Fire, Glass, and Steel: Enamel Experiment

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Introduction

Three years ago, I found the Christian II Elector of Saxony enameled sword while researching another project and thought it would be an amazing idea to make one for

myself in my own colors. There are also a matched set of doublet and pants that complement the color of the enamel, completed in a puff and slash style. While there is no concrete evidence these two works of art were worn together, they are assumed to be a matched set and are displayed in the Dresden museum in the same case. (Capwell, 2012)

For my mundane profession I wear blue every day, so I rarely wear this color in the SCA. My favorite color is red, so it only made sense to make this sword in a color I prefer. It was originally intended to be the sword worn for my induction to the Order of Defence. However, I did not have the opportunity to make such an elaborate design in the time provided. I only had two weeks between the offer and the elevation.

I decided to use this experiment as an opportunity to create an enameled hilt similar in design to Girard Thybault's two port cross hilt that is shown throughout his book "The Academy of the Sword". (Thybault) The images in this book are Highly detailed and show his preference for an AVB type 43 hilt. (Norman A. , 2019) I decided to make two hilts instead of only one so that I could try out each step of the process. That way if it failed, I would not ruin the hilt I worked so hard to make. How I made these hilts are discussed in Appendices A and B.

Gold, silver, and brass were the most common metals used for enameling during the Renaissance. These metals were made into thin sheets which were then plated to other metals such as steel (Norman A. , 2019). As these metals are very costly, I chose to experiment by enameling directly onto the steel itself. There was very little information about enameling on steel or thicker metals. It is believed that the first enameling of iron is to have taken place in Germany in the 18th century. By the end of the century enamel was used on cookware as a protection for cast iron vessels. (A concise history of enamel, 2022)

I did not know how the thickness of the metal would affect the outcome and final color of the enameling. Would the enamel adhere to the thicker metal, and would the heat distribute evenly? Would the steel oxidation from the hilt change the color of the glass? Steel expands and contracts as it cools. Would this cause the glass to crack or to shatter?

History and Context

Glass enamel is the colorful result of fusing powdered glass to metal. It becomes fused by introducing extreme heat. Enamel is a silica-based glaze created by adding elements to create different colors. The basic ingredients of enamels are boric acid, salt peter, and alkaline. The color of the glass enamel is determined by the type and amount of minerals used. For White, soda-lime silica with low potash and high levels of magnesium. Blue contains Cobalt oxides, chromium for green, manganese oxide for purple, and selenium for red. These colors can be opaque or transparent and often have different temperatures to reach their melting point. (Freestone & Bimson, 1994) Adding a lot of iron will create a grey color. Interestingly, the color red is the most difficult color to create during the 1600s. Buenovito Cellini spoke a great deal about the red enamel, how it was invented, and how the same process bonds to gold but not to silver. He said,

> "*I propose telling you first of how to enamel on gold, and then how to do it on silver. For both gold and silver, the same cleanness is necessary, and in either case the same method, but there is a little difference in applying the enamel and also in the actual enamels applied, for the red enamel cannot be put on silver because the silver does not take it. The reasons for this I would explain were it not too long a business, so I'll say nothing about it, especially as to do so would take us beyond the scope of our inquiry. Furthermore I have no intention of talking about how enamels are made, because that in itself is a great art, also practiced by the ancients, & discovered by wise men, but as far as we are aware the ancients did not know of the transparent red enamel, which it is said, was discovered by an alchemist who was a goldsmith as well. But all I need tell of it is that this alchemist, while engaged in the search of how to make gold, had mixed together a certain composition, and when his work was done, there appeared among the stuff in the metal rest of his crucible a sediment of the loveliest red glass, just as we see it to this day. After much time and trouble, & by many mixings of it with other enamels the goldsmith finally discovered the process of making it. This enamel is far the most beautiful of all and is termed in the goldsmiths' art 'smalto roggio,' red enamel, or in French 'rogia chlero' (rouge claire) that is to say, and which means in other words, red and clear or transparent. A further sort of red enamel we have also, which is not transparent and has not the splendid colour, and this is used on silver because that metal will not take the other. And though I have not had much practical experience of it, I have tried it often enough to be able to talk about it. As for the other, it lends itself more aptly to gold by reason of its being produced from the minerals and compositions that have been used in the search how to make*

gold. Now let us return to the process of enameling." (Cellini, The treatises of Benvenuto Cellini on goldsmithing and sculpture, 1898)

There are different variables which must be considered for enameling. The density of the metal, the type of metal used such as copper brass silver gold or steel. Silver is the most effective heat conductor, followed by gold, copper, and brass. Steel is the least effective heat conductor. It is because of this, special care must be taken to warm the steel and remove any oils from the metal to avoid ruining the colored enamel do to oxidation. (Barnette, 2024)

Glass enameling first appeared in Cypress in the 13th century BC during the Mycenean period. Six gold rings were discovered in the tomb of Kouklia decorated with enameled glass fused to the gold. Enameling was also found to have been used by the Egyptians as well as Chinese, Romans, Georgians, and Celts. (A concise history of enamel, 2022) Enameling is a process of adding fine ground glass either dry or into a powder mixed with water and a cellulose ether to create a paste. The dry powder or paste is applied onto a metal surface or to fill a carved-out section of metal to fit flush with the surface or set on top of a surface with wires to separate the colors. It is allowed to dry and then placed on a ceramic tile or metal plate and placed at the mouth of a kiln or heating furnace to slowly warm the piece before melting the glass. There are many different styles of enameling, but only a few styles were found on rapiers. These styles were Baisse Taille, En Plein, Champlevé, and Cloisonne.

