BRIEF HISTORY OF STAINED GLASS

RECIPE FOR BLACK WALNUT INK
(USED IN MAKING LEAD MOLDS)

BIBLIOGRAPHY

RESEARCH AND EXPERIMENTATION

INTRODUCTION

The goal of this paper was to re-search how to make a stained glass panel from raw material to final product. Many of the pictures here were taken while doing research when I was attempting to recreate a few stained glass panels currently on display at the Corning Museum of Glass. My plan was to follow as, closely as I could, the description of stained glass making found in the writings of the twelfth century Monk Theophilus in reproducing this panel (De Diuersis Artibus, book 2) so it wont be a surprise to see many references to his writing.

What I wanted to accomplish in this research was to work with construction techniques used in the early part of the middle ages. This includes, making my own solder, lead came, stain, cutting glass with a hot iron and experiment in making sheets of glass. As I sought this goal I discovered a few limitations. They are described later in this paper.

THE STAINED GLASS PATTERN

Research

The creation of the pattern itself is not well described in the literature of the Middle Ages. Theophilus says to draw your pattern or cartoon, adding any painting that has to be done onto a whitewashed board. A white washed board is smooth board that was covered with chalk and wetted down (Theophilus, pp 47). The whitewash board could be repainted and used several times over. Parchment paper was also used to create patterns (Raguin, pp 40,41), My research has shown that this process has not really changed much.

Experimentation

All of my work starts with a drawing or cartoon on paper instead of using a whitewash board. My paper is the equivalent of parchment.

MAKING THE GLASS:

Research

How the glass was made

In northern Europe glass was made with two parts Beachwood ash and one part sand. This is known as potash glass due to its high concentration of potassium. This glass can produce stronger colors but is also more subject to deterioration as the potassium creates a softer more brittle glass and tends to discolor over time. The stained glass from Northern Europe tend to require more restoration. In southern Europe they used sand and a soda rich vegetable ash (marine or desert plants). Since these were rich in soda it is known as soda glass. Because the vegetable ash has fewer oxides than the Beachwood ash, the color ranges are not as good. However, the glass is more durable (Royce-Roll, Twelfth Century Stained Glass Technology, Avista Forum,p14). Theophilus used two parts wood ash to one part river sand (Theophilus p39). This combination came about by trial and error not by quantitative means.

There were two techniques to make a sheet of glass. The first is called the Muff Method. Here the glassmaker or glazier gathers a ball of molten glass called a parison on the end of an iron rod called a pontil. He then molds the glass by rotating it. Then next step the glazier takes is to blow on the end the pontil, which is a hollow tube. What he creates is a hollow bottle shape known as a muff. He then cuts both ends of the bottle away to create a cylinder. While the muff is still hot, the glazier slices down the side of the muff length wise, and then flattens out the muff to create a flat sheet (Lee, Seddon, Stephens, pp 180,181).

The second method is called the sheet or crown method. Here the glazier gathers a parison onto a pontil and blows, shaping the glass as in the muff method. Once the desired shape is achieved, a second pipe is attached to the other end and the first pipe removed. The glass (crown) is rotated until it becomes flat and large. The crown is then removed from the second rod. The center of the crown forms an excrescence known as a bulls-eye. The resulting glass from both of these methods often had air bubbles and an uneven texture and thickness due to cooling and fabrication (Lee, Seddon, Stephens, pp 180,181).

Color of glass

The texts tell us that the color could be controlled by adding metal oxides to the glass. Red was made by adding iron oxide, green with copper, blue with cobalt, yellow with manganese (Brisac). Dr. Royce-Roll of the University of Alfred did research on this topic. His research was based on the methods of Theophilus to see if he could re-create the colors used in Theophilus' time. He went so far as to make a scaled down version of kiln whose design was based on an early 14th century furnace. What he found is that the colors may not have all been created by adding different oxides as the history texts imply. He found that the impurities in the materials that were used in the creation of the frit in concert with heating the glass in either a reduced (oxygen poor) environment, oxidized (oxygen rich) environment, or a combination (alternating) of reduced and oxidized environments caused the color differences in the glass. Beachwood ash contains a high concentration of manganese. It is these oxides of the manganese that produce the wide varieties in color. The manganese found in the ash can produce purple (oxidation), yellow (reduction), and pink (combination of oxidation and reduction). It was difficult to exactly reproduce colors the same from batch to batch because the concentration of manganese varied from tree to tree. With the addition of copper oxide you can produce red, green and blue glass. If you look through Theophilus' manuscript, the only oxide that is mentioned is copper oxide. Also because of these impurities in the raw materials, clear glass was very difficult to make (Royce-Roll, The Colors of Romanesque stained glass).

One of the problems with colored glass or pot glass is that it was not transparent enough to let much light in such as the color red. This problem was overcome by a method called flashing. Here a very thin layer of colored glass is fused on top of a clear piece of glass. It was also discovered that if several pieces of colored glass were layered, the top piece could be etched away to allow the underlying color to come through increasing the amount of detail an image in a piece of glass could have (Stained Glass msn Encarta p1).

