:

- Pottery basic beta plaster; plaster/water ratio: 2,4kg /litre
- Newcast 96 is a formulated hemihydrate plaster; plaster/water ratio: 1,75kg/litre
- Crystalcast Plaster is a formulated hemihydrate plaster produced from naturally occurring high purity gypsum mineral; plaster/water ratio: 3.57kg/litre
- Quartz

- Kaolin / China Clay:

Kaolin has been used for the refractory mould inner face coating (up to 3 mm) and for the refractory mix up to 20 %. The UK's china clay consists of approximately 40% of alumina and with its low plasticity and a high refractory quality allows for easy release of mould after firing.

- Refractory Sand

- Glass fiber

- Drill with mixer

- Releasing agents while working with plaster-silica mix: soft soap (applied with a large painting brush), shellac

- Wooden cocktail sticks used for casting complex glass shapes (sprues)
- Jeweller's scale - capable of 100 g with 0.01 gram increments
- Terracotta flowerpots
- Gum arabic, talc, quartz
- Metal fringes and chicken wire in case of making double-sided moulds

1.1.4. Glass

The RCA furnace, clear glass was used in almost all the tests as a colour binder. Taking into account both coefficient of expansion and viscosity range, Glasma supposes to fit a wide range of colours available from different glass suppliers: Kugler, Banas, Reichenbach, Zimmermann, and Gaffer. It is a soda-lime, lead free crystal with the inclusion of barium that gives relatively high index of refraction.

- Specifications for the Glasma glass:

Density = 2.54 kg/dm3 ± 0.01 kg/dm3

Refractive index n = 1.520±0.005

Recommended Annealing Temperature: 510 ± 5°C[3]

This formula, apart from having low working temperatures has also quite long working time.

The amount of the Glasma glass was highly limited as my main focus was directed on manufacturing an opaque patterned coloured glass. Through kiln casting I could manufacture my own colours using metal oxides although I have been limited in the creation of a rich colour scheme. Due to my pastel colour palette preference, at the beginning of my work I used additionally Gaffer, Kugler and Banas rods and powders.

3 http://www.glasma.se

- Specifications for colour glasses:

- Gaffer soda-lime transparent colours*[4]:

The amount of the Glasma glass was highly limited as my main focus was directed on manufacturing an opaque patterned coloured glass. Through kiln casting I could manufacture my own colours using metal oxides although I have been limited in the creation of a rich colour scheme. Due to my pastel colour palette preference, at the beginning of my work I used additionally Gaffer, Kugler and Banas rods and powders.

Linear expansion coefficient (a): 92 x 10^{-7} (20-300°C)

Density: 3,6 kg/l

Casting temperature (Recommended): 780-850°C

Annealing temperature (tg): 430°C
Strain point: 390°C / Softening point: T107.6 594°C / Working point:
T104 902°C (1655°F)

Refractive index (G-210): (nd) 1.620

* Specifications for the Gaffer opaque colours may differ as some of them are lead-free

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[4] http://www.gafferglass.com/technical/casting-properties/

- Kugler colour glass[5]:

The lead colour frits have been used in almost all tests.

* In actual fact, many lead-free frits available on the market are made of compounds of vitreous material with a very low percentage of lead.

Linear expansion coefficient for opaque colours: from 89 to 93 x 10^{-7}

Annealing temperature (tg): 500°C / Transforming temperature: 460°- 500°C

- Banas colour glass for casting[6]:

Linear expansion coefficient (a): 101 x 10^{-7} (20-300°C)

Casting temperature (Recommended): 820 - 860°C

Annealing temperature (tg): 475°C

Density: 2,5 kg/l

- Weight calculations:

The volumes of solids can be calculated from measurements by several methods. The weighing method applied was determination of volume by displacement. A submerged glass block displaces a volume of liquid equal to the volume of the object. The volumes of liquids easily can be determined directly

5 https://www.kuglercolors.de/en/products/kugler-colors/colored-glass-grits/
6 http://www.banasglass.com/en/barevnice/

with calibrated glassware, such as graduated cylinders, pipets and burets.

The other method of weighing solids, thus less accurate, is to measure the weight of a clay model and multiply it by 1,4 - the result is equal the approximate mass of the glass needed.

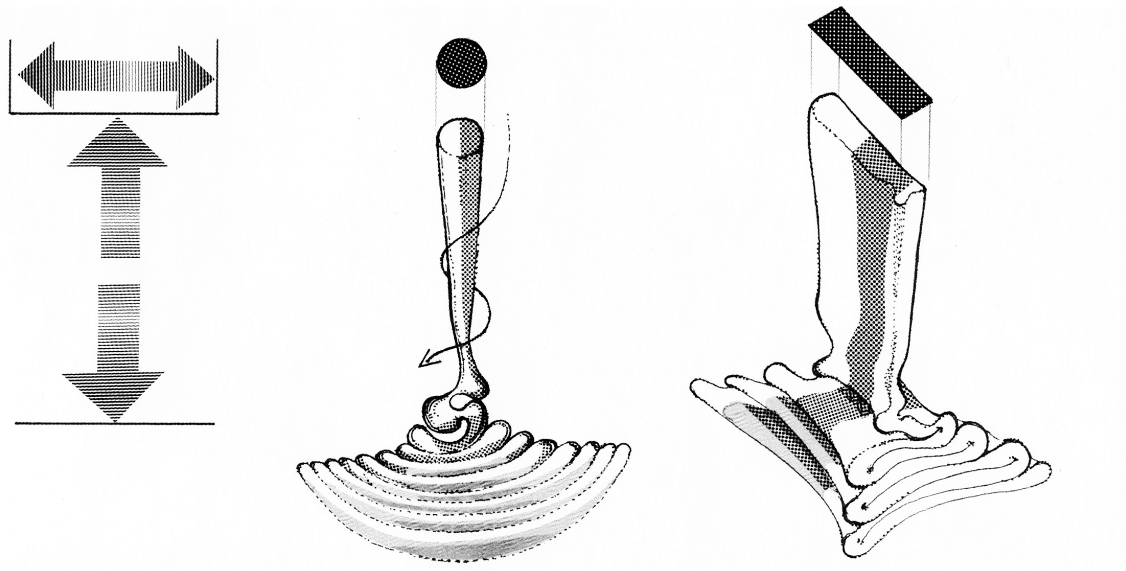
- Safety issues:

The chemical reaction that occurs when plaster-silica is mixed with water is exothermic and, in large volumes, can burn the skin. To avoid prolonged or repeated wet contact with it impermeable gloves should be worn and a barrier cream applied. A high quality dust mask should be used while working with silica-based materials and, if possible, with any other glassmaking materials - glass powders, metallic oxides. If available, the use of air extraction is highly recommended.

1.1.5. Glass casting through an aperture.

Figure 1: Glass sample with folded loops the result of coiling action.

By testing different metallic oxides, I aimed to find out how to manufacture an opaque pattern coloured glass, which resembles precious stones. My aim was to examine glass flow subjected to various conditions. Generally, a stream of glass is created either in crucible pouring or in kiln casting - through an aperture. My principle aim was to get control over the shape of the glass stream. The minimum casting temperature was looked for in order to create multi-coloured striated patterns instead of a coalesced mass of a single colour in glass. Furthermore, I was interested in recording the circular coiling flow that is peculiar to glass material. At low temperature pouring, the individual coils do not completely merge: the actual size stream of glass, and its boundary with the air, are captured (please refer to *Figure 1*).



Casting through an aperture. Influences and variables
When casting glass through apertures with the intention of creating multi-coloured striated patterns in the glass the two main variables are size of aperture and length of drop to the mould. The former influences the shape of the folded patterns and the latter the size of the actual stream of glass, and through it the density of detail within the patterns. Although all glass flows will tend towards a circular flow it is possible, by for instance pouring through a slot rather than a hole to cause a characteristic ribbon-like folded pattern in the glass. Also the way in which the reservoir is charged with differently coloured glasses, the relative size of the glass pieces and their position in the receptacle are all capable of influencing the way in which the flow is coloured, and through it the pattern imparted to the glass. Other possible variants are multiple apertures within the same reservoir or multiple reservoirs which will keep the colours separate until the glass reaches the mould. Variants can be achieved by relatively subtle changes in any of the circumstances including the configuration of the area into which the stream of glass is poured, and also how it is collected. Such casts are prime for slicing, cutting, grinding and polishing, providing jewel-like sections which may be used in their own right.