By the 16th century, enamel could be found on jewelry, tools, boxes, weapons and various trinkets as a way to beautify objects without the costly addition of jewels, fine carvings, or inlay of wire. It was an elegant way to add texture and color to these fine works of art.

Figure 1 Glass Kiln (Inside a Renaissance Glasshouse, n.d.)

The process of heating glass and enamel involved the use of a large central furnace with chambers of heat with doors that could be opened or closed, giving access to manipulate the glass in a controlled environment. This type of furnace would have been used for many types of glass work. (Inside a Renaissance Glasshouse, n.d.)

Figure 2 Glass enameled Sword (Capwell, 2012)

An excellent example of Champleve enameling is the enameled sword belonging to Christian II Elector of Saxony (1583-1611). This is the inspiration for my deep dive into this new art form. The ingenuity and craftsmanship of the shape and design of this sword inspired me to create my own version. The act of infusing glass into steel instead of Silver proved to be an endeavor worthy of an epic tale.

I chose to emulate the enameling style of champleve for the rapier hilts but not the shape of the hilt or the colors and metals used. Silver is much easier to shape and a better heat conductor but is also extremely expensive. I thought to myself that if I am putting this much effort into a sword, it should be a sword I prefer rather than just making a copy of a museum piece. I wanted it to mean something to me. My favorite color is red. My favorite hilt type is a 43 AVB Norman (Norman A. , 2019).

Four types of enameling found on swords

Baisse Taille is a technique in relief where the areas to be enameled are chiseled or chased and the enamel is lower than the surrounding metal. Translucent enamel is used to allow the light to reflect from the relief areas under the glass. This type of enameled hilt is commonly found in India.

En plein is a technique where the enamel is applied to the metal in a single layer as if it were the base layer of a canvas. The large surface area of guard plates and pommels of the 17th century European sword hilts allowed for this technique to grow in popularity as fashionable swords.

Cloisonne is a technique of soldering wires or bars above the metal to be filled with glass enamel to create distinct shapes. Opaque enamels are used for this purpose. It is most often found on Islamic armor and Japanese swords.

Champleve is a technique in which cells are carved or etched into the surface of metal to be filled with glass enamel. The uncarved parts remain visible as a frame for the glass as part of the design. It is most often found on European swords.

Hypothesis

For this archeology experiment I want to explore how glass enamel reacts to different thicknesses of steel. I want to see how enamel reacts to the differences in expansion and contraction[1] rates as it heats and cools. Steel is the least common and most difficult metal that can be enameled due to its higher thermal diffusivity. (how it conducts heat) (Barnette, 2024). I will experiment with 1/8th inch steel flat bars, 1/8th inch steel rounds etched in both relief and intaglio, 16-gauge steel plates that will be enameled on the surface of the metal, and two etched sword hilts that will be enameled on both sides of the sword. One side will be in relief and the other intaglio.

My hypothesis is that the enamel will be most effective in the Champleve technique of the main style used for the rapier hilts. I have doubts the enamel will adhere to the 16-gauge steel and may crack or flake off. Also, I believe the thicker metal of the medallions in addition to the etching will allow the enamel to have purchase to maintain cohesion.

Using a propane forge will be closer to what was used in the 16th century, but I believe the kiln will provide a more even heat source for enameling, resulting in a smoother and more even coat.

Tools and Materials

The process of enameling has not changed much from the 16th century to today. Glass is either sifted onto a metal surface or painted by making a frit of powdered glass, water and cellulose ether compounds modernly known as klyrfire. The types and styles, however, evolve and new ways of enameling grow still in our modern age. New Ideas and experimentation allow for new styles of enameling to develop.

The differences between torch firing, kiln firing, and furnace firing create different opportunities for these new styles to flourish and make the traditional styles efficient and attainable. New formulas for glass allow us to create new colors and ways to layer them to make beautiful works of art. (Cohen, 2002)

For this glass enameling experiment I used a pre-ground glass enamel, distilled water and Klyrfire solution. I mixed my own frit from this and added it to the metal with a fine point brush. The Heat sources I used were my home propane forge and an electric kiln. Both heat sources can easily reach temperatures of 1600F which is the highest possible temperature needed to melt the glass.