Experimentation

Theophilus described in his writings (I am summarizing in my own words here) that to make a sheet of glass using the muff method: 1) you take a glob of molten glass and place it on the end of a blowpipe. 2) you blow and rotate the glass until a bladder is created. 3) remove the bladder from the blowpipe. 4) you remove both ends of the bladder to create a cylinder. 5) you then cut down the center of the cylinder lengthwise. 6) while still hot, you open up the cylinder until it lay as a flat sheet of glass (Theophilus pp 40,41).

My first problem here was I don't have a kiln, blowpipe, or the furnaces to make glass. To solve these limitations, I contacted Harry Seaman who is the director of instructors for the Corning Museum of Glass Walk in Studio. I described what I wanted to do and we set up a meeting time at the museum's walk in studio.

By the time I arrived Harry had already blown two bladders of glass. As the annealing process requires an overnight wait, he wanted to have something to work with the day we arrived.

Because the studio only works with certain colors on certain days I really didn't have a choice of colors to work with, so we used what was already in furnaces. The color of the day was brown. To make this color, small amounts of nickel oxide (seven tenths) was added to the molten glass. This is not one of the colors that were produced by Theophilus's methods but still clearly illustrated the technique.

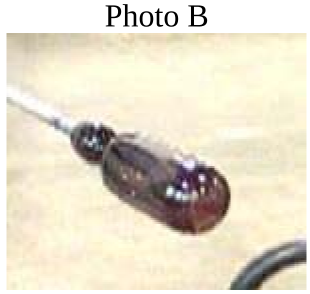
The first thing Harry did was to prop up one of the bladders that he had already made, and scored (scratch) it near the point where the curved top part meets the long portion of the glass. Then by heating and rotating the bladder we were able to create a crack running all the way around the top of the bladder. The left side of photo A shows where the top of the bladder had cracked and the right side shows the bladder with the top removed. We flipped over the bladder and repeated the process on the other side. When we were done we had a cylinder. We did this three times. Harry cut the first cylinder to instruct me in the technique, and then I cut the remainder.

Photo A

The next step was to create a crack going down the length of the cylinder without shattering the glass. We tried several methods. The first was to place a score down the entire length of the cylinder. Then heat the score until it cracked. This worked. Then we tried it by placing a score on each end of the cylinder. We applied heat again and still the crack traversed down the length of the cylinder. We noticed though that the crack did not match up with the scores on both ends of the cylinder. So we tried it again using one score. It worked just fine. Thinking back to the techniques described by Theophilus on cutting glass (see De Diuersis Artibus pp 48,49). We could have just as easily taken a hot iron, placed it on the lip of the cylinder, waited for a crack to form and dragged the iron down the length of the cylinder. I believe this would have accomplished the same thing and I would like to try this on another visit. Two of the conditions that could cause the crack not to form in a straight line would be defects in the glass such as air bubbles or impurities, or the varying thickness of the glass.

The next thing we did was go into the studio. Here we actually created a few more glass bladders (Photo B). Because of safety issues (I do not have any training in glass blowing), Harry did the actual forming of the bladder.

Photo B



For one of the bladders I was allowed to blow on the blow pipe to get an idea of how much (or little) pressure was needed to blow air into the glass. The bladders we made went into the annealing chamber and, once again, they had to stay there overnight.

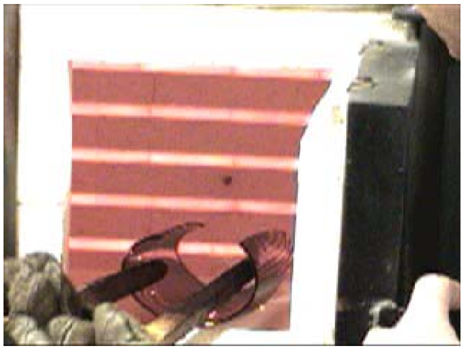
After lunch we met back at the studio to complete making the sheets of glass. We tried the following varying techniques.

1) The first attempt was to find the correct temperature needed to work with the glass and to figure out the best way to spread the glass. We discovered that the glass first starts to slump or soften between 1250 and 1260 degrees Fahrenheit. If we held the temperature at 1300 degrees Fahrenheit the glass would begin to slump or flatten on its own. When we spread the glass on this attempt we applied pressure near the top of the cylinder closet to the seam. The idea was to pry it apart using a spreading motion and a downward motion. This worked but with a lot of effort. We used two wooden sticks to pry the glass apart.

2) By the time we were ready for the second attempt, we had the temperature down but not the technique. Again we tried spreading the glass from the top of the cylinder thinking that we didn't have the temperature right causing the spreading to be difficult. We found that it was still difficult.