Figure 2: Casting through an aperture[7].

The main factors to consider before casting are gravitation - the length of drop to the mould and the size of aperture. Both define the final shape and density of folded patterns. Molten glass fills the mould from the bottom up.

[7] K. Cummings, Technique of Kiln-formed Glass, A & C Black, London: 1997, p.77

1.1.5. Refractory Mould-Making.

The refractory moulds had approximately 30 mm wall thickness. Most times, my moulds were built by the cottling[8] method where liquid refractory mix is poured onto a model stuck on a flat surface and surrounded by a containing wall made of rolled plastic (in this case). In order to cast a complex shape, sprues for air circulation inside the mould are recommended - particularly, if the casting temperature used is fairly low. The easiest way to create this wicking system is to push cocktail sticks into a clay or wax model (exactly placed where the glass stream cannot flow vertically into the mould). They are placed up towards the reservoir at an angle of around 45° (please refer to the *Figures: 6 & 8*). The other advantage is that by placing a mark on the wooden stick, the exact end and even thickness of the mould can be obtained. If it is not enough to get a satisfactory result some corrections in the refractory mould can be done after setting. Lastly, the most fragile parts can be strengthened using more liquid refractory mix with glass fiber. If needed, extra material can be carefully carved out and the required thickness of the mould is effectuated evenly.

After successful mould-making its reservoir can be filled with lumps or frits of coloured glasses. The size of the glass pieces, and their position when charged in the receptacle, determine the final effect of colour patterns. As for traditional pâte-de-verre, glass contained more than one size of granules to prevent shrinkage. Consequently, three different mesh sizes of Kugler frit colours have been used: > 0,25 mm, 0,25 - 0,50 mm, 8 - 14 mm (where frit size has been measured by manufacturer).

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[8] *Cottle* (Cottling) – "A containing wall usually made of wood, card-board or plastic film, to hold poured plaster around a model until the plaster has set." (in:) Ch. Bray, Ceramics and Glass: a Basic Technology, Society of Glass Technology, Sheffield: 2000, p.86

Furthermore, other tested variants included the same base reservoir with two conic reservoirs and then afterwards with three of them. The last solution with three separate reservoirs is meant to be repeated, and instead of colour frits, glass sticks (length: approx. 80 – 100 mm, diameter: approx. 5 – 10 mm) can be used (please refer to the *Figure: 7*). As the flow from the reservoir can be collected in a variety of ways, it is a possible to include more subtle changes: for instance regulating the void distance between the mould and the aperture and the way the flow is collected (actual shape of the object). All of the objects cast in this way when cut reveal internal sections with their rich linear patterns which resemble these of precious stones (please refer to the *Figure: 4*).

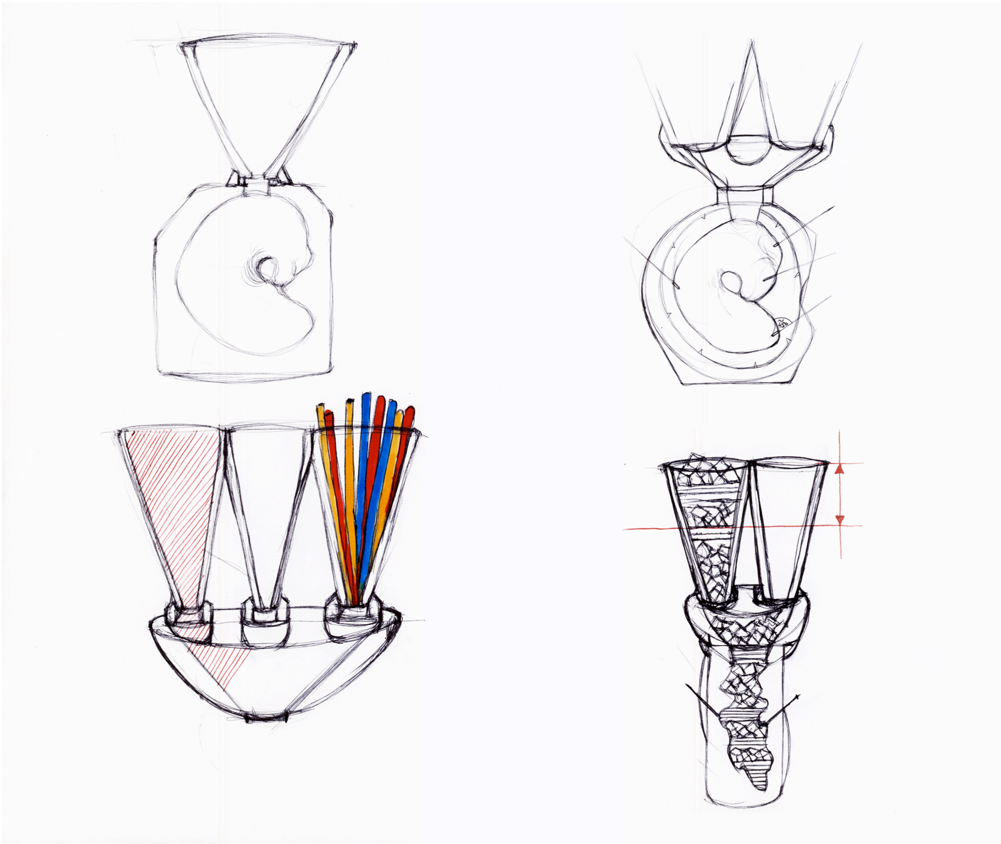
Lastly, one of the most important factors to consider before firing is the choice of glass. Whether lumps, ingots, billets, powders or rods all of them affect the flow and pattern and define nuances of colour scheme. In most cases, different sizes of glass ingots and powders were fired together and placed in a mould in layers (please refer to *Figure: 8*). Some of these colour bands were made of powders mixed with gum arabic and talc or refractory sand. The liquid Glasma glass was poured into a stainless steel bucket[9] filled with cold water in order to get clean, shattered glass pieces suitable for pâte-de-verre technique - a large enough quantity of water to be used to prevent scalding.

Figure 3: Sample of chalcedony glass G-109 manufactured by Gaffer shows relation between interior glass mass and its surface skin.

[9] To avoid glass contamination, a bucket made of stainless steel is recommended to use.

1.1.6. FIRING CYCLES.

Figure 4: Clay model destined for making a double-sided casting mould.



Figures: 5 & 6 & 7 & 8 (from top left): Single reservoir – the cottled mould with a single reservoir
Three reservoirs connected to the base, one adaptable on cottled or hand built mould
Two reservoirs – the hand built mould with sprues and packed with layers of clear and colour glass ingots and powders[10]
Two reservoirs – the cottled and hand built mould

1.1.6.A Firing cycle for kiln casting - October 2014

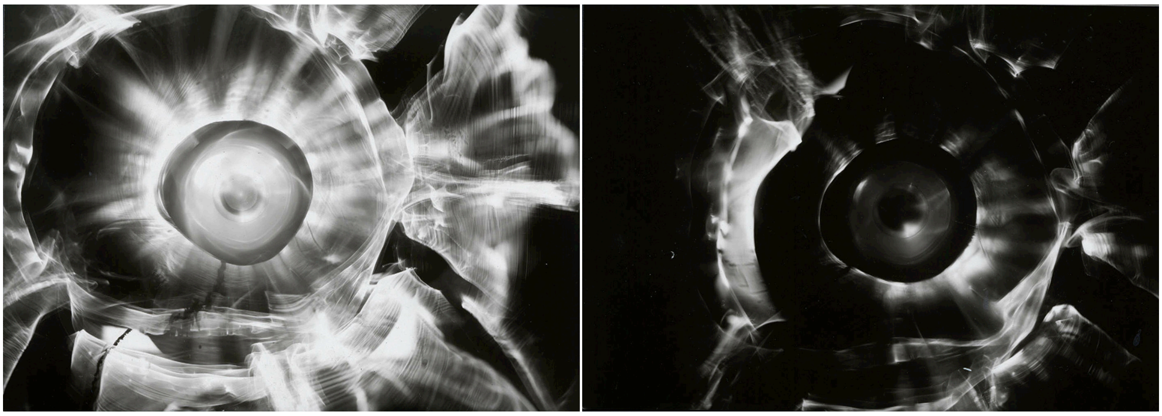
50°/h	->	200°C / hold 1h
150°/h	->	760°C / hold 5h
760°C	->	510°C / AFAP
AFAP[11]	->	510°C / hold 25h
15°/h	->	350°C / hold 2h
30°/h	->	200°C / hold 1h
50°/h	->	50°C / end

[10] Marked by the arrows is the extra amount of cast glass for the glassblowing usage

[11] *As Fast As Possible* will be whatever cooling rate results from the kiln power being cut off by the controller. This helps to avoid loss of surface quality and devitrification. However, glass pulls back from the mould surface when the temperature drops too quickly. As a result the glass 'sucks in' and creates a dimple.

