New Light on Old Panes – Current Results Obtained by Experimental Archaeology: Making Roman Window Glass

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Introduction

Beginning in the 1st century AD, window glass was commonly used in Roman building architecture. It served as passive illumination in bathhouses as well as public and private buildings, spreading from central Rome all over the Roman Empire. Two different types of early Roman window glass can be specified: square or rectangular flat glass panes[1] on the one hand, and round and domed window glass[2] on the other. Both are thick-walled, and feature both a matte and a glossy side, which easily distinguishes them from the later blown Roman window glass panes.[3] Both early Roman window glass varieties were reconstructed during the 'Borg Furnace Project 2015', as well as some of the later ones in the Archaeological Park Roman Villa Borg's hot glass workshop.

The Hot Glass Workshop

In summer 2013, a Roman hot glass workshop featuring a wood-fired furnace with a capacity of up to three 4.5 litre ceramic melting pots for glass, and an annealing oven to cool down the glass objects in a controlled manner, was reconstructed in the Archaeological Park Roman Villa Borg in Germany.[4] Although there were indications for glass working in the Roman *villa rustica* of Perl-Borg, the small daub furnace fragments did not allow any reconstruction. Therefore the reconstruction was based on the excavation of a small glass workshop at Trier,[5] less than 40 km north of Perl-Borg.

After the first test-run in October 2013 was successfully finished, and proved the general functionality of the glass furnace and the annealing oven, the glass workshop was continually enhanced with several small wood-fired furnaces for making glass beads, a second small furnace for glass melting and working, and a larger annealing oven. In 2018, the building of a second hot glass workshop was completed, which houses a reconstruction of a large tank furnace, capable of melting 300 litres of glass, another small furnace for glass melting and working, and two separate annealing ovens. All of the furnace and oven structures are made from daub, using local loam and in some cases grass or straw, and fragments of Roman roof tiles. The furnaces and ovens are operated mainly with birch and beech wood. Constant temperatures between 1,000 and 1,100 °C allow the manufacture of glass vessels and other glass objects at the glass furnaces. The annealing ovens are operated during the day between 400 and 500 °C for tempering the glass vessels and cool down gradually over night.

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In nine projects of one week each, and numerous research and demonstration days, these two hot glass workshops provided the opportunity to test and evaluate different glass manufacturing techniques,[6] ranging from core-formed and slumped vessels to free blown and mould-blown vessels. The manufacturing techniques were researched by Mark Taylor and David Hill (The Glassmakers, England), assisted by François Arnaud (Atelier PiVerre, France), Torsten Rötzsch (formerly LWL Industriemuseum Glashütte Gernheim, now at Glasfachschule Zwiesel, Germany), William Gudenrath (Corning Museum of Glass, USA), Jason Klein (Historical Glassworks, USA), Liliya Pangelova (Bulgaria, currently at Gozo Glass, Malta), Bettina Birkenhagen (Archaeological Park Roman Villa Borg) and the author. During the 'Borg Furnace Project 2015', a set of flat and domed Roman window glasses was reconstructed by Mark Taylor, François Arnaud and Torsten Rötzsch, assisted by the author.[7] Some flat windowpanes and one domed window were made by the author, assisted by Bettina Birkenhagen (Archaeological Park Roman Villa Borg), during the furnace projects 2017 and 2018.

Characeristics and Tool Marks as Displayed by the Glass Window Fragments of the *villa rustica* at Borg

The Archaeological Park Roman Villa Borg provides numerous fragments of Roman glass windows. Whilst most of the fragments derive from flat windows, featuring one matte and one glossy side, six of the fragments could be identified as fragments of domed windows.[8]

All of the Villa Borg's window glass fragments are so-called natural coloured, meaning a colour tint caused by natural impurities, mainly iron oxides, of the sand being used as the main ingredient for the glass. The colour tint of most of the fragments ranges from blue-green to a darker green, though green-brownish colours are exceptions. The thickness of the flat window glass fragments is between 2 and 5 mm, with one side featuring a glossy, fire-polished appearance, the other a rough, matte surface, in some cases with small crumbs of material embedded in the surface of the glass. The matte side and the tint in combination with the thickness of the glass causes this early Roman window glass to be translucent rather than transparent. Due to the small inclusions, the matte side will be referred as being the underside in terms of the manufacturing process.

