GENERAL INFORMATION ABOUT STAINED GLASS WINDOWS

Since the Middle Ages, with the rise of Christianity, along with which the craft of stained glass was *developed* for the decoration of churches and cathedrals, stained glass windows have been created using essentially unchanged techniques and materials. A stained glass window is made up of pieces of glass, usually but not always colored, held together with metal strips called **cames**, usually made of lead. Some or all of the glass is usually painted.

GLASS

Most glass is made up of sand, lime, and soda melted together at temperatures above 2000o F. The colors of stained glass are the result of the addition of various metallic oxides to the molten glass before it is formed into a sheet. These colors are permanent and do not, for the most part, change over time. The glasses found in nineteenth and early-twentieth-century windows are tougher than those used in the Middle Ages. The "glass disease" or corrosion commonly found in medieval windows, is not a condition usually found in windows made after the seventeenth century. This was due to a change in the basic ingredients of glass. Early glass used potash instead of lime, which made for a softer glass, much more susceptible to attack by water and air pollution. This sort of attack requires centuries to become evident, but should never affect nineteenth-century windows.

Antique Glass - There are essentially three types of glass used in stained glass windows, each characterized predominantly by its method of manufacture. The first is **antique**, or hand-made glass. The term has nothing to do with the age of the glass, but with its traditional means of manufacture: the glass is hand blown. Antique glasses are colored and transparent. Antique glass is somewhat irregular, often having bubbles (called **seeds**) or striations (called **straw marks**) which enhance its sparkle. Most nineteenth-century European painted stained glass windows are made of antique glass. The most common technique for making antique glass is the **muff** or **cylinder** method. A quantity of molten glass is blown into a bubble at the end of a blowpipe and elongated into a cylindrical shape. The bottom of this long bubble is opened and the top cut from the pipe, resulting in an open-ended cylinder of glass, called a **muff**. After cooling (**annealing**), the cylinder is cut lengthwise and the glass reheated to allow it to be opened out flat. Muff glass is fairly even in thickness throughout the sheet (as compared to crown glass); sheets today usually range from about 2' by 3' to 3' by 4' in size.

PAINT

In addition to the basic color of the glass, most historic stained glass windows are painted with fired vitreous paint before they are assembled into windows. This paint, used to decorate or enhance stained glass windows, is made up of metallic oxides and ground glass. Paint sometimes imparts additional color, but usually is a dark opaque tone. Details such as facial features, drapery patterns, and inscriptions are usually painted. Vitreous paint has been used to delineate details in stained glass windows since the early Middle Ages. The vitreous (glassy) powder is mixed in a liquid medium for application to the glass and then fired in a kiln at temperatures between 800o and 1300o F. During firing, the glass paint melts and fuses with the surface of the glass, making it very durable. There are several kinds of glass paint.

Grisaille (pronounced "gree-zi'"-- it rhymes with "brie sky") based on the ancient French term for "grey" or **glass-stainer's colors** are the oldest type of paint. They are dark, opaque browns, blacks, iron reds, and dull greens, usually applied to the interior surface of the glass. They are composed largely of iron and other metallic oxides with a small amount of flux (ground soft glass) to aid in their melting and fusing to the base glass. These paints are used for **trace** lines, the opaque outlines created with a thin brush, and for **mattes** (often misspelled "matts"), the shadows created by thin washes of paint that are stippled or blended to suggest form and shape.

A second type of paint is **silver stain**. This is a transparent color that can range in tone from pale lemon yellow to deep orange. In reflected light, it sometimes has an iridescent metallic appearance. The name derives from the material used to produce the color: silver salts are applied to the exterior of the glass and fired at very high temperatures. It was discovered in the early fourteenth century as an application in stained glass. It is found in many types of windows, especially Gothic Revival windows. It is the most durable of glass paints.

The third type of glass paint is **enamel**. Enamels are colored paints made of ground colored glass. They tend to be paler in tone than colored glass, but can also be intensely colored. They are shiny, are usually found on the interior surface of the glass, and tend to be fragile because they are fired at low temperatures and sometimes do not fully fuse to the glass surface. Enamels were invented in the sixteenth century and are used to this day. They are found largely on heraldic panels and in opalescent figural windows.

Often an artist other than the craftsman or glazier was the painter; sometimes the window's designer may have been the painter, but this was not always the case. The paints are mixed with various liquid media and other substances to aid in the application of the paint to the glass. These different media serve several purposes. In some cases, they handle differently, allowing the artist to obtain different effects. For example, an oil medium might be used for tracing very thin, fine lines, either with a tiny brush or with a steel pen. Alcohol or turpentine is often used for various degrees of soft appearance in a matte. A medium containing gum arabic or sugar is usually used for ordinary tracing. Another reason for using several different media is to allow the paint to be layered without firing between applications. For example, an alcohol matte can be applied over a water-and-gum trace line without fear of dissolving the trace line and washing it away. If a water matte were used over a water trace, the trace would first have to be fired. A fourth type of paint found in stained glass windows is not technically a glass paint. It is referred to as **cold paint** because it is not fired, as glass paints are. Cold paint can be any type of unfired paint, including artists' oils, house paints, or glass paint that simply has not been fired. While old glass-maker's wisdom has it that "good" windows never employed cold paint, many windows made in the nineteenth century did in fact use cold paint extensively.