Figure 9: Cast sculpture made using a double chamber reservoirs connected to a single reservoir with a single hole in its base.

Figure 10: Final version of the glass sculpture after being subjected to various resistance tests. Aurora, Izabela Dziepak, 2016, Royal College of Art



Figures 11 & 12: Heliograms of clear blown. Accumulation of the concentric ridges and riffles formed onto the glass surface can relate to the glass cooling while formed.

Figures 13 & 14: The light scattering formed by irregularities on the wrinkled, crackled surface of the glass. In this case scattered reflection takes form of diffused refraction (please refer to the *Figure: 10*).

The scattering of light[12] - the deviation from the law of reflection that is the deflection of a ray from a straight path, is caused by irregularities on a surface. Additionally in glassy structures the scattering effect depends on variations in their density or chemical composition. Scattering of blue light is stronger than red light as the longer-wavelength is transmitted rather than the shorter-wavelength that is reflected via scattering. Furthermore, any kind of translucent or opalescent glass, and therefore some kinds of coloured glass, with its dispersed particles and significantly different refractive index, scatter light by the Tyndall scattering mechanism. The principal interest in it is that the glass may change colour when exposed to different lighting conditions.

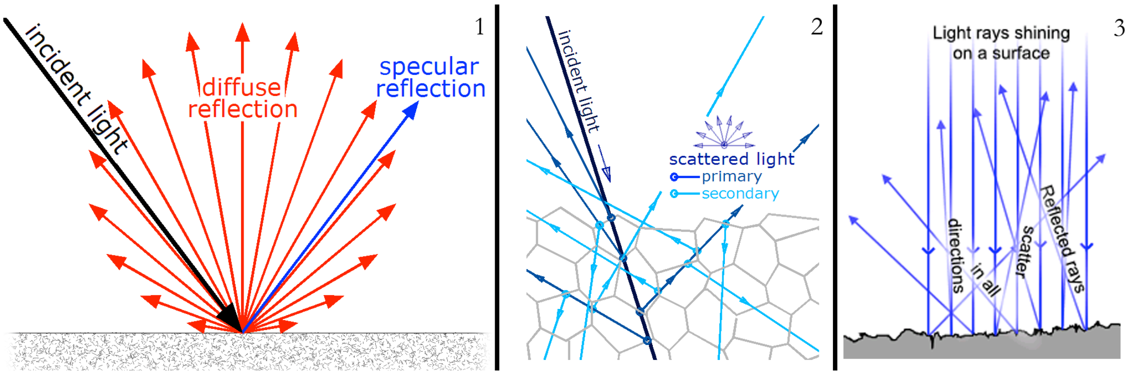


Figure 15: (from left:) 1. Diffuse and specular reflection from a glossy surface - the rays represent luminous intensity. 2. General mechanism of diffuse reflection by a solid surface. 3. Diffuse reflection from an irregular surface. [13]

[12] Weyl W. A., Coloured Glasses, Society of Glass Technology, 1967, p.369

[13] https://en.wikipedia.org/wiki/Diffuse_reflection

1.1.7. Glass surface treatment with a UV adhesive - May 2015.

The colour frits used to make the glass sculpture, containing lead, were obtained from Kugler Glass. As the Glasma glass has a slightly different annealing temperature range than Kugler's colours, annealing schedules were extended in order to find a compromise. Approximately 20 % of the soda-based Glasma glass, that is lead-free, was melted with the lead-based Kugler colour powders: 2226 Mustard Yellow, 2121 Opal Orange Reddish, 2091 Lapis Blue, 2078 Canary Yellow, 2061 Enamel White. All these colours were previously tested for compatibility between each other and with the Glasma glass in glassblowing. The glass sculpture is cracked all over as lead-based glass and soda-based Glasma glass have different viscosities and therefore they are not compatible together. The test was undertaken at the very low melting temperature of 760°C as the minimal casting temperature was looked for to determine the perfect conditions for colour pattern to be controlled. The other reason for that process was to understand what size of the glass frits need to be employed in order to get an evenly fused solid. I succeed in melting together incompatible glasses in hot glass forming technique. I decided to work further on my crackled sculptures making them solid and 'time resistant', as I understood that limitations create a unique opportunity for new discoveries.

- Materials:

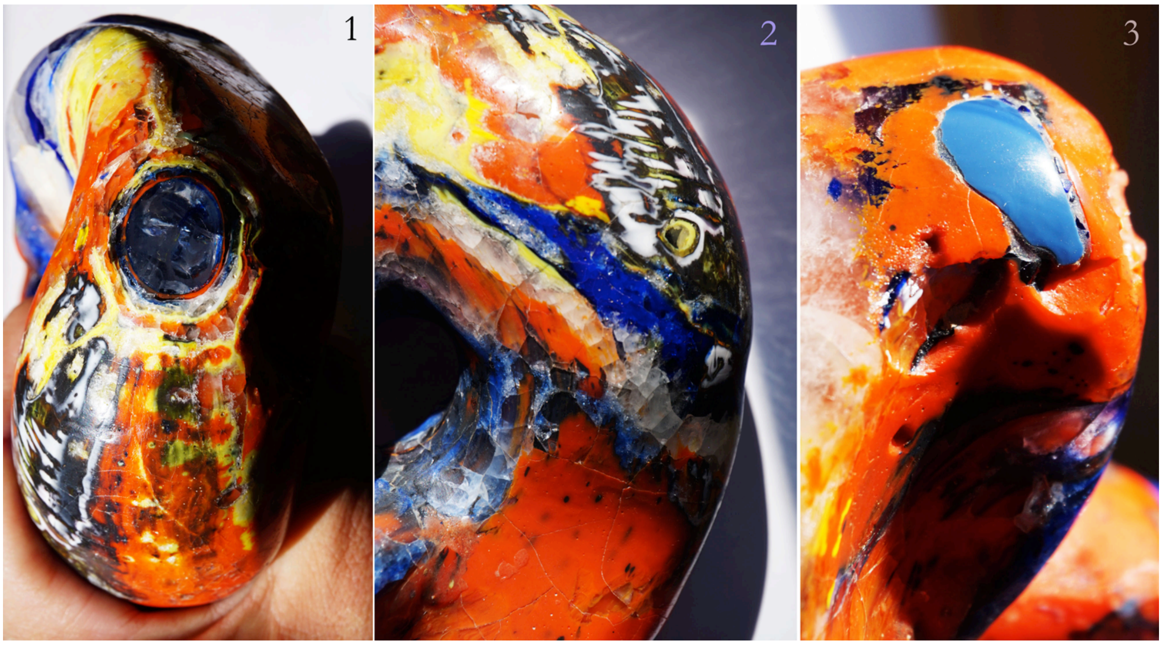
a UV adhesive for glass, a cotton cloth, acetone (or any other less aggressive thinner, alcohol-based in preference), protective gloves, a dust mask

My experiment included the application of UV adhesive - Drei Bond 6022 all over the glass surface. Although, in case of clear glass the adhesive is extremely strong when applied to close fitting surfaces, it may not work in the same way when applied to opaque or colour glasses. That was a reason for the test to be undertaken. After degreasing the glass surface with acetone, the first step was to let the glue spread evenly all over it. Any excess adhesive was cleaned off gently with a cloth soaked with a few drops of acetone. The bonding action is rapid when the applied adhesive is exposed to an ultraviolet light and setting can be completed even within a few seconds. Thus far, the glass was exposed to strong sunlight and so the process occurred slowly and under ambient conditions and without need of an ultraviolet lamp. As the adhesive is optically clear no polishing is needed afterwards. Apparently it has a high enough degree of elasticity to hold together the cracked pieces and the differences in its behavior need to be updated, if any (please see the specifications of adhesive below).