The edges, featuring a smaller radius towards the underside and a larger one towards the upper side, and the rather round corners are usually not reworked, so the windowpanes were without much doubt made to fit the desired final size. In most of the corners, indentions are visible on the upper side (fig. 1), which indicate the use of tools to pull out the corners. The cross-section of some of the fragments show a layering of the glass.[9] The following discussion of possible manufacturing methods refers only to the early matte-glossy Roman window glass and does not cover the later blown cylinder-glass.

Fig. 1: Tool mark in the corner of a window glass fragment from the *villa rustica* at Borg.

The Old Myth: Cast Window Glass

Several generations of archaeologists accepted the different suggested ideas of making this thick-walled Roman window glass by 'casting' glass onto an open wooden mould without questioning its feasibility, or even verifying it experimentally. The scope of ideas suggested has ranged from dry or watered wooden moulds to wooden moulds with a layer of quartz sand, or wooden moulds featuring a wooden frame to form the rectangular shape of the glass and limit its expansion.[10]

All of these ideas neglected the fact that glass of a Roman composition invariably needs reheating inside the furnace during the manufacturing process, usually frequently. Reheating inside the open flame of the furnace is not only essential for blowing glass, but also for making slumped vessels[11] – if not the glass is formed directly inside the flame, as seen for example at bead furnaces.[12] This is obvious to every glassmaker from Roman times until today. Therefore, reheating is very likely for the manufacturing process of Roman window panes, flat or domed alike. Since the heat emission of a glass furnace is quite significant, the manufacturing itself was very likely carried out outside of the furnace.

Following the idea of making the Roman flat window glass employing a wooden mould, the workpiece placed on this mould would need to be reheated at least to 1,000 °C once or several times inside the furnace. This definitely excludes wood as the mould material. Also a watered wooden mould is not suitable for this. A wet wooden mould would cause the additional problem of hot steam escaping from the mould when glass was poured onto the flat mould, which would undoubtedly cause an uneven underside to the window pane – something not seen on the Roman fragments. In contrast to wood, a ceramic mould might be suitable for frequent reheating inside the furnace and forming of the window pane outside of the furnace. Powdered clay, chalk or a similar material could act as a releasing agent, which prevents sticking of the glass to the mould surface. The small inclusions in the underside of some Roman window glass fragments and the texture of the underside support this idea.

Apart from the use of wood as a mould material, the suggested forming process by 'casting' needs questioning. For a casting process the viscosity of the glass needs to very low (lower than for blowing), which means that the glass itself has to be very hot. The glass based on a Roman composition, which was used at the Roman glass projects at Borg,[13] had its best quality for blowing at a temperature around 1,080 °C.[14] For casting, Roman glass might require a temperature around 1,200 °C. This high working temperature of the glass would cause even higher temperature peaks inside the wood-fired furnace, which tends to overstrain the ceramic melting crucibles for the glass, and the daub furnace structure as well. The ceramic cooking pots used as melting crucibles in Roman times soften at a temperature above 1,100 °C, so manipulating these with large steel tongs to pour the glass for casting seems impossible.[15] The daub structure of the furnace also suffers noticeably from overheating, causing a chipping of the surface or fusing and melting of the daub, depending its composition.[16]

A simple re-thinking, taking into account the physical issues of the Roman glass, melting crucibles and furnaces, of the postulated use of a wooden mould or frame, and the process of 'casting' results in the rejection of this theory. Unfortunately, neither written sources, nor pictures from Antiquity provide any information about the manufacturing process of the matte-glossy Roman window glass. However, the most probable experimental manufacturing technique should not only display the same characteristics and tool marks on the windowpanes, it should also explain their appearance.

An Alternative Method: Making Flat Window Glass by Stretching a Glass Disc on a Ceramic Support

Mark Taylor and David Hill suggested and tested the idea of stretching a glass disc to a rectangular shape, on a ceramic support, in their modern glass studio as early as 2000, published by Denise Allen in 2002.[17] This method was later re-evaluated by Taylor and Hill using both a reconstructed Roman glass recipe and a reconstructed Roman furnace during their 'Roman Furnace Project' in Quarley, England, in 2006. Almost a decade later, this manufacturing technique was demonstrated during the 'Borg Furnace Project 2015' at the Archaeological Park Roman Villa Borg in Germany, then again during the projects at Borg in 2017 and 2018.[18]

The idea suggested by Taylor and Hill comprises of a gather of hot glass, transferred from the glass pot onto a ceramic support, which can be frequently inserted into the working hole of the glass furnace for reheating. The upper surface of the ceramic support is prepared with a separator; powdered clay, gypsum and chalk proved suitable for keeping the glass workpiece movable on the ceramic support, without adhering to it. Gathering the glass using a solid iron bar and placing a large drop onto the support was practicable at a temperature around 1,080 °C, using the reconstructed Roman recipe glass and the reconstructed furnaces in Quarley and Borg as well. The required temperature is in the range of temperatures, which enable glassblowing, and suits both, the glass pots and the furnace. Allowing the gather of hot glass to run onto the support during pouring (fig. 2) may cause the layering, which was noticed in cross-section of some of the Roman window glass sherds.