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[1]

The basic requirements for enameling are to have metal, ground glass, and a heat source. This is a list of the main tools and equipment used in this experiment.

Eye protection Protecting the eyes is always important. Getting glass or chemicals in the eyes can damage your vision.

Leather gloves A good pair of leather gloves will protect hands from the heat of the metal and the heat source when placing each piece in or removing from the heat.

Heat source A Hot head torch, electric kiln/ furnace, or a forge, the heat source needs to be able to reach at least 1400-1600 degrees Fahrenheit. This is the critical temperature necessary to melt the glass. Being cognizant of the melting temperature of the metal worked with as well as the glass. I used my home forge and small ceramic kiln for this experiment.

Holding agent/Klyrfire I used a modern replacement for the additive for adhesion. Historic texts only vaguely mention adhesion as a way to help the glass attach to the metal. Other options are gum Arabic, Basque or lotus root, or gum tragacanth, but the texts do not explain how they were used.

Glass powders There are many different brands of glass frit and paints available. Frit can also be ground from recycled glass.

Paint brushes Fine point paint brushes made from natural fibers are the best type of brush for small defined areas. A small putty knife can also be used for larger areas.

Mortar and pestle A good stone or metal set to grind the glass as fine as possible is the best option.

Water Distilled water is recommended for enameling to avoid adding any chemicals or contaminants from regular tap water.

Tongs A pair of long handled tongs for reaching into the kiln or furnace to keep hands well out of the extreme heat of the process.

Heating plate This is an optional tool for drying the glass frit to make certain there is no water in the mix before putting it into your heat source. Placing the piece in the oven on low, (200 degrees) to dry out the glass frit is also an option.

Heat stand A heat stand will hold the metal while it is hot and keep it from moving or shifting as it is placed in and out of the heat. It helps to keep the heat evenly distributed by elevating it from the floor of the heat source, allowing heat to reach it on all sides.

Alundum Stone A ceramic sanding block of aluminum oxide used to file away excess glass from the surface of the metal without scratching the glass. This is used in combination with water.

Pickling Solution In the Renaissance white vinegar heated just below boiling point at about five percent strength in water would be used to remove scale and rust from the metal. This is what I used for this process. (Cellini, The Autobiography of Benvenuto Cellini, 1840-1893)

Techniques and Process

The steel, previously prepared by etching out the design, was ready to begin the enameling process[2]. It is important to remove any oil from the surface of the metal. This is performed by washing with Borax or Lye soap, both of which were used in the 16th century. It is important to wear gloves to make certain no additional oil is transferred to the piece. Then it is dried with a paper towel or lint free cotton cloth.

To prepare the enamel, the glass is ground and sifted to a fine 80 grit and a bonding agent can be added. Historically gum Arabic, basque or lotus root, or gum tragacanth, was used in combination with distilled water to make a paste called frit (Cohen, 2002). Methyl cellulose can be added as a thickener to bind the glass together if necessary. I used a modern equivalent called klyrfire.

A paintbrush is used to fill the cavities with glass paste and let each piece and medallion dry for at least 10 minutes for the thinner metals and 20 minutes for the hilts. Historically the metal was heated slowly by bringing it to the mouth of the furnace (Cellini, The Autobiography of Benvenuto Cellini, 1840-1893) for this experiment I used a modern stove to ensure an even heat. Following the recommendation of steps in Cellini's works, I created a steel mesh plate larger than the items that I could use to load the enameled pieces into the heat source efficiently and place into the heat source without touching the floor.

For my first experiment I used my forge. The uneven heat created bubbles in the enamel. The piece was placed indirectly to the flame to avoid the glass burning and turning black. Once the glass began to melt, I allowed it to reach an orange peel texture and then a smooth surface. Then removed it from the heat and air cooled. Steel and enamel cool at different rates so it is important to be aware of any cracking of the enameled surfaces to fix with a torch later.

The process required several repetitions to fill the deeper crevasses. With great care and maneuvering, you can work through curved shapes. Once you have a base coat the enamel

[2] See Appendix C

should adhere to the previous layers and should not drip. To remove excess glass an abrasive such as an alundum stone is recommended. An alundum stone is a composite grinding stone specifically designed to grind glass without any residue that would be damaging to the object when it is refined.

Experiments

For this experiment of enameling on Steel, I wanted to look at two different heat sources and also examine the differences in several thicknesses of steel. 16-gauge sheet metal that was cold rolled, 1/8th inch bar stock and rounds of the same thickness, and 2 sword hilts which were made from ¼ inch steel. This would give me two heat sources and 3 different thickness variations to work with to see how the iron would react with the glass enamel.