3) For the third attempt we tried spreading from the middle of the cylinder outward hoping that equal pressure on both sides of the glass would unfurl it (Photo C). This did in fact work better than trying from the top. For all the attempts we knew that once we got the edge of the cylinder spread back far enough, the glass would slump flat to table and not back on it self.

Photo C



Some of the things we learned:

1) Wood burns nicely at this temperate. In order to reduce the time before the wood sticks burst into flame (which were seconds), and set off fire alarms, we got them damp.
2) If we apply too much pressure on the glass it will crack even though it is in a semi molten state.
3) If we let the glass fold in on itself then it is not possible to separate the two pieces.

4) If we were to get a good sample, we needed to work the glass in small increments at the proper temperature. Work the glass a bit, let heat up again, work it some more, heat it up again, and keep this cycle going until the glass lay flat.
5) We had to keep a close eye on the glass while it was in the kiln else it would slump too quickly and fold in on it self.

In Photo D you can see the bladder, the ends cut off and sliced down the center, and then the resulting sheet of glass.

Photo D

GLASS CUTTING
Using a dividing iron.
Research

Theophilus tell us that to cut glass, all one needs to do is take your glass, place some spittle or water where you wish to start cutting. Then get a hot iron and hold it on that spot until a fissure in the glass begins to form. Then simply drag the iron along the line you wish to cut. When done, finish shaping it with a grozing or groseing iron (Theophilus pp 48, 49).

I don’t mind telling you I was a bit apprehensive of this part. My experience has shown that when two temperature extremes meet, nasty things happen. So out came the safety glasses and the apron. As I don’t have a forge I used my acetylene torch to heat the iron. I placed the iron to the glass and nothing happened. I tried it again several times and still nothing or so I thought. I picked up my test piece and lo and behold there was a crack. Because of the lighting, the type of glass, and the work surface I had the glass on, I did not see the crack form nor did I hear one. There is a distinctive almost bell like “tink” when glass gets a thermal crack. I got my iron hot again and drew the iron down the length of the test piece occasionally stopping to see the progress of the crack. The crack was in fact following the iron.

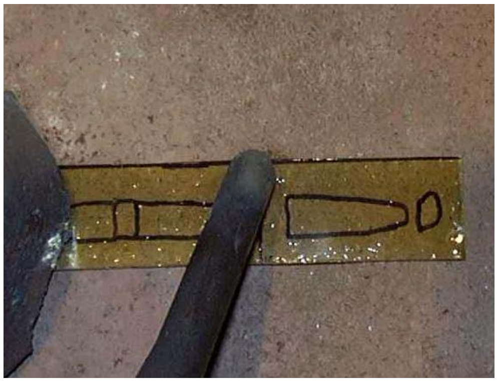
Thinking that this was dumb luck, I tried another test piece. For this attempt I tried cutting a curved line. I paid closer attention to the sounds when I placed the iron on the glass. This time I heard the “tink” of the glass cracking. I dragged the iron across the glass in an S pattern and watched as the crack followed the iron.

It took a few attempts to figure out how fast to drag the iron. If I went too fast the fissure just stopped. If I went too slowly the defects in the glass would heat up and cause the crack to go in an unwanted direction. Lastly if I didn’t follow my drawn line, neither did the crack.

Experimentation

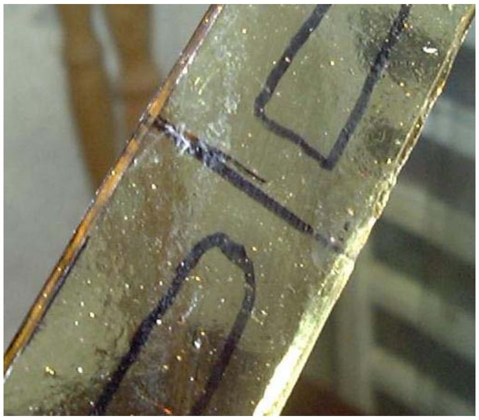
1) Once the patterns have all been traced, the next step is to start cutting. The process starts by placing a drop of water on the edge of the glass where it is to be cut and then place a hot iron on that same spot (Theophilus, pp 48,49) (Photo C). I flipped the glass over so that the inked side of the glass was facing down. By working this way the heat of the iron would not burn off my tracing lines.

Photo C



2) The hot iron then caused a fissure to form in the glass. It is difficult to see where the fissure forms as it is a subtle crack (Photo D). I have learned from past experience the when a fissure forms from thermal contact, there is an almost bell like "tink" that can be heard.

Photo D



3) Next I dragged the hot iron along the line I wanted cut. The fissure will follow the hot iron. As can be seed in Photo D, it is not always exact. It is however close. As I learned while experimenting with cutting glass (appendix 4), the glass doesn't always cut the way you want it to .I had two miss-haps where the fissure migrated into the glass that I did not want cut rendering those pieces useless. I ended up cutting additional glass. Photo E shows the cut piece of glass. I then used the same procedure on the remaining pieces of glass.