CAMES

After the glass is cut, painted, and fired, it is held together with I- or H shaped metal strips called **cames**. The pieces of glass fit between the **flanges**, or parallel legs, of the came. The center of the came is called the **heart**. The came is formed around the shape of the glass and joined at the ends with solder. Cames were traditionally made of lead, and most still are, due to its malleability and durability. Traditionally, stained glass windows are assembled in one contiguous layer. Occasionally a piece of glass will have another piece layered or **plated** over it to create a particular color effect.

Traditionally, lead was mined for the silver ore with which it occurs naturally. It has always been the byproduct of the smelting of silver and, in the Middle Ages, the lead left after the silver was removed still contained as much as 4% silver. In the middle of the nineteenth century, the smelting process was improved to remove that remaining silver. As a result, the lead available to stained glass craftspeople after 1850 was virtually 100% pure lead. While this sounds like a benefit, a century-and-a-half later we have discovered that it is not. Pure lead came has a life-span of only about one century, while cames from the Middle Ages sometimes last several centuries. Research into this phenomenon has deduced that without the silver (or copper, which performs the same way and is less expensive), lead fatigues much more quickly. In lead came in stained glass windows, this fatigue is caused by expansion and contraction, the effect of which is noticeable as cracks or embrittlement. This cannot be reversed or corrected. Came specified in restorations today should contain trace levels of certain metals other than lead to forestall having to re-lead the windows again in a hundred years.

ASSEMBLY

To build a leaded glass window, a drawing is first done of the proposed design. Drawings are rarely done full size; they are small scale sketches. These must then be enlarged to full size in order to make the pattern, called a **cartoon**. The full sized design is copied onto paper twice. The original cartoon is kept for reference; one duplicate is cut up for patterns and the other is placed on the glazing table (called the **bench**) on top of which the window is assembled. In order to cut the patterns, a three-bladed shear is used. This removes a narrow strip of paper between the pieces, leaving room for the heart of the came. The paper patterns may be tacked to the cartoon, or separated by color for cutting, depending on the nature of the design. Colored glass is selected by the artist or craftsman piece by piece. After a piece has been chosen, the paper pattern is placed on top of the glass. Using a steel wheel glass cutter, the craftsman scores the glass around the pattern piece, following its edges exactly. The glass is separated by pulling away from the score. Burrs, slanted edges, or inaccurate cuts must be adjusted in order for the panel to fit together. This is done by **grozing** or chipping the edge with grozing pliers or a grozing iron, a steel tool with a notch cut in the side. Many modern glass cutters have grozing notches on their sides. By levering the glass in the notch of the grozing iron or in the mouth of grozing pliers, tiny chips are removed and the shape of the piece is minutely changed. The pieces are then **waxed up** for painting. On a large sheet of plate glass, the lead line of the window is traced in black paint using the reference drawing. Each piece of cut glass is then attached to this plate glass easel in its correct position, using a beeswax mixture to keep it in place. The easel is then placed vertically in front of a light source (a window or light box) for painting. Alternatively, painting may be done horizontally on a light table, in which case there is no need to easel the pieces on the plate glass. After application of the paint, the pieces of glass are removed from the easel and placed on a kiln tray, usually on a bed of whiting. The tray is then placed in a kiln for firing. Firing melts the flux of the paint and softens the surface of the glass, bonding the paint to the glass. In the late-nineteenth and early-twentieth centuries, kilns were fired with either gas or electricity; today, most kilns are electric. Prior to the discovery of gas and electricity, kilns were heated with wood fires. When all the decorative processes on the individual pieces of glass are completed, the panel is ready for glazing. Placing the glazing diagram on the bench, strips of wooden lath are nailed to the bench as a guide for the corner of the panel. The lead came for this corner are cut and placed against the lath, and glazing has begun. Working from one corner to the other, diagonally across the window, each piece of glass is placed into the came, then another piece of came is cut and placed, then glass, and so on. The glazing guide beneath the panel ensures that the pieces are placed correctly and that the size of the panel is kept accurate.

In order to keep the assembly, which is not yet soldered, from coming apart, large nails are driven into the bench at the edges of each newly placed piece of glass. When the opposite side is reached and all the glass and came are in place, all the nails are removed and laths are nailed into place on the final two sides of the panel. The panel is ready to be **soldered**. All the joints of the panel must be soldered on both sides. Before soldering, they must be **fluxed**. Flux cleans the came and assists in the distribution of heat to allow the solder to flow smoothly. There is a variety of fluxes; in the Middle Ages, tallow was used. Today, zinc chloride, oleic acid, stearic acid, and other materials are used. Flux is wiped onto every joint and the heated soldering iron touched to the solder and the joint to melt the solder into the joint and connect the cames. When the upper side of the panel is completely soldered, the laths are removed and the panel must be carefully turned over to solder the other side. After soldering, the panel is cleaned to remove all traces of flux.

