FACT SHEET 341

Stained Glass - Production and Development

Learning More Talk by Kevin Hender 2024

1) **A bit of history first**

In Middle Ages glass regarded as magical even divine. To use a base material such as sand to turn into a nobler form was like alchemy. Ability of glass to transmit light and to be looked at as well, set it apart. Glass was precious, coloured particularly - generally only found in churches.
Light used as a symbol to describe the Spirit itself - glass also had a spiritual function of glorifying God for His own sake.

Gives a sense of mystery and vision.

In Saxon times the coloured glass would have formed a mosaic or kaleidoscope. No evidence of figurative work.
The Normans however brought story telling through windows with them; this was important given lack of literacy and written word.
During those Middle Ages, the church was the centre of learning.
The designs in the first stained-glass windows usually depicted scenes from the Bible.
In later years, workers' guilds and wealthy merchants paid for windows that glorified not only saints and kings but the donors themselves.
However, changes in religious belief in the 16C meant fewer commissions for religious works but demand for secular glass continued until the 17C when under Puritan rule the art was threatened with total annihilation. Heraldic glass early 17C kept art going

The next two centuries that followed, it survived, just, but the Victorian age saw a revival.

2) **The Making**

To make glass you need, silica (commonly sand), alkali (to lower the melting temperature), a stabiliser to solidify the glass (e.g. lime) and heat (lots of it).

Mix roughly - 70% silica, alkali 15%, stabiliser 15%

Various metallic oxides may be used to colour the glass batch.

A bit more chemistry….

Glass has a loose molecular structure as much like a liquid as a solid. In

fact, it is a super cooled liquid which sets at room temperature.

It has tremendous formability - you can cast a massive mirror or draw out glass as a fibre,
You can dissolve almost anything into glass and in great quantities.

Colouring is achieved by adding metallic oxides -

red - gold or pure copper;

blue - cobalt;

green - iron or chromium;

yellow - ferric oxide or uranium;

purple - manganese, to get red then add copper, or selenium or gold;

brown - add nickel to lime glass;

violet - add nickel to potash lead glass

Where did it all begin

Seems to have begun in Egypt 4000 BC and was a development of glazes used for pottery. Beads and later small vessels have been found. The glass was coloured using metallic oxides - copper, iron, cobalt.

Kilns

Started as pits then beehive kilns. High temperatures needed - 1320 C to melt the raw mix or 800 C to reheat and melt glass.

3) **What the Romans did for glass manufacturing**

The Roman industrialised the glass making process

Based in Egypt, they used pure desert sand mixed with soda (sodium carbonate) as the alkali, the primary source of which was natron, a naturally occurring salt found in dry lake beds.

Lime was the primary stabiliser in use during the Roman period, entering the glass through calcareous particles in the beach sand, rather than as a separate component.

I suspect this was a lucky break and they hadn’t yet understood the chemistry.

Evidence is scare but suggests there were only a few very large kilns in Roman times capable of reaching the 2400 F / 1320 C temperature required to melt the mix.

These kilns would have been sited close to the natural resources (Eastern Mediterranean) which would include large amounts of wood for the fire and a strong breeze to provide oxygen for heat!
The glass formed would be broken into chunks and then traded throughout the empire.
To reheat and therefore work the glass into a finished article requires a temperature of only 1600 - 1900 F / 800/1000 C which would have been similar temperatures accomplished in a simple shielded hearth or average Roman bread or clay oven.

Archeologists discovered a glass slab at Beth Shearim, during the Palestine clearances in the 1950's. **The slab weighed around 8 tonnes (6 foot by 11 foot by 18 inches)** and is believed to have been melted from a mixture of sand and soda in situ . It was off-composition, so abandoned. Clear evidenced of mass production though. The glass slab would have been broken up and sent to different parts of the Roman Empire by ship and wagon for subsequent re-heating to make items. Hence the secret of glass making preserved.