Techniques

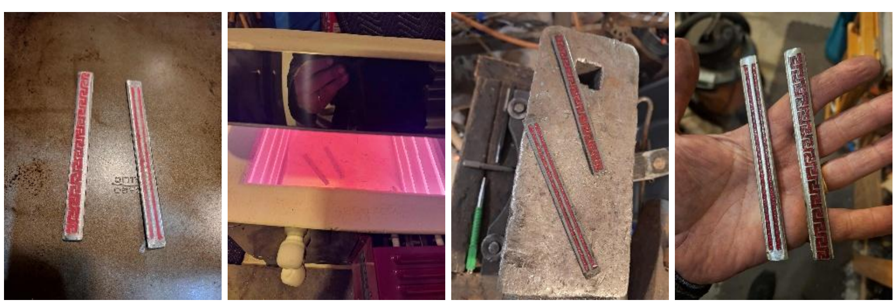
En plein I chose to use this style for the 16-gauge steel to see how the enamel would stick to the surface of the metal without any fissures for the enamel to bond to.

Champleve This style of enameling for the thicker metals that would give the glass deep grooved surfaces to surround and allow the glass to settle into the recesses of the metal. I wanted to see how the glass would react to how the metal expanded and contracted as it changed temperature.

Experiment 1 Heat source

Forge vs Kiln - process and comparison

For my first experiment, I added blue glass enamel to 1/8-inch bars and set it into the stove to dry out the moisture of the glass. After 10 minutes, it was dry and I placed it at the mouth of my propane forge to warm the metal. Once it was acclimated, I placed it further into the heat of the forge. I avoided the flame of the forge as it would become too hot too fast and would likely burn the glass and destroy the color. The heat of the forge was sufficient to melt the glass, but the open face of the forge and single heat source of the flame prevented the glass from having a uniform temperature and it caused bubbles on the surface of the glass. I added more glass in layers but continued to get bubbles and flaking. From this I learned that I needed a much more consistent heat in order to get a smooth surface and an even coat.



I then tried using an electric kiln for my heat source. I took two additional bars of $1/8^{th}$ by1/2 inch steel bars that had been etched and cleaned with borax to remove any oils and painted on a layer of red enamel. Once the kiln reached the temperature of1450 degrees F, I placed the metal in the kiln for 90 seconds. The first layer was more even than the forge heat. I then applied 2 more layers, heating between each application. The red enamel covered the areas more consistently and did not flake. The red color was more vibrant and though not as smooth as I would have liked, it worked well.

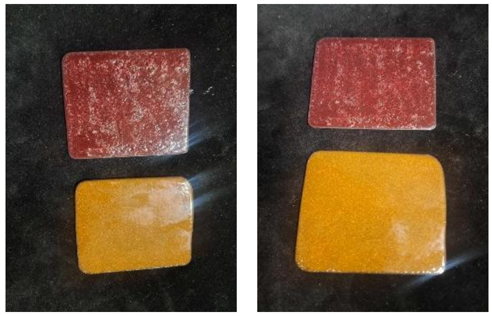
 

Both heat sources were able to reach the temperatures to melt the glass. The forge caused the blue color to degrade and be more subdued, and the open face and single flame heat source caused bubbles in the surface of the glass in one instance the glass shattered. The electric kiln kept the temperature constant, the enamel coated evenly and was able to fuse to the metal in a more appealing way. I was very happy with the results of the kiln heating process.

Experiment 2 Metal Thickness

16 Gauge for the 16-gauge steel I used the En Plain style of decoration. First, I sanded to a 120-grit finish and cleaned the surface with Borax to remove any oils from the metal. I brushed a thin layer of klyrfire on the surface of the steel to help the enamel adhere to the surface. Then I took some dry glass powder and sifted with an 80 grit to evenly put glass on the entire surface of the metal. When I was happy with the first layer, I placed the metal on a ceramic plate, using tongs, into the preheated kiln set at 1450 degrees F. I did not use a counter enamel for this piece because the steel was fairly thick and I did not worry if the metal would warp.



I coated the enamel 4 times and repeated the process with both colors to get a smooth texture. Each coat required full cleaning and scale removal from the exposed portions of the metal between each layer. It was a challenge to place the metal into the kiln because the kiln I used was designed for closed kiln operation and did not lend itself to be opened repeatedly. The kiln was difficult to load and lost much of its heat during loading and unloading the enameled metal into the heated enclosure. I got a sunburn like blister on my forearm where the gloves did not cover. I wore a leather jacket after this first experience.

1/8-inch medallions – for the medallions, I used the champleve style of decoration for the enamel. The medallions had already been intaglio etched and also in relief. This would give an opportunity to see how both styles would react to the enamel and the conductivity of the metal in relation to the glass. I sanded the medallions with 120-grit sandpaper and cleaned them with borax to remove the oils from the surface of the metal. Then I mixed my frit, using powdered glass sifted to 80 grit, distilled water and klyrfire. I added the liquids slowly to create a paste and painted it into the crevasses in the etched design. Then I placed the pieces in the oven for 20 minutes to dry out the glass and preheat the metal. Using tongs, I placed the medallions on a ceramic plate in the kiln set at 1450 degrees F. After 90 seconds I removed the medallions.