- Drei Bond 6022 UV adhesive specifications:

Strength class: High / Colourless / Viscosity [mPa.s/25°C]: 5500 - 7500 / max. thread diameter / gap filling [mm]: 0.03 - 2.0 / Full cure time [h]: 6 - 10 sec / Temperature range [°C]: -55 to +120°C / Tensile strength [N/mm2]: 8 - 12 (ASTM D-2095-69) / Elongation at break: 60 - 100% (DIN 53504) / Shore hardness: 50 - 60 (D) / Application Properties: High-strength. Fast curing. Specially developed for bonding glass/glass and glass/metal. Ideal for bonding precious crystals thanks to its very good optical properties. We recommend UV lamps with a high intensity of at least 100 mW/cmÇ between 365 nm and 420 nm.[14]

[14] Drei Bond GmbH · Carl-Zeiss-Ring 17 · D-85737 Ismaning · Tel. +49 89 962427-0 · Fax +49 89 962427-19 · info@dreibond.de · www.dreibond.de / http://dreibond.de/en_US/adhesives



Figures 16 & 17 & 18: Aperture mark through which the inside structure can be seen - the concentric flow of the glass stream. Glass with the higher viscosity profile is accumulated closer to the surface (for instance, the lead-based glass that is `softer`) 2. Black specks of red powder colour were formed when in contact with the white one. 3. Inclusion of coloured glass pieces into the dimple shows an additional method of reconstituting a damaged glass surface during the surface treatment with UV adhesive.


Figures 19 & 20: Sodium silicate of the Glasma glass forms a white crystal-like deposit visible at the surface.

- Crackled glass

The technique of crackled effects in glass was probably first developed in Venice at the end of the 16th century. Interestingly, marbled chalcedony and opal glass (Girasol) came into fashion again in this glass capital alongside the ice glass in the 17th century. The crackled effect remains on the outer surface and it is made by plunging the hot glass into cold water. After re-heating the fissures are slightly smoothed out. The hot glass technique was again successfully applied by the artists of Art Nouveau movement. The theory of Gilles Deleuze concerning folds as an image, and folding as an activity that relates to the Baroque style, may be considered accurate if compared with the decorative techniques applied in glass of this epoch.[15]

In 1888 at the glasshouse Stevens & Williams, John Northwood developed the glass technique called Moss Agate glass where soda-based glass is encased in lead-based glass, and then lightly rolled on the marver with selected powdered colours. The glass was shaped and reheated and cold water poured into it causing the soda-lime glass (as 'weaker' one) to develop a network of fine cracks. Frederick Carder made the Moss Agate glass again at Steuben c. 1903, but the original formulation was modified in favour of brighter colour schemes. This mysteriously rare technique was inspired by moss agate - a semi-precious gemstone formed from silicon dioxide. It is a form of chalcedony that includes minerals of a green colour embedded in the stone, forming filaments and other patterns suggestive of moss. The field is milky-white quartz and the colours are formed due to trace amounts of metal present as an impurity, such as chrome or iron. The metals can make different colours depending on their valence - oxidation state.[16] The way this mineral is coloured suggests new possibilities for glass chromatic variations. My creations in kiln casting technique can be

15 Deleuze G., The Fold, Continuum, London: 2006
16 https://www.cmog.org/glass-dictionary/moss-agate

compared with existing glass objects made in hot glass using glassblowing technique.

- Talc

Glass frit was mixed with talc and gum arabic that served together as binders for the colour glass matrix following the recipe of Art Nouveau artist Almaric Walter. Talc, largely made up of hydrated magnesium silicate, used in the ceramic industries, imparts whiteness and increases thermal expansion to resist crazing. It occurs as foliated to fibrous masses and rarely in a crystal form and that is why it can be employed as a flux in ceramics and therefore improves strength and vitrification of clay body. It can react as a flux and an opacifier taking into account that it is inert up to 850°C.[17]

* Fine dust traps microscopic air bubbles, which do not possess enough buoyancy to rise out of the melt during the casting process and thus increase the opalescence of the final piece. This effect is called glass veiling (please refer to the *Figure: 19*).

- Titanium dioxide

Apart from using talc, to get the desired opalescence in glass as much as 2 % of titanium dioxide (titanium (IV) oxide) was employed. It is a good chemical opacifier and it behaves like a photocatalyst under light exposure - especially when mixed with some of metal oxides. Its strong oxidative potential can contribute to the creation of oxidative atmosphere and therefor in preserving lead-based hues from colour changing.

[17] http://rruff.info/doclib/hom/talc.pdf

1.1.6.B Firing cycle for kiln casting - October 2014

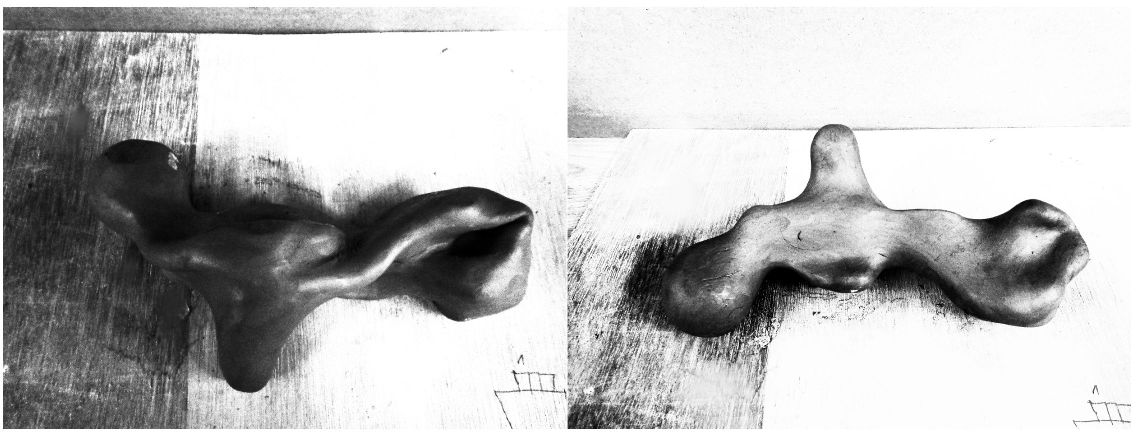
This cast was made with colour ingots of approximately 2 cm / 2cm; the glass thickness is of approximately 45 mm.

- Glass:

- the Kugler colour rods: Opal Orange Yellowish 2067 (lead free), Enamel White 2061 Turquoise 2086, Tabac Light 2222 (lead free)
- the crystal glass - manufactured by Nippon Sheet Glass Co., Ltd.
- the violet colour glass - unknown composition / gift

50°/h	->	500°C
AFAP	->	780°C / hold 5h
AFAP	->	505°C* / hold 40h
15°/h	->	200°C
30°/h	->	45°C

* 505°C was a compromise between recommended annealing temperatures of the Glasma glass: 510°C and the Kugler glass: 500°C.



Figures 21 & 22: First clay model inspiring the final sculpture

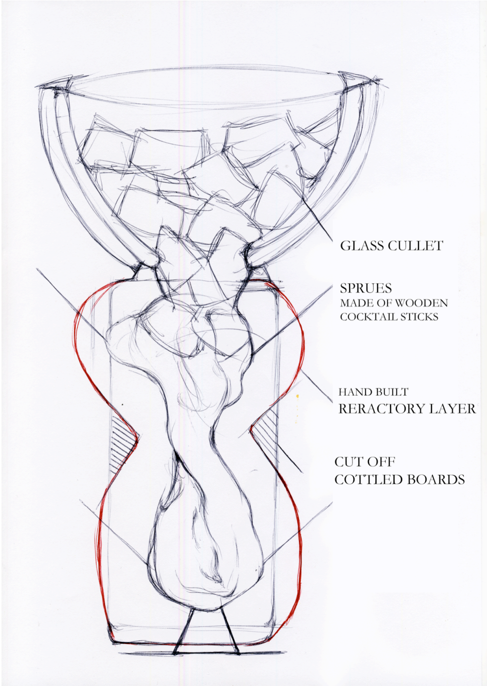


Figure 23: Refractory mould packed with lumps of coloured glass. It had a single chamber reservoir and a single hole in its base.