Besides the large kilns; expertise in understanding the need to slowly reduce the temperature in the kiln to allow the glass to set would have been needed.

We know this was achieved in later times by the use of an annealing kiln known as a lehr.

All glass must undergo a controlled cooling period, known as **annealing.**

If cooled too quickly, then cracking may occur.

If cooled too slowly, the glass can start to form crystals and has interior stresses, which make it hard to cut and can cause it to spring apart as it is scored.

The annealing cooling rate depends on the thickness of the glass.

In modern times a lehr is typically a long kiln with a temperature gradient from end to end, through which newly made glass objects such as glasses or vases are transported on a conveyor belt.

4) **Working the Glass**

It was in Syria, part of the Roman empire first century BC, where the technique of glass blowing was first thought to have been developed, and spread to the rest of the empire, ultimately including Britain.

Clay blowpipes dating from 1C have been discovered and are believed to have been used up to the 4C when evidence of metal blowpipes begins.

Glass sheets can be made into sheets in several ways.

1) Early sheets were cast. Cast panes were poured and rolled over flat, usually wooden moulds (wet) laden with a layer of sand, and once the glass had set, then ground or polished on one side

2) With the invention of the blowpipe, in the first century BC, glass could be formed much more quickly. Three methods have been used for blowing sheets.

First - the cylinder or muff method. A lump of glass is collected on the end of a narrow pipe and blown into a cylindrical mould creating the shape of an elongated balloon. When it was cooling the glass maker would split it along its length, using a wet stick and sensitively flattened it out into a sheet with a wooden tool like a bat in a spreading kiln. Glass sheets produced in this way were probably no more than 8" by 12" in size and may be identified as any air bubbles found in the glass form straight parallel lines. Sometimes the straight edge of the sheet with a rounded cross- section, or ‘muff edge’ is found. White glass using this method was made in England in the Middle Ages in Staffordshire and the Sussex Weald.

The second method - is the Crown method. A bubble is blown, transferred to a metal rod called a punty (or pontil), pierced, and spun out until in flattens like a plate, yielding a round sheet with no need for further flattening, but with a pontil mark remaining in the centre. The disc is typically between 9” to 18” in diameter although it could be significantly larger. Rectangular pieces then broken off (usually 11). The centre one has the most pronounced whorl pattern (pontil) and is less suitable for stained glass, more for pub doors! This method was not introduced into England until the 17th century, but imported crown glass from Normandy was used in the medieval period.

A third, less commonly used technique called 'Norman slab' was developed in the 19th-century and involves blowing the bubble into a mould to form a hollow square block, creating a glass box that is later separated into small sheets. When cooled it is cut at the corners making five rectangular slabs, not larger than 10 x 7 inches. They tend to be thicker and darker in the middle and thinner at the edges.

The modern process is for molten glass to run through mechanical rollers.

5) **Now to - Early Stained Glass**

When the Romans left England in the early 400’s they took the technology of glass making with them.

Interestingly we know the Romans had window glass in 1C but that when they left England, we reverted to animal skins / cloth and flattened horn until well into the 16C.

We entered the “Dark Ages” in the British Isles and whilst piecemeal recycling / re-melting of existing glass would have occurred it is most unlikely any ‘new’ glass made.

Writers in Europe however, as early as the 5th-century, mention coloured glass in windows.

By the 7th century, we know it was known that if metal oxides were added to the minerals in the clay pot before it went in the kiln-coloured glass could be produced.

The earliest English records date from about 670, when Bishop Wilfrid described his church at York as being glazed against wind and rain and the passage of birds but allowing the light to shine within - thus combining the practical and aesthetic roles of the material.

This early production is thought to have been linked with metalworking and the production of enamel jewellery because the technique of setting glass in frames of metal strips was similar.

France was a centre of glass production and enamel working and it was probable that it was here that the techniques were combined in the Middle Ages.
No coloured glass was produced in England at this time so it had to be imported from Normandy or the Rhineland.

