THE HISTORY OF THE RAPIER

The Culture and Construction of the Renaissance Weapon

An Interactive Qualifying Project Report

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Abstract

At the end of the Middle Ages, weapons began to be used not only on the battlefield, but for civilian use as well. The rapier became the essential self-defense weapon of the "Renaissance man." This project explores the evolution and manufacture of the rapier through history. This cut-and-thrust sword was manufactured by artisans who had to develop new methods of crafting metal in order to make the thin, light blade both durable and ductile. To study this process, a rapier was constructed using classical methods. Upon the completion of the replica, its material properties were studied using a surface microscope. The project also included contributing to the WPI Arms and Armor website.

Acknowledgements

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1. Introduction

As part of the Interactive Qualifying Project series "History of Materials in Arms and Armors," this project is focused on the study of Renaissance-era rapiers. The creation of a replica rapier, using modern materials and technology to imitate historical methods, will aid in the study of the rapier's material properties. In addition to studying the materials and methods used in their creation, the culture and history surrounding rapiers is investigated. The goal of this project is to attain a more complete understanding of the rapier in its historical context.

Personal swords were introduced into Western European culture at the beginning of the 16th century. Originally used by common folk and guards for self-defense in cities, the rapier would evolve into a status symbol of the gentleman, and the object of study for swordmasters and smiths.

The evolution of the rapier is closely linked with the evolution of the fighting styles that accompanied it. Practical use of the weapon demonstrated that thrusting was a more effective style than the slashing found on a battlefield, and this transition led to a different style of sword. This in turn resulted in the further development of fighting techniques, as illustrated by the many treatises written on swordplay during the era of the rapier.

This report consists of a record of the history of the Renaissance; a look at the culture of Renaissance nobility who might study swordplay, as well as the masters who taught it; and a summary of the historical construction of rapiers, specifically the methods and materials used. Finally, a record of the construction of a replica rapier is presented, including an analysis of the material properties of the blade.

2. History of the Rapier

2.1. Defining the Rapier

A rapier is a long, one-handed, thrusting sword commonly used throughout Western Europe during the 16th century. There are many styles of rapier created in different countries at different times. In general, the weapon consisted of a long, thin blade and an ornate hilt that provided protection for the wielder's hand. The rapier is associated with a specific historical period, but its form evolved from earlier bladed weapons.

2.2. The Origins of Renaissance

After the fall of the Roman Empire in the fifth century, much of Europe entered a period of destabilization due to invading "barbarian" cultures. The turbulent forces of these Middle Ages caused most people to turn away from the classical Greek and Roman cultures. Feudal systems developed, and knights and other contemporary warriors fought for their lords, while serfs worked in return for protection from invaders. This decentralization of power led to instability in much of Europe for centuries.

In the 13th century, levels of trade began to rise in Europe. The Crusades had created trade routes between European nations, especially Italy, and weakened the Byzantine Empire as an economic rival. Commerce led to improved economic conditions for peasants and feudal lords alike through the 14th and 15th centuries. Lords could rent their land to tenant farmers, who could work toward independence rather than relying on the lord. Participation in trade allowed serfs to pay money as a substitute for their feudal obligations and become tenant farmers themselves. The lords, in turn, could use this money to hire mercenary forces rather than depend on vassals, further weakening the feudal system (Cazel).

Towns across Europe became more and more independent from feudal lords as power was re-centralized. When they could no longer rely on the lords for protection, towns began to create schools of fighting in order to train common folk how to defend themselves and their town. These lower-class schools did not have the wealth to teach the combat characterized by heavy armor and cavalry. Indeed, the creation of the longbow and the polearm and reintroduction of infantry tactics had made mounted combat less effective. As a result, these early schools focused more on teaching technical skill with a variety of weapons. Anyone with the desire and means to learn martial skills could now do so. Such schools became the roots of the middle-class fighting guilds that would spread across Europe and develop fighting techniques through the generations (Castle, p.14).