Using a pair of trowels and pincers, the gather of glass is flattened to a glass disk (fig. 3) and then stretched to a square shape (fig. 4), starting in the middle of the glass disk. This inevitably causes tool marks as noticed in the corners of the Roman window glass fragments (fig. 1). Even frequent reheating (fig. 5) cannot eliminate all of these tool marks completely. If the window pane has already exceeded the desired size, opposite edges may be pushed back using the trowels (fig. 6). This may cause the distortion which is displayed on the undersides of some of the Roman window glass fragments, because the underside tends to be colder than the upper, and therefore stiffens faster, and also picks up heat to lesser extent during the reheating than the upper side.[19]

The reconstructed Roman glass stiffens rapidly outside of the furnace, so frequent reheating is essential for this manufacturing process. A pusher, a long steel bar with a grip for the ceramic plate covered with powdered release agent, serves best for reheating the glass inside the furnace's working hole. The procedure of heating – working – heating – working – heating is repeated until the flat window pane is finished to its desired square or rectangular shape. The temperature is kept at 1,080 °C during the whole manufacturing episode. After a final reheating, the window pane is transferred into the annealing oven, which is kept between 400 and 500 °C throughout the whole working day and which then gradually cools down over night to an ambient temperature. This tempering procedure virtually eliminates the internal stresses which appear inside the glass, if it cools down rapidly.

On the next day, the windowpane is removed from the annealing oven, washed to clean off any remains of the release agent on the underside – and ready to be mounted. All of the flat window panes produced by the four different teams of glassmakers, assistants for operating the pusher, and stokers for firing the furnace, featured tool marks directly comparable to the Villa Borg's Roman window glass fragments. Each reconstructed flat window glass pane had a matte and a glossy side, some with a few inclusions of the release agent in the underside. Even the less experienced team was able to make a flat window pane measuring around 23 cm in square within 12 minutes.

Fig. 2: Placing the hot gather of glass.

Fig. 3: Flattening the glass disk.

Fig. 4: Stretching the corners to form a square/rectangular shape.

Fig. 5: Reheating inside the furnace.

Fig. 6: Last corrections of the flat window glass.

Domed Window Glass – *oculi*

Whilst the flat Roman window glass discussed above is usually either square or rectangular, the domed Roman window glass may be described as a hemispherical segment of about 30 cm diameter, with a surrounding rim measuring 4 to 5 cm. Its other specifications, such as the thickness of 2 to 5 mm, the layering visible in cross-section of the sherds, the blue-greenish colour, and the either matte or glossy surfaces are identical to those of the flat window glass panes. Tool marks are visible primarily on the glossy upper side, especially in the rim area, and also where the flat rim meets the sphere.[20] Judging by the rim radius, thickness, and colour, the six fragments of domed window glass identified at the Villa Borg derive from at least two domed windows of an outer diameter somewhere between 36 and 42 cm.[21]

In 1997 Sylvia Fünfschilling and Beat Rütti,[22] and independently in 2002 Denise Allen,[23] suggested a manufacturing method by slumping a hot glass disk over a mould. This technique shares many parallels with the technique of making flat Roman window glass discussed above. Whilst flattening the gather of hot glass on the ceramic support is the same as for making flat square window panes, the flat glass disk now is not stretched or pulled to a square shape, but transferred onto a preheated hemispherical mould (fig. 7), and slumped over it by reheating inside the furnace and the use of tools.

Fig. 7: Slumping the flat disk over the hemispherical mould.

Fig. 8: Last corrections of the domed window glass.

Once more, trowels and large pincers are suitable tools for forming the glass disk into a glass dome with surrounding rim (fig. 8).

This method was tested for the first time during the 'Borg Furnace Project 2015', then repeated during the 'Borg Furnace Project 2018' with two different teams of glass-makers, assistants for operating the pusher, and stokers. Due to the limited widths of the working hole and the annealing oven's door alike, the two reconstructed domed window glass panes were smaller than the Roman fragments suggest, but they share all the same characteristics and tool marks. Without further practice it took both of the teams around 20 minutes to make one of these domed window panes.