After removing the medallions from the kiln, I removed the scale and added another layer to the enamel. I made certain to scrub any residue from the metal and remove any oils from the surface, being careful not to introduce new oils from my hands. The red MOD medallion was first and performed well. The second was the blue medallion which during the cooling process of the second coat began to ping and nearly all of the enamel flaked off in two pieces. The medallion did not have enough for the glass to adhere to, and I should have put a layer of Klyrfire to give the enamel something to cling to. The blue Pelican medallion came out perfectly in the first coat but bubbled out some in the second and third coats. I would be able to fix this in the next process.

Once I was content with the levels of enamel, I again washed the pieces, (this time with dish soap as I had run out of borax). And wet sanded each piece with an alundum stone to remove the excess glass and scale. This revealed the design and brought the enamel flush with the metal and created a beautiful look. It only required one more round of heat to seal the enamel and give it a shiny coat. Then remove the final scale and wet sanded with a 220-grit sanding sponge.

1/8-inch bar – I made 2 additional ½ inch bars of 1/8th inch steel to further explore the Intaglio experiment. I sanded with 120 grit sandpaper and cleaned the bars with borax to remove any oils from the metal and used the Cobalt blue frit for one and a combination of red and green frit for the second. I used a paint brush and a dental scraping needle to apply the enamel. This is called wet packing. It seemed to work more efficiently for the intaglio designs. It allowed me to get the frit into very tight places and deep into the pattern. I daubed with small pieces of paper towel to remove excess moisture without disturbing the glass. I allowed the metal to warm in the oven for a few minutes and then placed the bars in the kiln at 1450 degrees F and removed them after 90 seconds.

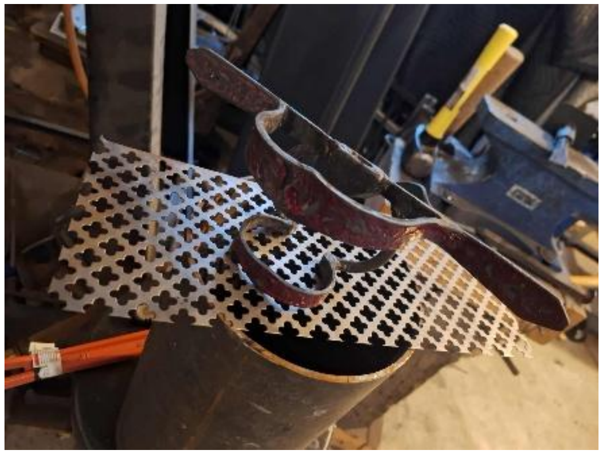
Hilts – The hilts were etched with intaglio on the inner guard and relief on the outer guard. Each hilt was sanded with 120 grit sandpaper to give the enamel texture to adhere to.

For the first attempt, I used the green enamel for the AVB Type 52 hilt and thoroughly scrubbed the hilt with dish soap and painted on a good coat of klyrfire to help the glass adhere to the steel. I learned this from the failure of the blue mod medallion. I let the klyrfire dry and began to wet pack the green enamel with a brush and dental tool. I recognized it would be difficult to clean the places where the hilts arms came together but decided to enamel them anyway. I packed more enamel than would fill the places I thought may be difficult to get to adhere or may take more wear with the idea of filing away what I did not need later. This turned out to be a good plan. Once the hilt was covered in enamel, I let it dry for 30 minutes while the kiln warmed to 1460 degrees. I used a higher temperature to ensure the thicker metal would be thoroughly heated. I set kiln blocks up in the bottom of the kiln to support the hilt and keep it from touching the base of the kiln because there was enamel on both sides of the metal. I donned gloves, safety glasses and grabbed my tongs and pulled the hilt from the oven and placed it directly into the kiln for 2 minutes. Then removed it from the kiln and set it on the heat stand to cool.

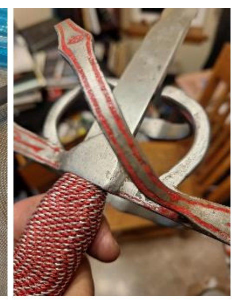
The green enamel came out a brownish red color and I was very upset. As it cooled it took on a green tint and finally a gorgeous green! I was so very relieved. The enamel moved with the expansion and contraction of the metal and had puffed ever so slightly. I would have to use the alundum stone to remove quite a lot of glass from the surface to reveal the pattern within.

Once the hilt had cooled, I brought it to the sink and rinsed it and placed it in a container of shallow water. I wet sanded the excess glass, being careful not to scrape away too much of the enamel. There were places that needed filled with more enamel to give it a smooth finish. I used an exceptionally fine brush to fill the areas that required additional enamel and put it back into the kiln for another 2 minutes. Removing the hilt and placing it on the heat stand to cool, the color change did not frighten me. I rinsed and filed the entire piece with the alundum stone, placed into a vinegar pickle, and then a 400-grit sandpaper. Finally, I coated the entire piece with museum wax.