In the cities that developed in prosperous areas of Europe, more attention could be paid to the arts and sciences. Wealthy families sought to increase their prestige by commissioning sculptures and paintings. As the wealth spread, others could turn their thoughts toward the mysteries of the world. Great thinkers such as Petrarch, Da Vinci, and Galileo emerged. As stability returned, so too did humanity's desire to look inward upon itself and expand its capabilities.

The key thought of the Renaissance was that man could better himself, be it by study or hard work. Swordsmen were not immune to this ideal, and fighting styles continued to develop as knowledge spread across Europe. Baldassare Castiglione's *Book of the Courtier* listed competence in swordplay as an essential aspect of the gentleman. *Courtier* was one of the most read and influential treatises written in Renaissance Europe. Its wide popularity led some of the same minds who studied arts and science to turn their attention to combat, and sword fighting in particular. For the first time, fighting was studied as a science and respected as an art form.

The Renaissance ideal was not exclusive to the upper class. Continuing social development meant that the sword was no longer a weapon for use only by knights and nobility. In the fighting schools that were developed and maintained across the Western world, the common man was welcome to enter and better himself.

3. Schools of Combat

3.1. Italy

To many, Italy characterizes the rebirth and growth of culture that came about during the Renaissance. Despite this, the independent city-states of the Italian peninsula were constantly at odds with each other and outright warfare was common. The fighting schools of the cities reflected this competition, each teaching its own style and fashion. With so little collaboration, Italian swordplay progressed slowly until the 16th century, when the great Italian masters began publishing fencing treatises.

Achille Marozzo was among the first masters to emphasize the use of thrusts in sword combat rather than cuts. Marozzo's 1536 treatise *Opera Nova*, which was reprinted a number of times, was the first to describe a variety of grips, stances, and attacks. It should be noted that masters of this time considered a good offense to be the best defense: few parries were described, with special attention being paid to counterattacking ripostes (Castle, pp.35-36).

The Italian masters were consistently on the cutting edge of the art of swordplay and, in many ways, the state of knowledge itself. Camillo Agrippa analyzed fencing with the eye of an engineer, recognizing the efficacy of thrusting over cutting. He was the first to describe the action of disengaging from an opponent's blade to attack a body part left unprotected, a tactic discovered by studying fighting chickens. The notion of viewing animal movement as an analog

to human movement was unheard of in Agrippa's time, evidencing the forward-thinking minds of European fencing masters (Cohen, p.26).

Another master, Giacomo di Grassi, emphasized training both the body and mind in his treatise, *The Art of Defense.* He stressed the importance of footwork when engaged in a duel, a thought that was well ahead of his time. His insights into the psychological aspects of the duel shaped swordplay in the following decades (Cohen, p.27).

The works of the Italian masters paved the way for other well-established masters to publish their own treatises, increasing the flow of information between the schools of the various city-states of Italy and across Europe.

3.2. England: The London Masters

It is not surprising that schools of combat were at first rather dangerous places, attracting those who would use the skills they practiced not for noble pursuits but instead for personal gain. The schools of London, England were especially troublesome and had to be regulated by edicts from the king. One edict in particular, from Edward I in the year 1286, expressly forbade the maintenance of fighting schools in the city. The schools persisted regardless, either in secret or possibly with some form of licensing (Castle, p.16).

Figure 1: A fight on the streets of London (Clements *Renaissance*).

Although the crown objected to the existence of these schools, there was much demand for the services they provided to common folk. The right to trial by combat was frequently exercised in this time; in many cases courts insisted upon it. If the situation arose that a combatant preferred not to fight for himself, they could hire a proxy from a local school to fight in their stead (Cohen, p.32). Alternatively they could seek training at such a school in preparation for their combat. Records exist of prisoners being granted bail so that they could study at a local guild until their trial, even when fighting guilds were expressly forbidden (Anglo, p.8). The right to trial by combat was not removed from English law until 1819. In the duration many skilled duelists had no qualms about breaking the law, confident in their ability to prove their "innocence" by defeating any accuser.