Photo E

4) If the glass did not cut the way it was intended but was still useable (i.e. the fissure went outside the line to be cut into spare glass), a grozing iron could be used to finish shaping the glass.

5) The glass can be smoothed down using another piece of glass or a stone (see Art History Final Project). Glass is predominantly quartz. According to the Mohs hardness scale quartz has a hardness of seven (see Cornelius p184). Also According to this scale the only material that can scratch or smooth quartz would be a material that has a hardness greater than seven. Seeing that the glass we are working with is not pure quartz, the impurities in the glass would make it either greater than seven or less. So it is possible to smooth glass with glass or a common rocks such as pumice (volcanic glass), granite (composite of quartz, mica, feldspar, hornblende), corundum (mineral hardness 9), or obsidian (volcanic glass). I smoothed down the edges with a piece of granite.

Creating a dividing iron

The first time I tried cutting glass u used a modified punch. I was unable to find a picture or description of the rod that was used until I tried another project. Photo "D" shows a picture of what a dividing rod looked like.

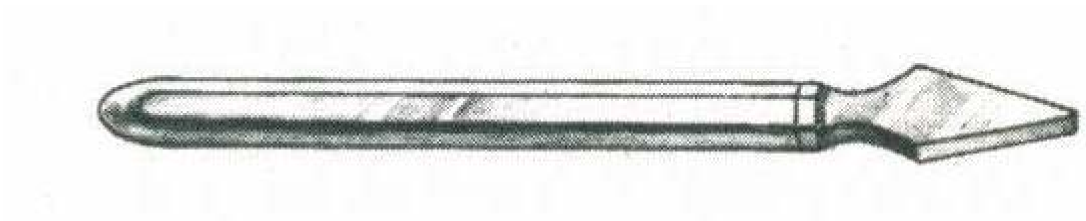


Photo D

This device looked like it would have worked well. The large flat diamond point could store the heat, and the point used to focus heat on the glass. Off I went and with the help of some blacksmiths, I forge a tool similar to what is pictured in Photo “D”. Mind you this was my first time at a forge. Photo “E” shows the resulting tool along with the other two tools I tried. The ruler gives an idea of the size of each.

Photo E

Photo “F” shows me attempting to cut a piece of glass. I was successful but I found the new tool to be too heavy and too unwieldy. I think that a smaller version would have worked just fine.

Photo F

Photo “G” shows the resulting glass that was cut.

Photo G

GLASS CUTTING
USING A DIAMOND POINT
RESEARCH

It had been known for a long time that diamond was used to etch glass or create intaglios in stone but there was no reference to the diamond being used to cut glass. Finally that reference was found in manuscript 2861 section 217 of the Bologna Manuscript dated around 1425 to 1450. In short this section describes how the use of diamond points can be used to cut plate glass (Tolansky, 132). In their natural forms a diamond is an octahedron shape. The diamonds were set into rings so that one of the points faced up out of the bezel or mounting (Scarisbrick, 300). That exposed point would be used for engraving or creating a score.

Before I continue lets talk a little mineralogy. A scratch test is used help determine a type of mineral you have. The Mohs hardness scale is a scale used to measure the relative hardness of a mineral. 1 is the softest and 10 is the hardest. Diamond (10) can scratch anything from itself down to a mineral with the hardness of one. Corundum (9) can only scratch itself and down to talc (1). Corundum cannot scratch diamond. Feldspar (6) can only scratch itself and down to talc (1) but not anything 7 or above. It follows that a diamond, corundum (emerald, sapphire, ruby), or topaz could scratch glass which is about 6.5 to 7 on the mohs hardness scale.

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1)	talc	
2)	gypsum	finger nail about 2.5
3)	calcite	copper about 3
4)	fluorite	
5)	apatite	steel about 5
6)	feldspar	glass 6-7
7)	quartz	emery 7-9 garnet 6.5-7.5
8)	topaz	
9)	corundum	ruby, sapphire
10)	diamond	

To cut glass one simply places the diamond point on the glass, apply a firm downward pressure and drag the point across the glass where you want the glass to be separated. The diamond will scratch or score the glass. Then you just need to manually apply pressure to the edges of the glass on both sides of the score and the glass will break. This is exactly how we do it today. Modern glass cutters use a carbide wheel to score glass but diamond is still in use as well.

Glass guilds closely guarded their trade secrets so it is not unreasonable to assume this is why the use of the diamond point was not a well publicized technique until much later in history. It is most probable that the first person to cut glass with a diamond did it by accident. My best guess would be that someone was engraving a piece of glass and the glass broke. The engraver realized that the break was along the etched line.

Experimentation

We have all heard about cutting glass with a diamond, but trying it is something else.

I went ahead and ordered a small low quality but still gem quality diamond. I mounted the diamond in the base of wood dowel, table side down. I wanted the point of the diamond facing up.

I took the diamond embedded dowel and scratched an arc on a piece of stained glass. The diamond (as it should have) scratched the glass easily.