I then repeated the process with the red enamel and the AVB Type 43 Hilt. I began by cleaning the hilt with soap and removing any oils from the metal and applied a layer of klyrfire and let it dry. Then painted the red enamel onto the outer and inner guards. I placed the hilt in the oven for 30 minutes and then directly into the kiln for 2 minutes. The glass successfully adhered to the etched surface on the inner guard, but some of the enamel on the thicker metal flaked off the outer guard and needed another coat. I cleaned the scale and used the alundum stone to reduce the glass flush with the metal of the hilt. Then cleaned again and filled any fissures that required additional glass. I returned the hilt to the oven to heat and then another 2 minutes in the kiln. And then catastrophe struck.



The enamel began to flake off the outer guard on the larger sections of the hilt. About a third of the enamel came off as the glass started to ping and fall from the metal. I removed the scale once again and checked and looked at the damage. I gave it another coat and placed it back in the kiln with the same result. I lost even more enamel. The large ring at the quillons also lost most of its enamel. I had to decide what to do from here. The glass was not adhering to the larger metal with the relief pattern because of the expansion and contraction of the metal. The more I fought with the glass the worse it began to flake.

I made the decision to use a modern enamel. This enamel had an adhesion component included with the formula and did not require such extreme heat. I could coat the flaked portions with the modern enamel and not risk losing more of the glass still attached to the outer guard. The color of the enamel would match the period glass and the two worked well to layer together. I chose to try it on a bar of metal to test it and the two enamels were nearly impossible to tell where one began and the other left off. I coated the outer guard section that had flaked off and heated it to the required temperature. It came out perfectly in one coat. I used the alundum stone to clean up the enamel and placed it in a pickling bath. The coat was even, smooth, and the pattern was easily visible. I sanded and polished the entire hilt and museum wax was applied with cotton cloth.

Findings

The first experiment with the two heat sources proved the inconsistency of heat from the forge was not conducive to enamel effectively. The kiln worked better to provide an even and controlled environment. This led me to use the kiln for the second experiment. This aligns with the images found of renaissance glass kilns which were a closed heat system.

For this portion of the experiment the 16-gauge steel using the en plein technique worked well to create an even coat of enamel on the entire surface. The 1/8th bars and medallions were etched with intaglio and relief, and champleve technique was used resulting in a clearly defined enamel within the etched design. The two hilts, etched in both intaglio and relief required more time to heat at a higher temperature in the kiln and were more of a challenge to clean up due to the complexity of the hilt design. The thicker portions of the red enameled hilt had a catastrophic failure during the last process and I had to use a modern equivalent enamel to finish the piece. The period enamel and the modern enamel matched so closely it was difficult to distinguish the difference between them.

The medallions and the 1/8th inch bars behaved well throughout the experiment, other than the one failure. Both allowed the enamel to adhere to the metal and did not warp from the heat or the enamel. The hilts having thicker metal took longer in the kiln and more time to cool. They did, however, warp slightly from the heat of the kiln. I did not dare to attempt to bend the hilts back into shape for fear of cracking the enamel. The slight warp of the hilts was within reasonable accommodation.

I found that a 1 to 1 ratio of klyrfire and distilled water worked well to mix with the enamel and could be rehydrated to be used at a later time. With the cost of glass powder this was an excellent discovery. I was glad to have purchased the alundum stone as it was exceptionally useful in evening out the surfaces of the glass and steel. I think if I had tried to file or sand the glass with sandpaper, I would have had many more failures and fissures where the enamel flaked away, due to the coarseness of the sandpaper. The final heat is when all of the hard work finally comes together and the beauty is revealed as the enamel takes on the glassy surface. But pickling and final sanding is still necessary before the pieces are finished. The red hilt was much more difficult to enamel due to its thicker mass and necessity for a longer heat which resulted in the enamel flaking away.

Conclusion

This was a successful experiment. The first portion of the experiment proved the kiln was more effective as a heat source. The glass melted more consistently and evenly due to the closed environment and more consistent heat source. While the kiln was more difficult to load, the lack of single source flame provided a larger area to place each piece without danger of exposing to the flame. The kilns only limitation is the inability to monitor the process of the glass reaching melting temperature.

The 16-gauge en plein enamel showed how sifting dry enamel onto the steel created a smooth coat of glass across the entire surface of the metal. My original hypothesis that the enamel would flake and crack was incorrect. The addition of klyrfire aided the enamel to adhere to the metal. The limitation of this style is that it is difficult to transfer to the kiln without disturbing the consistency of the coat. Any jostling while placing in the kiln can disrupt the dry glass powder. It works well to coat a solid color or simple pattern but is difficult to create defined shapes.