We know most early medieval glass was soda-based, and although the use of soda glass in Northern Europe was almost wholly superseded by forest glass after c. 1000, there are some examples of a richly coloured blue glass that was produced in the medieval period using soda as the alkali.

In the UK, a considerable quantity of blue soda glass has been identified in stained glass from York Minster.

Evidence of recycling Roman tesserae to produce window glass in the 9th century has been identified in Italy.

Interesting to speculate how this blue soda glass came to York Minster - recycled Roman?

Prior to c. 1000, most coloured glass was of a soda-lime-silica composition. In Northern Europe soda glass was eventually almost totally superseded by potash-lime-silica glass (Forest glass).

I think our earliest window c 1290, is in the Chapter House depicting two Castles for Elenor of Castile, wife of Edward 1.

6) **Early Development**

It was not until the advent of the monumental cathedral and church building campaigns in the 11th and 12th centuries that the demand for coloured glass began to increase significantly, reaching its highest level in the 14th and 15th centuries.

Forest glass continued to be used in stained glass for the duration of the medieval period until soda glass again began to be used in the 16th century.

Another interesting fact is that forest glass is of low durability and weathers badly in damp conditions. This is because of impurities present when using wood ash and local sand. This leaves the structure of the glass quite open, so water is able to eventually leach out these impurities and in time an iridescent surface is formed which can in itself look like painted glass!

Soda glass which has a higher concentration of lime provides a more stable and therefore durable platform. Roman glass because of the absolute purity of its components does not deteriorate. If discovered the roman blue/green glass looks as fresh as the day it was made.

Now a couple of important developments

We have heard about pot metal glass which is transparent glass that is coloured throughout, while still molten in a 'pot' in the furnace. However red pot metal glass, was often too dark to transmit much light.
In the twelfth and thirteenth centuries streaky reds were used, which had interspersed lines of red and clear but by the 14C a new solution was -

Flashing

'Flashed' glass was made by dipping a lump of white glass on the blowpipe into a pot of red glass and then blowing. This could be repeated to produce many laminations. Clear glass, then red glass and so on. This provided sheets of glass with a thin surface layer of colour. Later, parts of this layer could be removed by grinding with an abrasive wheel or using acid to etch away; this produced two colours, red and white, on the same piece of glass.

This technique was sometimes used for other colours.

One could then have two colours side by side on one piece of glass without needing a lead line, so more intricate designs could be executed with fewer leads. Later, hydrofluoric acid was used to dissolve the flash in a chemical reaction and abrasion was abandoned. Abrasion removes all of the flash, but with acid etching it is possible to have gradations of removal, allowing shadings and various densities of colour.

Then a real breakthrough for the Artists

Silver stain

From the early fourteenth century a further range of colours varying from a pale lemon to a deep orange could be achieved on one piece of glass through the innovative use of 'silver stain', a silver compound painted on the back of the glass and then fired in a kiln. This is the only real staining of glass.

Producing a strong clear yellow was difficult in early stained glass as it relied upon the careful control of furnace conditions in order to create the appropriate reducing or oxidising environment. The discovery of silver stain not only provided a solution to this difficulty, but also allowed greater flexibility in the way in which colour could be used. The first datable example of the use of silver stain is in the parish church of Le Mesnil-Villeman, Manche, France (1313).

Silver stain was a combination of silver nitrate or silver sulphide blended with pipe clay and applied to (usually) clear glass then fired in the kiln.

This technique enabled a more flexible approach to glass painting, allowing, for example, the hair of a figure to be painted on the same piece of glass as the head. It was also used to highlight details of canopy work or grisaille and, it was the perfect way to depict hair, halos and crowns.

The chemistry is that during the firing, silver ions migrate into the glass. They are suspended within the glass network, rather than fused onto the surface, as glass paints and enamels are. After firing, a transparent yellow is revealed. Actually, glass can be stained a pale yellow to a deep red, depending on the composition of the glass and stain, the number of applications, and the temperature of the kiln. The stain can read as green when fired onto blue glass.