I then took a pair of pliers and applied pressure to the glass. The pliers act the same way a grozing iron would. Another way would be to tap the glass along the line of the score to propagate the score line deeper into the glass thus weakening it more. The glass broke along the scratch or score line.

GLASS STAIN

Research

To start this section of the project off I picked up an old cast iron pan, and a granite mortar and pestle. Theophilus used one third copper oxide, one third blue glass, and one third green glass, ground them to together to make a fine powder and added urine or wine as a binder (Theophilus pp 49).

Experimentation

The first step is to make copper oxide, which is a black powder. The basic theory is to heat the copper and the oxide forms, and then just brush it off into a container. I tried several ways to make the copper oxide. My first attempt was to take copper shavings or filings and heat them up grind, re-heat, grind, until all the copper filings were reduced to copper oxide. It took me and hour to get enough filings to work with. I had to use a steel file because any other method (that I could think of) would introduce other materials into the collected filings. Steel is harder than copper. I had a very tired arm by the time I had enough filings to do anything with. I then put the filings in the pan and placed the pan on the stove on high heat. The reaction went quickly (more surface area the faster the reaction). Unfortunately it took a long time to reduce the filings to oxide (or what I thought was oxide). I then ground down blue and green glass to a fine powder.

I combined all the oxide I had with equal amounts of the blue and green glass. I ground them together and added some wine for a bonding agent (really couldn’t bring myself to use urine which Theophilus suggested as an alternative to wine). On my first attempt I added too much wine because it painted on too watery, although I did have a dark enough "paint" to try the fusing. I painted a letter onto yellow glass noticing lumps in the paint, and placed it in the kiln. While I was mixing everything in the mortar, the grinding cleaned off the filings revealing that there was still a lot of copper that did not reduce to copper oxide. This explained the lumps in the paint. I fired it anyway. The temperature was not listed in Theophilus’s manuscript so I went to two of my jewelry books that touched on enamel and decided to use the temperature outlined in the books. I set the temp for between 1300 and 1400 degrees Fahrenheit. My kiln does not have a reliable way to control the temperature accurately. The kiln relies on a rheostat that turns the kiln on and off to maintain temperature levels or to control the rate of heating. I let kept the temperature steady for 5 minutes then turned the kiln off. I let it cool slowly. When the kiln was cool I took the sample glass out. Per Theophilus, I did a scratch test on the stain and it did not come off.

I had a temperature to fire at, but I still did not have a good way to make the copper oxide. The next method was to put an entire sheet of copper in the pan and heat it instead of filings. I lightly sanded the sheet to reveal a bright copper. I then put the sheet in the same pan as before and heated it on my stove on high for 20 minutes. What resulted was a layer of copper oxide coating each sheet that I could then brush off into a container. This was a better method, as I knew that all I was getting pure copper oxide. I then cleaned off the sheet, sanded to reveal clean copper and heat it again.

The yield was not that great but for the same amount of time I spent on the first method I found I was getting about the same amount of copper oxide without working as hard and knowing that I was getting pure copper oxide.

While the copper was cooking for my second method, I decided to play with the stain I had made with the previous batch of copper oxide. A few days had lapsed since I made this stain and the wine I had used evaporated. Instead of wasting what I had. I tried adding various amounts of wine to try and figure out a good consistency. I found that a thicker mixture worked better than a thinner. The stain held to the glass better and did not spread out.

I really wasn't satisfied with the way my copper oxide production was going. The next attempt was to use a propane torch instead of the stove. The torch had a higher heat and the reaction went quicker but it wasn't much better than the stove. Now Theophilus described how he made his copper oxide. Remembering Theophilus put thin sheets of copper in a fire and burned it, my third attempt at making copper oxide would be closer to his method. A fire was not feasible in my basement so I used the next best thing. I placed a thin sheet of copper in my kiln and fired it to about 1200 degrees and let it sit for about ten minutes. When the kiln cooled down some, I placed the copper sheet into a pan and covered it with a wire mesh screen. I learned and found that when the copper cools, the rate of contraction of the copper is faster than the rate of the copper oxide. What resulted was the copper oxide popping off the copper sheets sometimes making the copper sheet itself jump (see Chapter 3: Electrochemistry- make a solar cell in your kitchen). By placing the hot copper into the container and covering it, the copper won't jump all over the place and I can catch the copper oxide in my container instead of trying to clean it out of my kiln. This worked very nicely. What resulted were big thick flakes of copper oxide. I also found my copper oxide yield to be much higher than the other methods and didn't take anywhere as long.

I used the copper oxide that I made with kiln and once again grinding equal amounts of copper oxide, blue and green glass. I added a few drops of wine until I had the proper consistency and tried painting on piece of clear glass. This time the stain was smooth, covered the glass evenly, and there was no spreading. As last time, I fired the glass in the kiln at 1300-1400 degrees for about ten minutes. After the glass cooled in the kiln, I performed a scratch test on the paint and it held. Photo A shows some of the powdered blue and green glass, some copper oxide still on the copper (black residue), and my good stain sample.