Conclusion

Using a flat ceramic support, by stretching and pulling a gather of hot glass to create a square shape, four different teams of glassmakers and assistants re-created several of the matte-glossy windowpanes typical of the 1st century AD. The observable characteristics and tool marks not only matched those of the Archaeological Park Roman Villa Borg's Roman fragments, they also explained their appearance.

Furthermore, Mark Taylor and the author reconstructed two of the Villa Borg's domed window glasses by slumping a stretched hot glass disc over a hemispherical mould. Again the characteristics and tool marks were not only identical to those seen on the Roman fragments, but also explained their existence. From a technical point of view, the Roman domed window glass may represent a direct link between the Hellenistic and Roman mosaic and ribbed bowls[24] and the matte-glossy Roman flat window glass.

Taking a making time of between 12 and 20 minutes for these first trials into account, the manufacture of window glass seems rather to be limited by both, the amount of molten glass available for working, and by the capacity of the annealing oven itself, rather than by the workforce of glassmakers, since the larger furnaces should offer at least two comfortable workplaces for teams of glassmakers and assistants.

According to current research and knowledge, the slumping method seems to be the correct technique for making domed Roman window glass panes, and the stretching and pulling method is likely to be the method of manufacturing the early Roman matte-glossy square or rectangular window panes. For theoretical and practical considerations, the often-suggested method of pouring hot glass into a wooden mould is very unlikely. Therefore the term 'cast' window glass, though still widely used, is not appropriate for these glass objects. It should either be replaces by 'stretched' or 'pulled' window glass or, without any interpretation of the manufacturing method, as 'matte-glossy flat window glass'.

Notes

[1] So-called *cast window glass.* Allen 2002; Komp 2009. Due to its appearance, the term *matte-glossy window glass* would be more appropriate.

[2] So-called *oculi.* Allen 2002.

[3] So-called *cylinder-glass* which was made by cutting open and flattening a blown glass cylinder.

[4] Wiesenberg 2014.

[5] Archaeological excavation 'Trier Hopfengarten' undertaken by the Generaldirektion Kulturelles Erbe Rheinland-Pfalz in 1999/2000. Pfahl 2000; Wiesenberg 2014, 12–17.

[6] Wiesenberg 2016c.

[7] Wiesenberg 2016a; Wiesenberg 2016b.

[8] Birkenhagen – Wiesenberg 2017.

[9] Cf. Wiesenberg 2016d, 51–56.

[10] E.g. Kisa 1908, 363 f.; Komp 2009, 30 f.

[11] E.g. Wiesenberg 2017.

[12] E.g. Wiesenberg 2018.

[13] Provided by Mark Taylor and David Hill. For the projects at the Archaeological Park Roman Villa Borg, the glass was melted from raw ingredients (sand, soda, lime, and metal oxide to meet the analyses of Roman glass) inside Mark Taylor's and David Hill's modern glass furnace, crushed down in water, and re-melted inside the wood-fired reconstructed glass furnace at Borg.

[14] Re-melted genuine Roman glass fragments required a slightly higher working temperature. Taylor 2016, 21.
[15] Since the glass pots are very exposed to the flame, the small glass furnace GO-Borg-2 regularly overheats the glass pots at temperatures above 1,150 °C, causing distortion and cracking of the pots.
[16] The lime in the loam being used for building the furnaces and ovens at Borg causes deterioration of the daub when exposed to high temperatures. The sand added to the daub to build the furnace at the Provinciaal Archaeologisch Museum Velzeke in 2008 did flux and gradually melt at high temperatures, which resulted in a partial collapse of the furnace's inner domed roof structure in 2016.
[17] Allen 2002, 103–106.
[18] Wiesenberg 2016d.
[19] Wiesenberg 2016d, 53 f. fig. 4. 5. These fragments disprove the use of a mould frame, because any frame would make pushing back the edges impossible.
[20] Wiesenberg 2016e.
[21] Birkenhagen – Wiesenberg 2016.
[22] Fünfschilling – Rütti 1997, 52.
[23] Allen 2002, 108.
[24] The process of slumping a hot glass disk over a hemispherical mould seems to be the probable method of making Hellenistic and Roman bowls (Isings 18) and ribbed bowls (Isings 3), mosaic and monochrome alike, as discussed in Wiesenberg 2017. Whilst the rims of the (ribbed) bowls exactly meet the ceramic support in order to create an even rim, the 4–5 cm wide rim of the domed window glass requires the use of tools to create the sharp indent.

Image Credits

Fig. 1: Frank Wiesenberg. – Fig. 2–8: Manuela Arz.

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