This is the only true “Stained” glass. Examples in the Chapter House (IHS) and the B window in the South Quire Aisle

IHS - first three letters of Jesus in Greek (Iota, Eta (capitalised form is H) and Sigma (Sigma sometimes a C i.e. IHC)

7) **Making of Stained-Glass Panels**

Theophilus was a Benedictine Monk, a metal glass and pigment worker who practiced in the late 11th and early 12th centuries.

He commented on a number of processes:

He stated that mosaic tesserae: “little square stones from ancient pagan buildings” along with “various small vessels in the same colours” could be used to produce glass; “they even melt the blue in their furnaces, adding a little of the clear white to it, and they make from it blue glass sheets which are costly and very useful in windows.”

We know for instance that stained glass analysed at York could indeed be Roman in origin, or slightly later, glass re-melted in France and imported into England’

Theophilus, in his book explained the practical techniques of making windows had little changed over the centuries: “…if you want to assemble simple windows, first mark out the dimensions of their length and breadth on a wooden board, then draw scroll work or anything else that pleases you, and select colours that are to be put in. Cut the glass and fit the pieces together with the grozing iron. Enclose them with lead cames...and solder on both sides. Surround it with a wooden frame strengthened with nails and set it up in the place where you wish…"

Sketch

It begins with the artist's sketch, known in medieval times as the 'vidimus' (Latin for 'we have seen’), produced on a small scale for approval.

Once approved, a full-size rendering, or cartoon, is made, which may be done by hand or, as is often the practice today, blown up mechanically.

Cartoon

A cartoon can be very detailed, with painting worked out and the basic colour selection indicated together with the lead lines marked out.

Before paper was readily available, the full-size drawing was made on a whitewashed table that was used for cutting and painting the glass, as well as for putting the finished window together. One such medieval table has survived, if only because it was later used to make the door of a cabinet. Two fourteenth-century windows made on it also survive in Gerona Cathedral in Spain. Examination under ultraviolet light has revealed several layers of drawings on the board, which contain lead lines, symbols indicating colours and some of the dark trace lines that were to be painted on the glass. There are also nail holes from the glazing, or leading-up of the panels.

Sheets of the selected colour glass would then be placed over the cartoon and cut to shape.

Glass Cutting

So, after the layout and patterns are made the glass is cut.

This demands great accuracy so that the result will be a strong and stable window and fit the designated opening!

Hot Iron

In the Middle Ages sheets of glass were first split into smaller pieces using a hot iron.

A red hot piece of Iron was drawn across the surface of the glass slowly in the generally desired shape. Then the glass was quickly quenched in water to break it. This method is still used today on round objects.

Grozing tool

Later a "grozing" tool made life simpler. Basically a piece of metal with a slot notched the approximate thickness of the glass so little bits of the glass can be nibbled off the side or "grozed "because it left a course edge”. Skilled craftsmen could make difficult and intricate shapes.

Most pieces had simple cuts and the craftsmen used broad lead lines to cover any imperfections!

Scratch

At some point in the history of the craft, an observant artisan realised that a deep scratch or score made on the glass surface would give better control of the breaking. One can sometimes see these scratches coming off edges on medieval pieces.

Diamonds

Diamonds set in handles were known to have been used for scoring by the 14th-century and were probably used earlier, although edges were normally still grozed. Diamonds are still used to score glass today.

Steel wheel

The steel wheel cutter was developed in the 1860s. As the wheel is rolled across the glass it focuses a tremendous amount of pressure just at the point where the wheel meets the glass, creating a surface fissure. The scored glass is then snapped apart, using the hands or a pair of pliers as a fulcrum.