Photo A

After this successful trial I attempted several other stains by varying the amount of blue and green glass. I found the one third method produced the best results.

LEAD CAME AND SOLDER

Research

Lead came is used to hold the individual pieces of glass in place. There are two types. There is an “H” or “I” shape (channel) and a “U” channel. The “H” or “I” have two leaves and a heart forming two channels for glass to slide into. This used to keep the inside pieces of glass together. The “U” channel only has on channel for the glass to go into and is used for boarder pieces.

Theophilus proposed two methods in making his molds for the lead. The first method is to cast iron molds that are hinged at the end with an opening in the top. Molten lead is poured in the opening at the top. When full, the two halves are separated and you have lead came. The second method called for taking a flat piece of wood and marking it where the ends of the came should be. Then take a string soaked in ink and lay it across the length of the wood where you made your markings. Take a second flat piece of wood and press it down on the first. When separated a line will be drawn on both pieces of wood where you need to cut. Repeat this step with the second set of markings. The next thing to do is to take a knife and cut into the wood to the desired depth of the came along the lines you just created, on both pieces of wood. Next match the two sides up and bind them. Heat your lead and pour it into the mold. Let it cool and separate the two pieces of wood (Theophilus pp 53-56). You now have your H came. To create the U came, flip one of the boards around so that its flat side matches up with a cut side. Bind them together, melt your lead, and pour. Let it cool, separate the boards and now you have the U channel.

The Lead Came Mold:

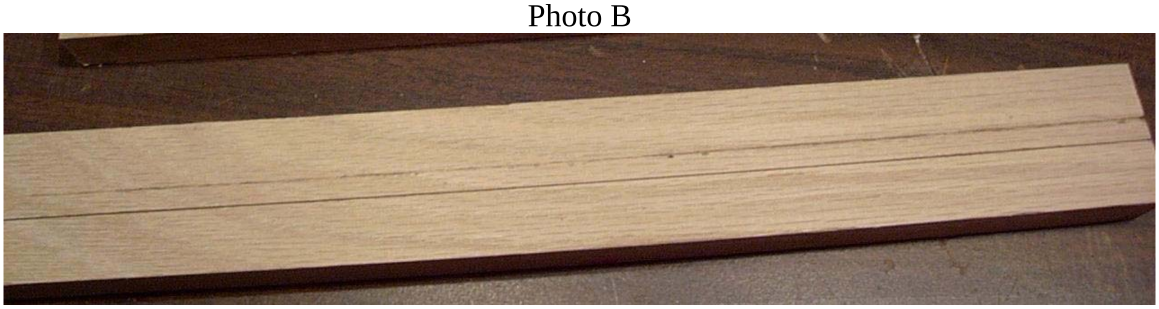
To create a mold for the lead came and for the solder that I am using in this project, I am again, using the methods according to Theophilus’ writings. Theophilus gives to methods for making molds. The first is using iron (Theopilus pp 53,54), which is more durable or wood (Theophilus pp 55,56). Since I don’t have the means to make the iron version I chose wood.

1) I started off with two wooden blocks about 12 x 2 x 2 inches and sanded the surfaces smooth. This would end up being my mold. Theophilus does not state what kind of wood to use so I used a maple, which is proliferate in Europe. Maple is a hard wood and I believe, would survive multiple castings.
2) I marked the edge of one of the boards with two notches (Photo A). This represents the distance between the leaves of the came. I repeated the markings on the opposite end of the same board.

Photo A

3) I then soaked a string in some of my Lady’s Black Walnut ink (see recipe – Black walnut ink) made from some of seemingly thousands of black walnuts that rain on my house every year.
4) The string was slipped into the first set of notches at both ends of the board. I took the second board and placed it on top of the first and pressed. This created a line down the board representing where I needed to cut to create the first set of leaves. I then repeated this process with the other set of notches to make the line for the second set of leaves (Photo B). In retrospect, I probably could have used two threads and made both lines at the same time.
5) I also marked each board so that I knew how they went together when I actually got around to casting the lead.

Photo B



6) With the mold now marked, I used a series of knives and chisels, and files to cut the channels that would be leaves. Next I used a chisel to lower the middle section of both pieces of wood between the two channels to create the heart of the lead came.
7) In order to pour the lead into the mold I needed to cut a sprue. This is a funnel shaped cut so that the liquid lead can pour into the mold with out splashing around. I cut half a sprue on one end of both pieces of wood so when put together formed the full funnel (Photo C).
8) Once the wood was clean of dust and debris, I put both pieces together lining up the ends and clamped them together. The mold was ready to go.