Figure 24: Florian, Izabela Dziepak, glass; fused, cold assembled, carved, polished, Dimensions: ≈ 9 cm x 22 cm or ≈ 22 in x 55 in, 2015, Royal College of Art, photo credit: Sylvain Deleu

1.1.6.C Firing cycle for kiln casting - November 2014

Figure 25: Wax model for lost wax casting before surface smoothing.

Figure 26: Cast sculpture before polishing made using two conic reservoirs connected to a single chamber reservoir with a single hole in its base.

45°/h	->	500°
AFAP	->	780°C / hold 7h
AFAP	->	505°C / hold 25h
7°/h	->	320°C / hold 2h *
10°/h	->	200°C
25°/h	->	60°C / end

* The necessary annealing time depending on the type of glass and its maximum thickness. In this case, for the first time it was extended between the upper annealing temperature - 505°C and the lower one - 320°C / 200°C. This change let the melting cycle of the glass become more accurate - the thermal stresses are not retained.

1.1.6. D Firing cycle for kiln casting - November 2014

- Glass used: billets of Kugler colour rods, Kugler colour powders (lead-based), > 10% of the Glasma frit

70°/h	->	500°C / hold 25min
AFAP	->	800°C / hold 5h
70°/h	->	505°C / hold 20h
25°/h	->	320°C / hold 4h
25°/h	->	200°C / hold 15min
40°/h	->	50°C / end

Figures 26 & 27: Ribbon-like series of casting patterns. Cast sculpture made using a double chamber reservoirs connected to a single reservoir with a single hole in its base.

Figure 28: Tamesas, Izabela Dziepak, 2015, Royal College of Art, the same sculpture after being subjected to various resistance tests. The visible cracking appeared.

1.1.6. C Firing cycle for kiln casting - November 2014

Throughout the firing the kiln vents were closed. Reduction of oxygen caused black specks at the glass surface where the lead-based glass frit was present.

- Glass: Kugler colour powders (lead-based), > 10% of the Glasma frit

55°/h	->	500°C
AFAP	->	770°C / hold 5h
25°/h *	->	505°C / hold 25 h
15°/h	->	320°C / hold 1h
25°/h	->	55°C

* The time factor between the melting temperature - 720°C and the upper annealing temperature - 505°C was extended. It could be an additional factor contributing to the presence of the surface devitrification.

Figures 29 & 30: Blackish specks signalise the surface devitrification in glass - (from left:) before and after partial polishing.

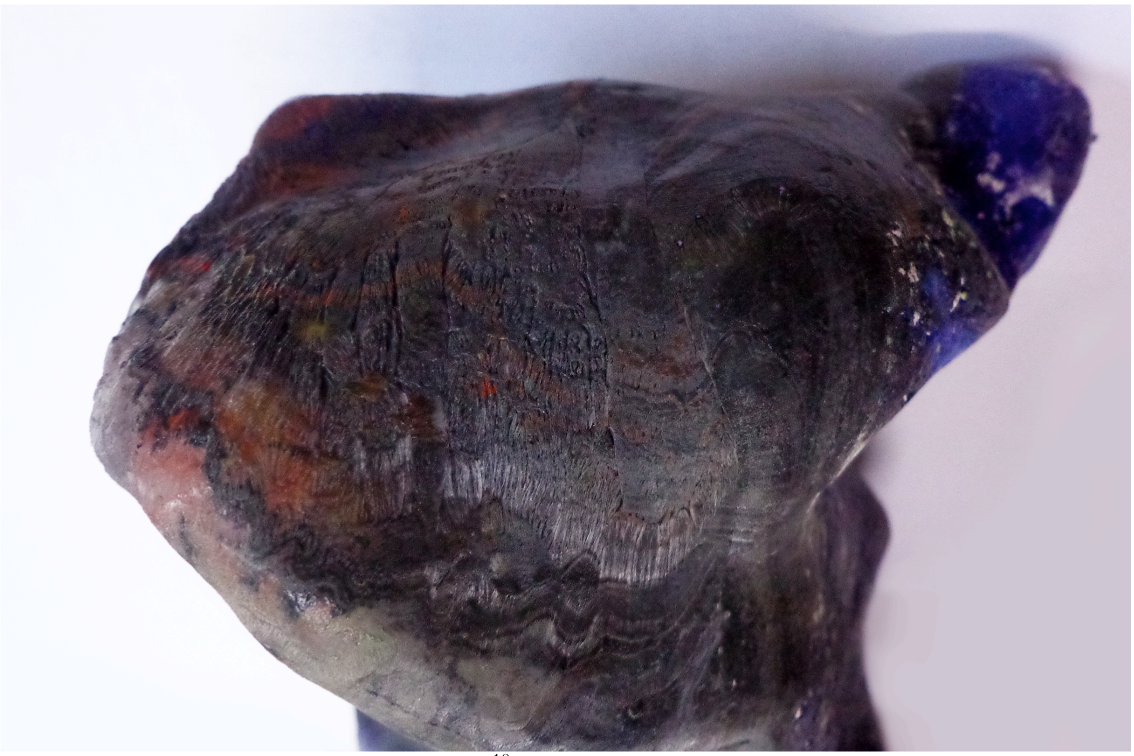


Figure 31: Detail: Surface devitrification[18] in glass.

[18] Crystallization, that in glass is called also devitrifivation (from latin: *vitreus* = glassy), is a process of formation of crystals through natural or artificial transformation of the state of matter.

1.2.6. Cooling and Annealing

- Thermal expansion coefficient (COE) of glass and its viscosity

As a starting point for any kiln casting proceeding, the updated research concerning compatibility of glasses need to be revised. A Technical Supplement from Bullseye Glass Co. written by Daniel Schwoerer was published on their official company website in 1997 and it was updated in 2013. It states that thermal expansion coefficient does not equal compatibility. This paper is important to include in my research, as I analysed fusing different viscosity glasses.

The expansion of a glass may be determined by calculation or by measurement. The most common laboratory test consists of using a dilatometer that measures the actual expansion properties of a glass over the temperature range of 0 - 300°C. The glass viscosity - its resistance to flow, is equally important as its expansion characteristics. The measured COE number is not intended to describe the expansion characteristics of a glass for compatibility purposes, as it does not take into account its melting cycle that is as important as its composition. Whereas expansion affects the compatibility predominantly in the lower temperature range - below the strain point - the viscosity properties predominantly affect compatibility in the middle temperature range - from the annealing to the strain point. Differences in viscosity between two glasses will cause compatibility problems. If one glass is 'stiffer' than the other they will strain each other as they cool through the annealing range. For glasses of different viscosities to be compatible their expansions must be different.

For instance, if the viscosity differences result in tension between the two glasses, and the expansion differences result in an equal amount of compression between the two glasses, the two stresses cancel each other out.[19]

Chemically, glass is a metal oxide polymer with silica SiO_2 being its principal copolymer. It is an amorphous solid liquid that cannot flow easily and thus cannot undergo the rearrangements required for crystallization but instead forms disordered networks. Accordingly, to understand crystallization occurring in glass means to understand glass itself.

At the beginning, I tried to use raw materials and Ancient Egyptian glass recipes in order to explore the physical limitations of glass material from its basis. Chiefly, the experimental value obtained depended on the time scale of the experiments. On slow cooling the structural units have more time to reorganise and thus the glass transition point - the temperature region where the polymer is in transition, is lower. The bonding forces, responsible for the formation of network structures in crystalline silicon dioxide - quartz glass, can be broken by the addition of modifier oxides (alkaline earth oxides). Their principal effect is to lower the melting and working temperature by decreasing the viscosity. An excess of modifier can make the structural units in the melt sufficiently simple and mobile that crystallization occurs, rather than the formation of glass. A glass in this condition is described as 'devitrified', which means that is partially crystallized. Commitment to the idea of the crystallization in glass demands a precise analysis of different glass techniques and my extended research in this subject contributes to my understanding of this process.