I was able to successfully enamel all, but one medallion. That failure was fixable, but I chose to leave it as a failure for comparison and lessons learned. I will attempt to enamel it at a later date. The reason for the failure was that it did not have enough adhesion to the metal. A coat of klyrfire before enameling would have prevented the glass from flaking off the steel. The 1/8th bars etched in intaglio showed the ability to use distinct colors simultaneously and to show contrast between the steel and glass.

The final result of the two hilts culminated all of these experiments to result in a beautiful glossy finish to enhance the shape and design of the hilts. Both required a higher temperature and longer cooking times to achieve optimum results. Removing the excess glass was difficult in areas due to the complex design and narrow connections of the hilt. The larger sections of the hilt proved much more difficult to enamel on the outer guard due to the amount of space allowed for the glass in the relief style. The differences in metal mass of the red hilt caused the enamel to flake away due to the expansion and contraction of the steel during the heating process. I used a modern enamel for these areas, and the result was nearly indistinguishable from the period technique.

This experiment has proven that enamel can be added to steel

directly. It has provided new skills and knowledge that I will utilize to create hilts with a refined and polished texture. This new level of enhancement will be a new tool to create elevated rapier hilts.

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Appendix A

Figure 3 (Carlotta, n.d.)

Figure 4 (Carlotta, n.d.)

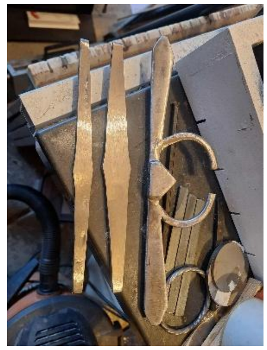
Figure 6

Gerard Thybault was a fencing master during the 16th century. He was very fond of the AVB Type 43 hilt (Norman A. , 2019) and used it throughout the images of his book the Academy of the Sword. (Thybault) I am a student of Destreza and also fond of this hilt type. I chose to make this style of hilt because of its simplicity in design and enamel it in red. The design I finally decided on was from the Malmo Museum in Sweden (Carlotta, n.d.). It is the same AVB type 43, but the inner guard has only one diagonal bar stemming from the forward arms to the quillons, rather than the crossed inner guard that Thybault preferred. I loved the points at the center of the horizontal rings and the dramatic swells at the ends of the quillons. This left plenty of real estate for enameling.

The Malmo Sword itself is from Stockholm Sweden made around 1560. The blade had been broken about 70 centimeters from the tip and been repaired. The grip is made of wood and capped in metal. The grip gives evidence that it was once wire wrapped but now missing the wire. The pommel is a faceted oval with longitudinal lines along the sides of its faces. The hilt is an AVB type 43 with finger rings, two parallel side rings forming the outer guard and a transvers inner guard. The hilt has been blackened likely by being heated in the forge and rubbed with oil or beeswax to prevent oxidation or rust. It lacks any major ornamentation other than the lines of the pommel and was likely an everyday carry weapon for a Swedish gentleman. It is not a showpiece, but a weapon of defense. (Carlotta, n.d.)

This type of hilt is my preferred esthetic and design. It is not flamboyant. It is subtle. Its form follows its function. It has a job to do and will perform its duties efficiently and elegantly. It needs little upkeep as the blackening protects against rust and the thin flexible blade can take a lot of abuse. The pommel is counterweight to the sword and balances the design. After 466 years it still is an imposing and deadly looking weapon you would not want to be pointed at you in a darkened alley.









Making the Type Malmo Museum hilt to the specifications and design took nearly a year to create and I took great care in every step of the process. Each piece was hand forged to shape by hammer and anvil.

Every weld was filed by hand for a clean fit and finish. I was not able to get exact measurements, and I did not care for the upswept curve of the quillons or how narrow the ring at the quillons were. I created a design based on the concept rather than an exact copy incorporating my own preferences into the design. I used a similar sword from the Metropolitan Museum (Estoc Thrusting Sword, n.d.) for the inner guard as it was difficult to see the details of the inner guard from the museum images from Malmo.

Once the hilt was assembled and cleaned up an oil paint was applied, the design was drawn using pencil, scribed using hand made tools, and etched in a copper sulfate and salt-based acid bath for 6 hours. The paint was removed and sanded with a 120-grit sanding sponge and scrubbed with borax and water to remove any oil from the surface of the metal. It was then prepared for enameling.

Appendix B

The second hilt made is an AVB type 52 to use as a prototype project. This type 53 is made up of a set of quillons bent in an S curve with the rear quillon facing forward and the forward shaped into a knuckle guard. The forward arms support a horizontal ring and an S curved bar stretching from the rear arm to the end of the knuckle guard. The inner guard is swept ending on the inside of the knuckle guard. It is not based on a museum example, and I spent about a month creating it. The design is much simpler and allows for more creative license and freedom to make decisions based on my preferences.








Each piece of the hilt was hand forged and welded and filed by hand for fit and finish. I used 1/8th flat bar for the assembly to experiment with a medium thickness in contrast with the ¼ inch bars of the other hilt. While I am not a big fan of knuckle guards, I have always been intrigued by the shape and design of this type of hilt. It offers excellent hand protection and is ergonomic in its design.