Although the process of making a stained-glass window is not difficult, as in any other craft it requires practice. There are things that make glazing substandard. These include using a too-cool soldering iron or using the wrong solder or flux, which causes pointed or lumpy joints; using came of the wrong size, profile, or metal; not lining up cames that should continue from one section to another, or across a bar line or another came; failing to remove all of the flux, which can cause corrosion.

PURPOSE OF PROTECTIVE GLAZING

The issue of protective glazing is a sticky one. Many windows do not require it. If installed improperly, it can cause more damage more quickly than any other factor except vandalism. It has practically no value as an energy conservation measure in a historic building. Generally we do not recommend its use except 1) if the building or window is in area where vandalism, theft, or accidental breakage from impact (located next to a playground, for instance) poses a real and significant threat; or 2) if the windows contain fragile glass or glass paint which would otherwise be exposed to the elements; or 3) if restoration procedures or materials have been used which are not weather-stable (such as epoxies); or 4) if the market value of the windows is extraordinarily high and/or the cost of restoration would be very high in the event of damage.

Protective Glazing Ventilation - By far the most critical aspect of protective glazing is its ventilation, which must allow a complete and continuous exchange of air between the stained glass and the protective glass. If this exchange does not occur, moisture will collect between the stained glass and the protective glass. It is impossible to completely seal that space because a stained glass window will always leak air. This trapped moisture will condense on the came and very rapidly corrode the glass, glass painting, glazing compound, and came. It will also cause extensive damage to the framing of the window and often seeps to the interior of the building, causing damage to plaster and finishes. This will happen more quickly in a closed environment than in an open one, because water is always present. Therefore, unventilated protective glazing will actually damage a stained glass window more quickly than natural aging could. One of the principle questions surrounding the design of protective glazing concerns whether to the vent to the inside of the building or to the outside. There is no one simple answer; it depends on many conditions, including the framing materials, the type and condition of the stained glass, the construction of the building, and the orientation of the windows to the sun. Generally speaking, it is usually less expensive to vent to the exterior; and it is usually impossible to vent to the interior in stone settings or if the windows are not being removed.

GENERAL RECOMMENDATIONS

Glazing Material:

Plastics - We do not recommend the use of a plastic material, such as polycarbonate (General Electric's Lexan®) or acrylic (Plexiglas® or Lucite®). Polycarbonate, the toughest available plastic, is sold as being unbreakable, but the manufacturer guarantees this for only 2 years. Tests and experience have shown that polycarbonate becomes very brittle after five to ten years of exposure, and by that time can be as easily broken as glass. In addition, despite manufacturer's claims to the contrary, polycarbonates change in appearance after several years of exposure. They can become opaque, scratched, or yellowed.

Acrylics - Are more brittle than polycarbonates, although cell-cast acrylic is stronger than other forms. Acrylic tends to yellow and scratch from wind abrasion more rapidly than polycarbonates. The rate of expansion of plastics is very high, and if not set properly— i.e., if set by drilling through the plastic to fasten it —shear tears, cracks, and other degradation usually occurs as a result of expansion stress. In addition, the warping and bowing of plastic gives the building an unattractive appearance and contributes to its degradation over time. A better installation requires the plastic sheet to be set in wide frames, usually aluminum. These frame sections, which are sold specifically for the storm glazing of stained glass windows, are usually 2" to 3" wide. Unfortunately, it is extremely rare that such framing can be made to coordinate or harmonize with the exterior appearance of an historic building. As a result of these various degradation modes, plastics typically require replacement within ten years. Finally, the cost of polycarbonate averages four times the cost of glass. Compounding this cost every ten years makes polycarbonate an extraordinarily expensive, as well as unattractive, alternative.

Glass - We recommend the use of clear glass for protective glazing. In most buildings, we recommend ordinary laminated glass, at least 1/4" thick. Although the glass itself can be broken on impact, it is far more difficult to penetrate the polyvinyl inner layer of the laminated glass, which preserves intact the stained glass it's protecting. If there is a very high risk of vandalism, burglar-resistant laminated glass is also available. Due to the difficulty of cutting laminated glass into complex shapes required in tracery, ordinary 1/4" plate glass is generally sufficient in these areas, which are usually quite high up on the building and therefore protected from ordinary vandalism. In areas where accidental breakage, such as falling tree limbs, may be a more realistic concern, tempered glass may be suitable. The process of heat-strengthening creates a glass that is typically two to four times as strong as ordinary plate glass. Tempered glass cannot be used in windows with complex tracery, nor can it be used in settings that require drilling of the glass for fastening.

Framing and Setting

Designing a framing and setting system is often the more difficult task. In general, framing should be visually subordinate. It should not obscure tracery and framing on the exterior, or cause shadows on the stained glass from the interior. It should place the protective glazing not less than 1" away from the stained glass. Mullions, if required, should align with mullions or major divisions in the stained glass windows themselves so that the exterior mullions do not cast shadows on the stained glass visible from the interior. Whatever kind of framing is designed, the space between the stained glass and the protective glass must be vented to allow full circulation of air. Vent holes at the top and bottom of each independent light is required. The jambs should be sealed, which will create a convection current and allow air movement.

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