Photo C

Casting the lead came itself in the handmade mold:

1) Theophilus is very clear on how to cast the lead (Theophilus pp 54,55). In a very well ventilated location, I placed raw lead into a cast iron pot. I melted the lead using a torch as I didn't have the means to make a fire, and poured it into the mold. After cooling I pried the two pieces of wood apart using a knife, and there I had my first piece of lead came (Photo D). Upon inspection I found gaps and holes in the lead in both the leaves and in the heart.

Photo D

NOTE: **Theophilus had left out on thing**! Obviously I had to modify the mold. I needed someplace for the air to go.

2) Adding more air vents: I built a second mold this time I added more sprues along the edges of the leaves to allow the air to escape (Photo E). This new mold worked much better and I used it to create the lead for this project.

Photo E

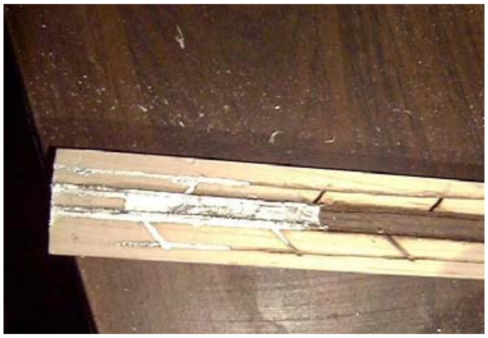
3) After I pulled the lead from the mold, I cut off all the lead from the sprues and cleaned up the edges.

4) Now as described in appendix A for lead, there are two shapes for the lead came. One is an H came (two leaves and a heart), of which we just finished making. Now we need to make the U came (one leaf and a heart). Theophilus does not describe how to make the U came or even mention the U came. To create the U came, I used intuition and simply turned one of the wood blocks around so that the uncut side faced the cut side of the other block. I then poured the lead following the above method (Photo F).

Photo F

For the solder, I took one part lead to five parts tin (Theophilus pp56). I melted them together and used the lead came mold to form the solder (Photo G). As Theophilus described there is no reason to make a mold when you already have one.

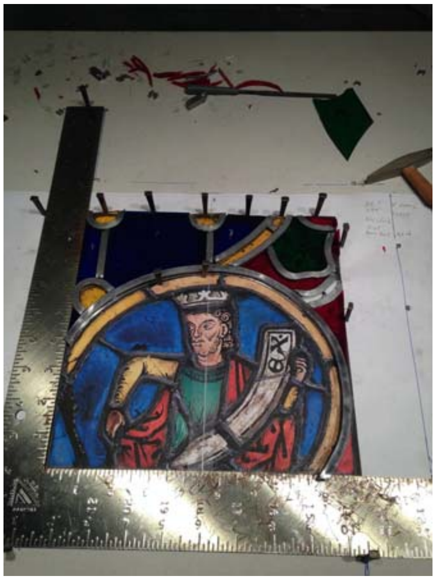
Photo G



ASSEMBLING THE GLASS PIECES

Research

Theophilus started with a center figure and worked his way outwards. A piece of glass was fitted into the lead came. Pins or nails were placed around each piece to keep it from moving during assembly. The next piece of glass was fit into place next to the first. Again, the exposed lines were encased in lead and pinned into place. When all the pieces of glass were set in their proper spots, lead was placed around the entire outer edge of the piece (Theophilus pp 56). Not much has changed since then. Modern glazers assemble the glass in a similar manner (Valldeperez, pp 58-65).



SOLDER

The next step was to permanently connect all the pieces together using solder. Solder is a low melting metal alloy composed of lead and tin, cast into sticks. Theophilus used one part lead to five parts of tin (Theophilus pp 56) . But it has been shown that this may have been a personal preference. Some artisans used a 50 percent mixture of tin to lead. This mixture is by percent weight (Pizano May). Theophilus notes that you may cast the solder in the same molds that were used to create the lead came. After each junction of the lead cames is cleaned, a hot iron is used to melt the solder into the joints between the cames, locking the glass into place. Then the assembled piece is carefully flipped over and, the other side is soldered in the same fashion (Theophilus pp56-57).

WHITIING

Once the soldering was complete, the last step was to cement the piece. This was done by creating a mixture of powdered whiting (calcium carbonate), and linseed oil then rubbing this mixture under the edges of the lead. After the excess was removed and the glass dried, the window became waterproof and had a bit more stability to it (Art History Final Project).

SUPPORT

At this point the window itself was complete. In order to install the window a little bit more work had to be done. The next step was to install the banding wires. These are copper strips about 4 to 5 inches in length, soldered onto the leading and are used to secure the window. There are two types. One is called a division tie and is used to connect adjacent panels of windows. The division tie had one long strip of copper that twisted around a division bar along with the tie from an adjacent panel, holding the panels together. The second type has two strips of copper called a middle tie and is used to connect the panel to a supporting bar. The copper strips wrapped around the supporting bar, almost like a twist tie, adding extra support to the panels (Lee, Seddon, Stepens, pp.188-189).