[19] https://www.bullseyeglass.com/images/stories/bullseye/PDF/TechNotes/technotes_03.pdf

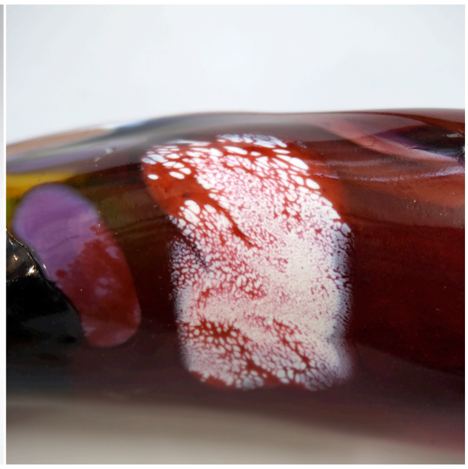
The Glasma glass formula supposes to be flexible enough to fit a wide range of colours. Although, as noticed, it tends to devitrify more than Kugler coloured glass. Taking into account both coefficients of expansion and viscosity ranges the question arose concerning the importance of the size of used glass pieces for melting. The idea that finely crushed glass with colourant agents can be mixed with gum arabic, talc or refractory sand, and after melting together result in a solid, hardly breakable object seemed to have become a crucial part of the research. Previous experiments in glassblowing technique proved that almost all tested samples of chemically different glasses, after fusing together, became uniform glass solids. A particular way of mixing colours together decides its coherent mix. A very few glasses even after repeated re-heating still proved incompatible. All of them were kiln cast and have no visible cracks whatsoever (please see *Figures: 34 & 35 & 36*).

Figure 32: Sample of unknown glasses of four different colours (brought from Olomouc, Czech Republic); After the first hot forming the glass had visible cracks. After second melting its pattern was denser and the glass had no visible cracks.


Figures 32 & 33: Unknown colour glasses (brought from Lviv, Ukraine) delivered in form of colour rods and melted together twice in glassblowing, proved incomparability - in both cases the surface had visible cracks. The maximal mass thickness is of approximately: 400 mm.



Figures 34 & 35 & 36: Sample of unknown glasses of four different colours (brought from Olomouc, Czech Republic) melted together. The colours were mixed in glassblowing once - the surface had visible cracks. After kiln firing the colours became dark grey but no visible cracks can be found (please refer to: firing cycle for kiln casting - March 2015 below).

Figures 37 & 38: Organic-like pattern occurs when different viscosities glasses are melted together.

1.1.8. Glassblowing.

Figures 39 & 40: The hot glass workshop and the view from the window, the Royal College of Art, Kensigton Gore, London

- Equipment and materials:

a marver, lehrs, termal resistant gloves, a copper tube for glassforming, punty irons - Ø 12 mm (1500 mm with 200 mm heat resisting end), straight shears, cutting shears, a pucella tool - jacks, pincers - tweezers, blocks of three different sizes

Glassblowing, in general, demands considerable control, ordered movement and virtuosity. Moreover hot glass can be worked for just a short period of time. Any hot glassforming process has to take these special behaviour characteristics into consideration. In this view, an idea of becoming a painter or a sculptor with their spontaneity is rather a challenging one. Nevertheless, I prepared my working space carefully and I tried to be as flexible as possible in making colour choices.

A coloured glass may be created by the addition of ions, either of transition metals, of colloidal particles, or of coloured crystals. There are many variations for colouring glass while in its hot state. In most cases, I worked with ingots of my own colours manufactured from the Glasma base glass and metal oxides. They were placed on a marver in the middle of a lump of Kugler colour powder. Principally, two methods for gathering colour powder and /or frits were employed.

1.1.9. Pattern making in hot glass.

- Mastering pattern making on a marver:

A small, round gather of the furnace glass is picked with a hot punty iron. Then this is placed at the distance of 2 cm above colour frits that are on the marver. While I keep spinning the punty-iron for about one minute, the heat coming from the hot glass warm up the billets. Then the gather is flattened onto them on the marver to create a homogenous skin with powder colour glass (please see *Figure: 41*). The hot glass is rolled on the marver and this circular, repetitive movement allows the formation of an ovoid with the twisted colour strips inside. The glass is heated for the first time in a previously warmed up glory hole and after, for a few minutes it is marvered again and is shaped using a block - a wooden tool used to smooth and form molten glass into a spherical shape. At any time, blocks should be soaked in water which results in having a layer of steam when the molten glass is shaped with it too long. The glass is re-heated until almost liquid at the end, and is thus ready for picking up bigger colour ingots from the lehr. The colour glass ingots are heated in the lehr up to 580°C - 600°C and they are kept in there at this temperature for at least one hour (after that temperature is lowered to 500°C for annealing purpose).

The heat from the lehr is too strong to bear it for long time so the adhesion of the glass surfaces should happen quite quickly. If the glass sphere is hot enough the pieces stick to it, and partly melt within it, thus it is important to maintain the right temperature. The gather is then placed in the glory hole, at its entrance at the beginning, for quite a long time. The colour pattern can be created by folding the glass inside the glory holy. The molten glass flows slowly and is folded by the rotation, spinning movement (back and forward if needed). When the glass is evenly warm, jacks (a large pincer tool) are applied to create a constriction that is essential to separate the glass from the punty iron at the end.

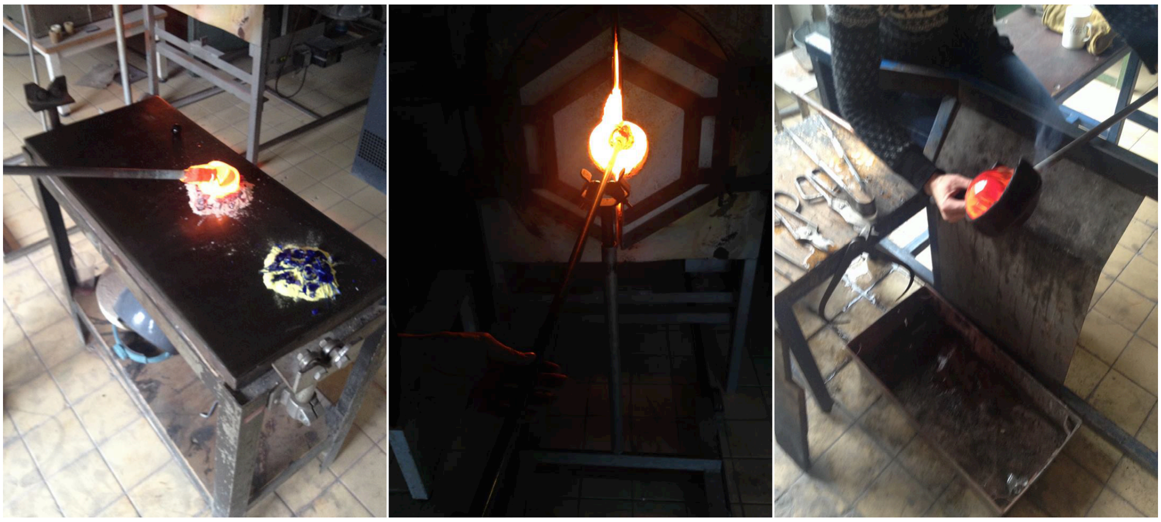


Figure 41: Melting and hot forming glass processes, Izabela Dziepak, 2015, Royal College of Art

When the desired colour pattern is obtained, the final glass form can be created. The hot sphere is flattened from both sides on the marver and a copper tube is pressed from the bottom of it stretching the glass until the shape of a symbolic heart is created. The glass is swung and is formed again to get a final shape. It is then cut off the punty-iron by creating thermal shock reaction - a few drops of water are sprinkled onto the constriction circle line using a pair of tweezers.

The glass is carefully placed over a wooden box filled with grinded mica and the punty iron is held at the edge of it. Next, it is tapped gently at about 15 cm from its end with the opposite end of the tweezers and the glass object can fall down on the bed of mica. The sculpture is gripped with thermal resistant gloves and is carried to the hot lehr for annealing at the temperature of 500°C.

- Mastering pattern making with tweezers:

The second method of pattern making differs from the previous one in handling on tweezers rather than on a marver. The coloured glass is placed directly inside a concavity made in a glass sphere (please see *Figure: 43*) and then grasped and closed up with the tweezers. This method gives the chance to obtain a particular swirled colour effect by twisting the glass mass with the tweezers.

During the spring term I developed my glass blowing skills in order to be able to sculpt freely in liquid glass and test various methods of marbling. All glasses made in both ways are directly carved using diamond and sandstones and in most cases finished with polishing to a shiny surface. As a continuation of my tests in pâte-de-verre I have recently started to recast the coloured glass and also use it as the coloured matrix base in glassblowing.