Oil

However, as we have learnt glass is essentially a super cooled liquid. Fresh glass will therefore be inclined to self-heal if cut (given its open molecular structure) so today that is why, metal cutting wheels are slightly oiled - the oil left in the cut prevents the glass reforming before the break is made!

Glass Painting

Glass painting, enabled stained glass to move beyond its obvious decorative and practical functions to develop into a powerfully expressive medium.

Once cut to shape the pieces of glass are laid over the cartoon and the details of the design are painted onto the glass, traced from the painting underneath.

Line drawings (trace lines) are made with thin and thick washes which can be modelled by smearing or stippling, and some paint is removed (relieved) with a stick or needle to leave highlights. Paint is normally applied to the inside surface, but silver stain is applied to the back.

A badger brush can also be used to apply texture to the wet or dry mat through a striking action, called stippling.

The paint applied to glass is composed of a low-firing, essentially clear glass-flux and opaque metallic oxides. Generally iron or copper; powdered glass; wine, urine or vinegar; and gum Arabic, other recipes could include sugar, treacle or vegetable oil.

The binder, such as gum Arabic or oil, is used to temporarily hold the paint to the glass.

A variety of brushes, sticks and other tools are used to apply and remove the paint before it adheres permanently.

The glass is then re-fired in a kiln, at which point the glass-flux fuses to the base glass, which is beginning to soften, holding the opaque metallic oxides in place.

The painted glass is laid on trays of whiting (calcium carbonate) and loaded into the hot upper part of the kiln where it is fired at a temperature which fuses the paint to the glass**.** The glass is then left in the cooler part of the kiln to relieve the strains created in the glass by firing.

This ‘paint’ would be applied in a series of washes, being re-fired to set each time and with fine details added last. Both the external and internal faces of the glass could be painted, adding depth if required.

Enamel

By the mid-16th century a whole range of enamel paints which could be applied to glass were being produced. Enamels are intensely coloured ground-up glasses that are painted onto the base glass. They fire at lower temperatures than opaque vitreous paints. Enamels are fused onto the glass surface, and, while they are not completely opaque, they lack the transparency of pot-metal sheet glass.
This technology led to a total shift in artistry, because it was now possible to apply separate colours to one piece of glass, it was like painting in oils on a sheet of canvas.

With changing tastes and with the Reformation in full swing this newer style took hold and pot metal glass production fell off.

As a result lead joining was no longer necessary to provide an outline to a design; instead often its sole use was to hold the panes together. The designer’s aim was to conceal it rather than integrate it into the image.

Revival

The revival of stained glass in the 19th-century was very much a reaction against the extensive use of these paints.

As a rule, enamels are not as durable as vitreous paints, although vitreous paints can also fail, due to poor composition of the paint or the base glass, or to under-firing, as well as to environmental factors.

Back to our window making….

Assembling

When cooled the glass is laid over the cartoon and fixed together with strips of lead, which is ideal for the process, being flexible and durable. The lead strips (known as calmes or cames) are grooved with an H shaped cross section.

The Use of Lead Cames

originally reeds were used as moulds - latin for reed is calamus hence cames!

The advantages of lead in window glazing are several and significant: it is malleable; it can be formed to almost any shape; it solders well and easily; it can survive for centuries with little or no maintenance. The earliest lead cames were cast.

Molten lead was poured into a heated mould and planed to shape after cooling. By the end of the 16th-century, almost all lead came was milled.

When the glass is ready to be leaded together, or 'glazed', the glazing guide is placed flat on the bench and strips of wood are nailed down to hold the assembled pieces.

Once all the glass and leads are in place the panel is ready to be soldered at the joints, both front and back. Lead mixed with 60% tin was used as solder

The space between the glass and leads must be filled in order to give the panel additional strength and to make it waterproof. Linseed oil putty is either brushed or thumbed under the leads on both the back and the front of the panel.

Finally, excess putty and oils are cleaned off the glass and leads.