INSTALLATION

The last step was the installation. The window aperture was cut so that the window will fit into a L shaped channel. The bottom piece gets set into first. The next piece gets set into place on top of it. To ensure a watertight fit, the lead on the top edge of the first panel was bent over and the bottom edge of the upper piece got placed over the top edge of the bottom panel. The two windows were loosely tied together. To give more support, bars were embedded into the cement in the window frame and stretched across the window aperture. The middle ties were used to attach the window to these bars. Once the full window was in place, the ties were tightened down securing the window. The very last step was to cement the window in place to ensure weatherproofing, and securing up the window (Lee, Seddon, Stepens, pp 188-189).

THE HISTORY OF STAINED GLASS UP TO THOPHILUS

There is a story that was told by Pliny the Elder (23-79 AD) of a ship carrying a cargo of natural soda that made shore for the night. Having nothing to hold their pots and pans on for cooking, the crew took several blocks of the soda and placed them over the fire. The blocks, mixed with sand began to heat up and the crew saw a strange liquid begin to flow. This was the discovery of glass (History of Glass Engraving, pp 1). Who knows if it is true or not, but it is an interesting tale. What we do know is that glass has been around for a very long time.

Colored glass has its roots as far back as ancient Egypt around 3000 years ago. The Egyptians pressed glass for perfume bottles, beads, and a wide variety of other uses. Glass was preferred over pottery. They discovered that by heating silica (sand, quartz) with potash, the silica could be fused. It wasn't until between 1554 BC and 1075 BC that the Egyptians discovered how to make clear glass. At this point in time they learned that they could cast this new glass into rods and while hot, mold them around sand cores to create vessels. The colors they created were more accidental than design due to the impurities in the materials they used. Color could be somewhat controlled by heating or cooling (Brisac).

The blowing iron came into use somewhere in the second century BC. This allowed the artisans to attach a blob of glass to the end of a tube and blow air into it. The glass could be easily shaped by heating, blowing, rotating, and then repeating the process again until the desired shape was achieved (Lee, Seddon, Stepens, pp 10).

By the first century AD, it was discovered how to make glass transparent and colorless. Color could be controlled by adding certain oxides.

The Romans had also been working with flat glass in the first century AD. They had inserted small pieces of colored glass into mounts for decoration. The Muslims used the flat glass to make mosaics in windows.

The earliest known pictorial glass is from records dating back to the 9th century. The oldest remnants were of a depiction of Christ's head from the Lorsch Abbey in the Rhineland (France) dated between the 9th and 11th century (Lee, Seddon, Stepens, pp 13). Medieval stained glass was not used to pass light but more to capture and reflect it and really did not take off until the Middle Ages in Paris. The Abbot Suger commissioned the windows for the Abbey Church of St. Denis between 1144 and 1151, starting the stained glass trend. Soon after that windows were commissioned for the Charters, Bouges, and Le Mans cathedrals. Stained glass reached its peak in the Middle Ages between 1130 and 1330 (History of Glass Engraving, pp 1). Popular scenes were iconic and religious. Another popular style is called a "rose" such as the one commissioned at St Denis. Most rose windows use one of two themes: either the glorification of Christ and the Virgin or Christ as the apocalyptic judge. Sources of inspiration of stained glass come largely from the Bible (Brisac).

BLACK WALNUT INK

I used the black walnut ink for making the mold for my lead came and solder, not on the glass itself. I have to give Dana Robertson (Baroness Clarice Roan), credit for providing the ink. Even though I did not make the Ink I took notes as she made it. NOTE WELL: When making black walnut ink wear gloves and old clothes as the ink stains everything.

The black walnut tree (Jeglans regia) is native to the Capathion Mountains in eastern Europe. It was introduced to the Americas via Spain through Chile and to California in 1867 (see Juglans regia L. pp 3of 6). Juglans nigra or Black Walnut is a hybrid of the European Walnut. (see Black Walnut – hybrid pp 10 of 14).

The ink recipe below is an amalgam of several recipes found in the Translation of Manuscript of Ibn Badis ca. A.D. 1025 (Levey pp18-21), and experimentation.

The Recipe is as follows.

1) Shuck green outer layer from nut or pick up walnuts from the ground with the husks already rotted off being wary of any territorial squirrels.
2) Fill a bucket with the walnuts & top of bucket with water (this batch had 35 walnuts).
3) Soaking the walnuts in water releases the tannins from the walnuts. The batched used for this project had been soaking for five months.
4) Place all the water now brown from soaking walnuts into a pot with some of the walnuts (this batch yielded about 19.5 cups).
5) Boil the walnut and water combination to release the last bits of tannin.
6) Strain walnuts from liquid and return liquid to pot.
7) Reduce ink by continuing to boil.
8) Every half hour test for darkness. This batch boiled for two hours.
9) When satisfied with color add 1 tsp gum Arabic, 1 tsp kosher salt, 1 tsp vinegar.
10) Let settle overnight.
11) Strain out silt and solids.
12) Put ink into bottles.

This batch yielded about 12 four ounce bottles.

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