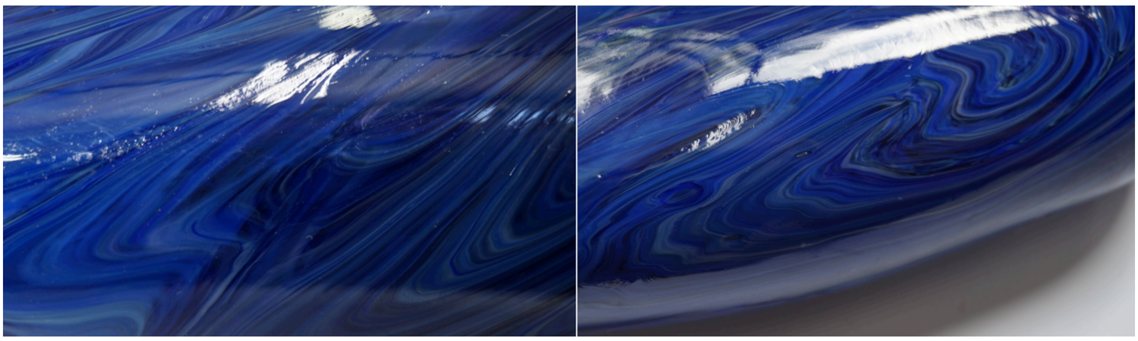


Figure 42: Swirling effect in colour glass, Izabela Dziepak, 2014, Royal College of Art

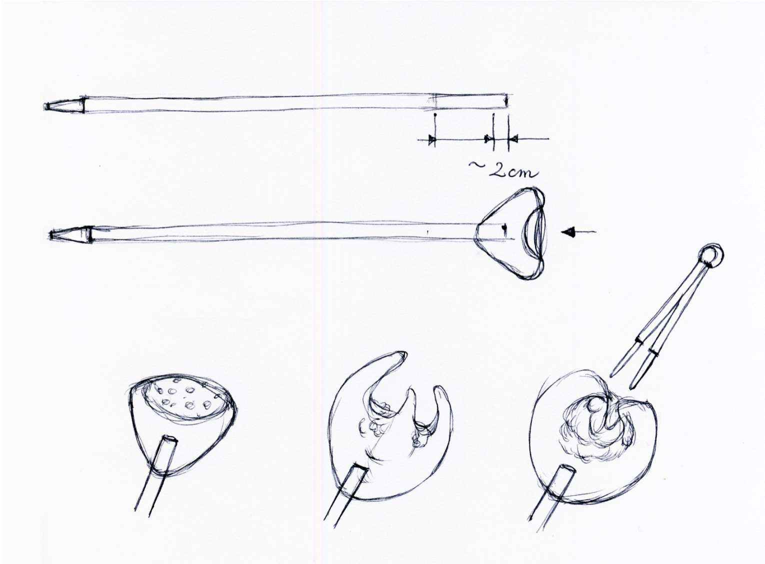


Figure 43: Filling the concavity in glass with the glass powders and closing it with the tweezers.

- Glass:

- Gaffer colour rods:

These colours are manufactured from eight base glasses mostly lead-free that have almost identical viscosity characteristics. The rods vary in diameter between 30 - 32 mm and has the length up to 400 mm. Generally, lead-based colours have better elasticity properties than any other type of glass and they are less prone to devitrification resulting in brilliant and deep chromaticity (lead glasses are about 15% more elastic than common soda-lime glasses, allowing for a greater expansion mismatch). The reds and yellows are based on a soda zinc matrix, they are colloidal colours and work best with soda-lime clear glass with a close expansion match around 96 x 10-7 coefficient. It is advisable to limit reheats and working time in order to avoid over-striking. All other colours are lead-based - 28 % lead oxide crystal matrix is used as a colour base glass.[20]

[20] http://www.gafferglassusa.com/index.php?route=technical/technical&technical_id=22

Liam Reeves, with whom I worked at the beginning of my research, used marbling technique to create banded and often combed cups that were filled afterwards with transparent or monochromatic marbled glass. The outer coloured layer is of approximately 3 mm. First forms were overlaid with clear glass. The next step was to include the differences in viscosity of the glasses for strictly aesthetic purposes - to reveal their dimensional colours and tactile structures.

Figure 44 & 45 & 46 & 47 & 48: Untitled, hot-formed glass object, Izabela Dziepak, Liam Reeves, marbled glass cup filled inside with clear Glasma glass, Dimensions: 34 cm long, 2014, Royal College of Art, photo credit: Izabela Dziepak
Detail views.

Figure 49: Untitled, hot-formed glass object, Izabela Dziepak, Liam Reeves, marbled glass cup filled inside with clear Glasma glass, Dimensions: 30 cm long, 2014, Royal College of Art, photo credit: Izabela Dziepak

Figures 50 & 51 & 52 (from top): Elaboration of different pattern effects seen in the three hot-formed glass objects, Detail view, Izabela Dziepak, Liam Reeves, 2014, Royal College of Art, photo credit: Izabela Dziepak

- Safety issues:

Long-sleeved cotton or woolen clothes, denim trousers and foot protection safety shoes should be considered to wear while blowing glass. The most important issue is to protect chest, face and arms. Often contact with raw materials carry health and safety risks. That is why some of metal oxides were excluded throughout the research.

2.1.1. Metal Oxides.

Figure 53: (from left:) Yellow Iron (III) Oxide, Cuprous Oxide and Cobalt (II) oxide.

- Specifications for chosen metal oxides:

- Cobalt (II) oxide

- Most common colour in glass: ultramarine

I manufactured a few glass colours using metallic oxides melted in a crucible with the Glasma glass. I proceeded as follow:

The crucible - a terracotta flower pot of 8/16 cm was filled with the Glasma frit mixed with cobalt oxide in proportion: 3 kg of the Glasma glass and 3 g of the oxide (please see *Figure: 54*).

Obtained coloured glass was carefully crushed with a hammer made of cemented carbide and re-used in both kiln casting and blowing techniques. The principal reason was to get a desired opaque blue that can be matched with any other colours as it is relatively consistent in colour result in any working conditions.

Figure 54: (from left:) Coloured glass samples - Glasma clear base with cobalt oxide 2 % and 0,2 %, Izabela Dziepak, March 2015, Royal College of Art

In most circumstances, cupric oxide (copper (II) oxide) produces an aquamarine green tonality whereas cuprous oxide (copper (I) oxide) makes red. The fact that the colour hue of cuprous oxide may vary, depending on the oxygen atmosphere for instance, shows that as a colouring agent its potential is not fully exhausted. One of the most precious hues obtained with it is a ruby colour. Copper in its pure metallic form produces a very dark red, opaque glass that can be used as a substitute for gold in the modern production of ruby coloured glass. The copper particles are subjected to molecular division when melted (colloidal state) that result in ruby coloured glass and a new realignment at the annealing temperature.

Interestingly, archeologists: "Neumann and Kotyga did not find cobalt in any of the specimens of ancient Egyptian blue glass they examined and state that it was never used until Venetian times and that the colour is generally due to a copper compound, but occasionally to an iron compound."[21] The same copper compounds have been found to be the colouring agent of Egyptian green glass.

[21] Neumann B., Kotyga G., Zeitschr. F. angew. Chemie XXXVIII (1925) (after: Lucas A., Harris J. R., Ancient Egyptian Materials and Industries, Courier Corporation, NY: 1962, pp. 662-3

Copper oxide may produce blue and red colours at the same time, thus this oxide is of particular interest for my investigation into the characteristics of dichroic glass. In this respect, my methodology included a schedule for kiln castings with an oxidising atmosphere and progressively adjusted temperature. In terms of a mould, I chose double terracotta flowerpots placed one into the other and secured from the bottom with a ball of porcelain, covered by terracotta plates with ceramic paper and protected from the kiln shelf with the use of sand. The pots were filled with clear Glasma glass cullet successively layer by layer while each of them was covered with a paste made out of clear finely crushed glass (Glasma), colourant agents (oxides, ochres) and gum Arabic.

Cuprous oxide is one of the principal oxides of copper and can be found in nature as the red mineral named cuprite. I also found that chalcopyrite - a sulphite mineral that contains the cuprous oxide, can serve as a colour reference for a glass maker. In my tests, the oxide was used mostly in kiln casting as I was particularly interested to get scarlet coloured glass made primarily by the early Egyptians and brought about by its addition.[22] As a result I obtained patchy carnelian colour and using alongside the cupric oxide - indigo blue (please see *Figure: 61 & 62*). In order to obtain the red colour in glass I reduced the cuprous oxide's exposure to oxygen while heated. It was enclosed between two layers of clear glass and in the result its concentration was sometimes too great for the glass flux to combine with afterwards. The visible effect is a deep turquoise colour with a silver, metal-like glassy inclusions, which are cracked where in contact with glass. A conclusion is that the exact sizes of the fused materials have to be matched beforehand.