The lead did more than hold the pieces together; it became part of the design. The lead strips outlined sections of glass and kept the colours from appearing to overlap. Large windows were given a framework of iron bars for added strength.

Barring

The final assembly was done back on the table, with larger panels supported by iron saddle-bars to strengthen them

In an architectural setting, windows are subjected to extremes of weather - to wind pushing in and pulling out, to rain, sleet, hail, snow and so forth. The malleability that makes lead ideal for the freedom the artist needs also makes windows vulnerable to gravity and wind, so support bars must be anchored into the frame and attached to the stained glass. Panels are often set individually on T-bars set into the frame in order to support the weight of glass and lead.

8) **Modern Techniques**

The revival of stained glass making in the 19th century, highlighted a major problem. Production of high-quality pot metal glass was inhibited largely because medieval methods and techniques had been lost. As a result, much of the glass produced was of an inferior visual quality.

In response, in 1849 Charles Winston instigated chemical analyses of 12th Century glass. He subsequently worked with James Powell & Sons of the Whitefriars Glass Works and by 1854, the firm were supplying a whole range of new 'antique' glass to the trade.

At this time a new method of sheet glass production, the adoption of machinery to roll out a much superior finished product. Rather than using air to forge a shape from the glass, rolled glass is formed by pouring molten glass into a table that’s made of metal or graphite to withstand such high temperatures. The molten glass is rolled straight away, like dough, with a machine. Once it cools, the rolled glass forms a sheet perfect for cutting up. The rolled glass can be turned into textured glass by pressing patterns into the sheet as it cools.

Strangely, perfecting stained-glass techniques did not improve the windows. The bubbles in the first glasses and the unevenness of their surfaces made the sunlight seem to dance. The later glasses, with fewer imperfections, had less sparkle. Therefore, despite such innovations, antique glass blown by mouth continued to be made to order.

Now a final word on

9) **Conservation, Preservation, Cleaning and Repair of Stained Glass**

Stained glass has been repaired and restored since its earliest days.

Complete windows survive that date back at least 900 years, and some individual panes are even older still, but this cannot change the fact that glass is a highly vulnerable medium.

Glass is itself vulnerable to decay. Seemingly innocuous water is the first to attack. Its presence, in liquid or vapour form, promotes the leaching of the alkalis from the glass, weakening the network and building up corrosion products on the glass surface, although rainwater can actually be beneficial to a window, as it can wash away leached alkalis before they become concentrated on the glass surface.

The way each glass ages depends on its composition and its environment. Certain glasses can develop an opaque surface crust that retains moisture and becomes highly alkaline. As the leaching solution becomes more alkaline, the silica network itself is attacked.

Air pollution is thought to exacerbate the process. However, not all corrosion is due to weathering. It was observed that windows removed for storage and kept in damp conditions, notably during World War II, showed marked deterioration, while those kept in dry conditions fared much better. At the time, it was not realised that damp conditions would negatively affect the glass and paint.

Protective glazing, an external layer on the exterior of a window, is now a conservation possibility and, in Europe, has been one of the most effective ways to protect medieval glass. Such treatment is valid only if the space between the stained-glass window and its protective glazing is vented to allow a moving column of air.

The iso thermic double glazing of both the West and East windows are examples of this.

Otherwise, the window traps moisture, which actually accelerates deterioration of the historic glass.

Nineteenth- and twentieth-century glass is less vulnerable than medieval glass, owing to its different composition,

Just as glass paint is a film on the surface of the glass, so too are dirt and corrosion, which obscure the painted details and cut down significantly on the light passing through the glass. Since stained glass relies on transmitted light, these foreign materials must often be removed so that light may shine through.

However, such cleaning is not always easy, nor is it simple to do under even the best of circumstances. It must be approached with great care. Glass paint can be fragile and hard to distinguish from the film of dirt.

Opalescent windows are often several layers thick. Soot, dirt and old putty trapped between the layers can be very difficult to reach and they considerably diminish a window's effect.

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