Once the hilt was assembled and cleaned up an oil paint was applied, the design was drawn using pencil, scribed using handmade tools, and etched in a copper sulfate and salt-based acid bath for 6 hours. The paint was removed and sanded with a 120-grit sanding sponge and scrubbed with borax and water to remove any oil from the surface of the metal. It was then prepared for enameling.

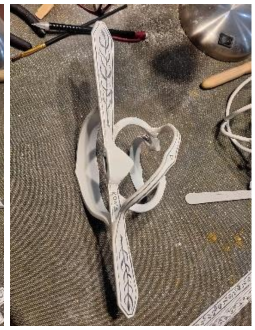
Appendix C

Etching Process for the Rapier Hilts.

I used the same type of period etching acid from my etching experiment for the patterns on both of the hilts for this experiment. I used copper sulfate, salt, and warm water. The resist is a white oil-based paint. I used white because it was easier to see the design even though the chemical makeup is modern, it uses the same principal of design and function. This is my preferred resist for etching because it will cure and be ready for use in about 24 hours, has a good reliable consistency, and has produced repeatable results.






After coating the entire surface of both hilts, I began to draw the patterns for the overall design of the hilts. For the AVB type 43 hilt, I incorporated the master of defense symbol on the rear parallel loop and peacock feathers sprawling over the entire piece. I etched the outer guard in relief, and the inner guard in intaglio to give a contrast in the design. As an added bit of whimsey I added my name "ROMA" to be Etched into the quillon on the inside of the inner guard near the quillon block.

For the AVB type 52 hilt I scrolled leaves across the entire piece flowing in a single direction. The outer guard was etched in relief and the inner guard in intaglio.

Using my hand made scribing tools I carved out the designs drawn onto the resist and removed the places I wanted the acid to eat away the metal to create the patterns. This was painstaking and meticulous, but I particularly enjoyed the minutia of the Zen of working on this project. Everything from my day would fade away while I was scratching away at my little art project. There were a couple of mistakes made in the design, and I had to touch up a couple of places where the scribe slipped or scratched too much. I simply added a bit more of the same paint with a small brush and cleaned up the lines.




It was time to put the hilts into the acid. I used a slightly larger and deeper container so that I could etch both hilts at the same time. This worked very well. I was also able to string some other pieces for etch at the same time.



I mixed the 1/3 cup of copper sulfate to an equal amount of kosher salt and filled the container with warm water. I placed the hilts in the acid and gave it 2 hours to begin the etching process. After 2 hours I removed and cleaned the oxidation from the pattern, being careful not to damage the resist and replaced it for another 2-hour period. I repeated this process for a total of 6 hours. Then washed each piece with borax and placed the pieces in a container of acetone to remove the resist. This revealed the beautiful pattern that would be filled with glass enamel.





Appendix D

Extant examples

Figure 7 Glass enameled Sword (Capwell, 2012)

Fully enameled rapier hilts are rare and this blue enameled rapier created for the Elector of Saxony Christian II, made with Saxon silver may be the only one of its caliber. It is believed to be matched with the Electors collection blue parade costume though there is no pictorial evidence of it. They do mirror the motif in both the cloth, buttons and the design of the hilt. It has a Solingen bade dated between 1605 and 1657. The parade costume and the blue enameled hilt can be seen at the Dresden Museum. (Capwell, 2012)

Figure 8 Rapier (Rapier, n.d.)

This is another rapier from the Dresden collection. It differs from many other hilts because this one is cast in one piece in bronze and then chiseled, gilt, and set with precious stones. This sword is dated 1606 and can be seen at the Dresden Museum. (Michael Coe, 1993)

Figure 9 Italian Enameled Rapier (The MET, n.d.)

This AVB type 57 is a beautifully etched and enamelled rapier from Milan Italy. The steel hilt has been bronze plated after the etching process and then enamelled. The grip is wire wrapped and the pommel is bronze cast, etched and enamelled. This Italian rapier is dated 1580 and can be seen at the Metropolitan Museum. (The MET, n.d.)

Figure 10 Saxon Style Rapier (Carlotta, n.d.)

This hilt is a blackened steel AVB Norman Type 43 with the classic Saxon style quillons. It has two parallel loop guards. One spanning the quillons, and the other at the ends of the forward arms. The inner guard is a diagonal loop from the forward arms to the quillon. The grip is wood and has a double conical pommel. This rapier is from the Malmo Museum in Sweden dating around1560. (Carlotta, n.d.)

Figure 11 German Rapier (Rapier, n.d.)

This is a simple steel swept hilt AVB Norman type 52 German rapier with a wire wrapped hilt from the first part of the 17^{th} century. (Norman A. , 2019) This hilt is a composite rapier. (Rapier, n.d.)