[22] Lilyquist Ch., Brill R. H., Wypyski M. T, Studies in Early Egyptian Glass, Metropolitan Museum of Art, NY: 1993

Figure 55 & 56: (from left) Inlay figure, Ptolemeic glass, 299 – 1 B.C., H=21,5 cm, Corning Museum of Glass, NY, USA[23]
Model faience wig for a statue[24], H=10cm, W=9,5cm, Thebes (?), Egypt, c. 1350-1250 BC, Ancient Egypt & Sudan Dep., the British Museum, London, N° EA2280

[23] "Unlike the earlier inlays, in which the various parts of the body were fitted into separate recesses, the wig, head, collar, torso, loincloth, and legs of the Corning figure - which dates to the last centuries of the pre-Christian era - were fitted together and originally held in place with an adhesive. This technique, developed by the Ptolemaic glass industry, coincided with the revival of gesso and plaster objects. Such inlays decorated wooden coffins, and they were also employed in household furnishings and religious shrines." (in:) http://www.cmog.org/artwork/inlay-figure-1

[24] "This wig was probably one of a number of faience and glass elements placed on a (probably wooden) royal statue. It is made of a particularly glossy type of faience, one that was very common around the time of the Amarna Period (1390-1327 BC). (…) Set into the wig is a representation of a headband, with attached streamers of gold inlaid with red and blue glass as substitutes for carnelian and turquoise" (in:) https://www.google.com/culturalinstitute/beta/asset/model-faience-wig-for-a-statue/VQEzBoijohmKSQ

Figure 57 & 58: (from left:) Egyptian opaque red glass face inlay of Akhenaten, New Kingdom, Dynasty XVIII, c. 1353-1336 B.C., H=4cm
Egyptian glass face inlay of Nefertiti probably as the personification of Hathor, New Kingdom, Amarna Period, Dynasty XVIII, circa 1353-1336 B.C.

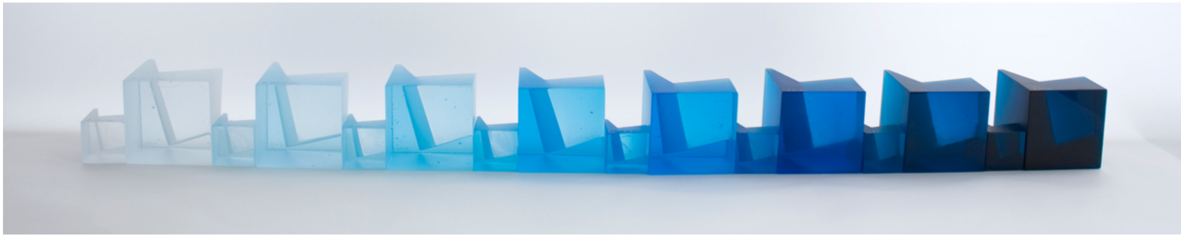


Figure 59: Heike Brachlow, 2012, Royal College of Art, « 3 ccm and 6 ccm cubes coloured with copper oxide. From left: 0.01%, 0.05%, 0.1%, 0.25%, 0.5%, 1%, 1.5%, and 2%[25]

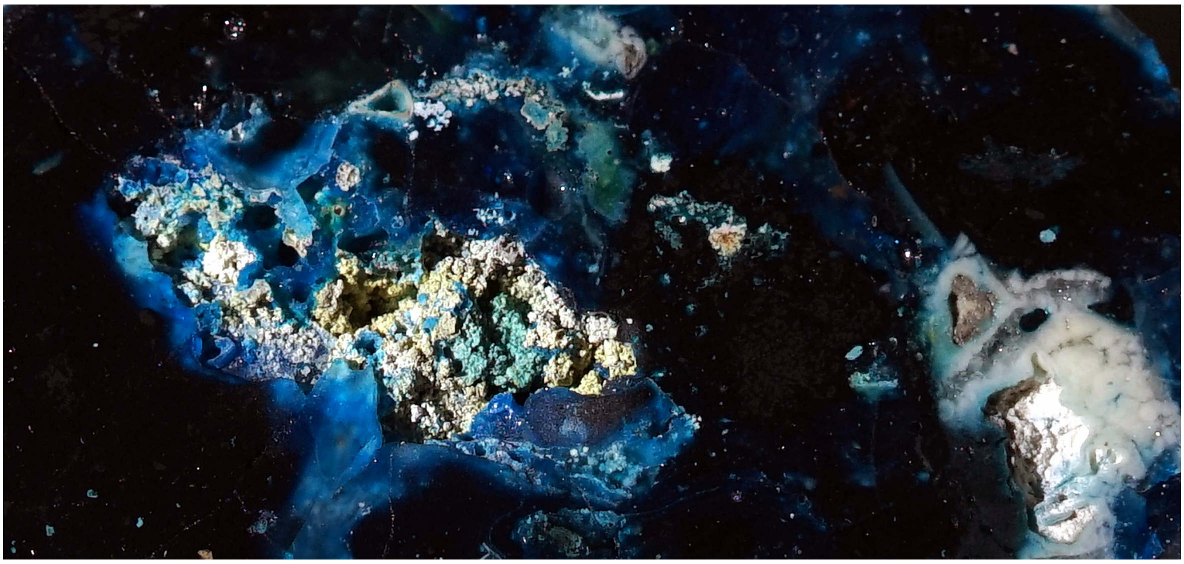
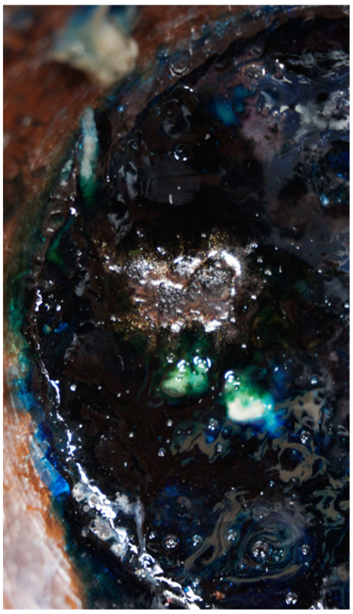
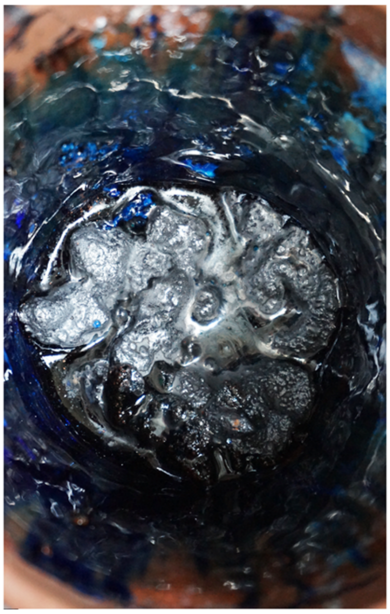


Figure 60: Glass coloured with oxides and ochres, Izabela Dziepak, 2016, Royal College of Art, Detail view

[25] H. Brachlow, Shaping Colour: Density, Light and Form in Solid Glass Sculpture, PhD Thesis, Royal College of Art, London: 2012, p. 213

Figures 61 & 62: Sample of glasses coloured with copper oxide and rutile, Izabela Dziepak, 2016, Royal College of Art

The incontestable 'dictionary of colour' was proposed by Heike Brachlow as part of her research project at the Royal College of Art completed in 2012. Not only the density of colour in glass was investigated in this respect, with adjusted quantities of chosen metallic oxides, but most of all, the manufactured polychromatic glasses, and frits created from them, were used for exploring movement through a sculptural form. Her attraction to transformation is expressed by an examination of colour in movement with different lighting conditions: incandescent, fluorescent light and daylight. Both her practical research, and the glass sculptures, were a source of inspiration for my own creation; my own folding.


Figures 63 & 64 & 65: The metallic material formed in ceramic pots used as reservoirs for melting glass with metallic oxides., Izabela Dziepak, 2016, Royal College of Art