Many who were not on trial also sought instruction at schools of fence. In such a rough world, it was common for regular people to seek lessons in self-defense. Swordplay in general was hugely popular all over Europe, and would-be gentlemen were eager to partake of the

swordsman's art. By the time of Henry VIII's rule, commoners often had the time and money to pursue the path of a master (Cohen, p.32).

King Henry VIII, who ruled between 1509 and 1547, took a different approach toward regulating the fighting schools. In 1540 he granted a charter to the Company of the Masters of Defense, a major guild centered in London. The charter gave the London Masters a monopoly on teaching the weapons of the era and served to gather together all the great masters of England while outlawing any school that was not a part of the official guild (Dylan). For the King, the guild would provide a stable source of skilled warriors to draw upon in times of need. For the masters, the charter would prevent relatively unskilled swordsmen from calling themselves "master" and thus insulting proper masters with their sub-par teaching.

In order to gain rank within the guild, members were required to take part in public trials known as prizes. These prizes took place in markets or theaters and were overseen by four masters of the guild. After issuing a challenge, the "prizor" would engage anyone who answered in a series of bouts, progressing through different weapons as the masters wished. The London Masters taught a wide variety of weapons, including the long sword, the slightly shorter bastard sword, staff, and dagger. The rapier was only made a part of the prize system in 1578 (Dylan).

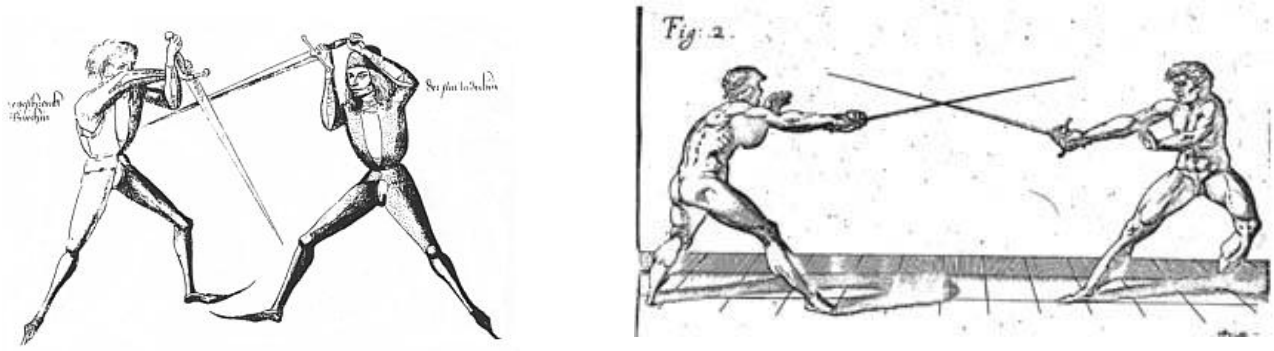


Figure 2: *Left*: Combat with long swords (Talhoffer).
***Right*: Combat with rapiers. Emphasis was put on thrusting over slashing (Giganti).**

Although the rapier had become popular on the Continent through the 16th century, it was not widely known in England until the 1570s. It was soon recognized that the long, thrusting rapier was a much more effective weapon than the common sword. In 1624 the King's charter of the London Masters was voided by the Statute of Monopolies, and foreign masters became the most popular instructors of the time. There are many records of bouts fought between English and foreign masters for pride (Castle, pp.23-27).

3.3. Germany: The Marxbrüder and Federfechter

Whereas in England masters were gathered by a decree of the King, German masters came together on their own. In the 14th century a group of fighting masters gathered together and unified all schools of combat in Germany into one. The Fraternity of St. Mark, or Marxbrüder as it was known, became a university of armed combat, attracting would-be swordsmen from across Germany. Only those who graduated were allowed to create their own schools. The renown of the Marxbrüder brought it recognition from the crown, and schools of combat spread across Germany (Castle, p.29).

Other societies arose in time, despite the expansiveness of the Fraternity. Only one society, the Federfechter, ever grew large enough to rival the Marxbrüder. They took their name

from “feder,” a slang term for rapier, which spread to Germany in the 1570s. It was the Federfechter who first adopted Spanish and Italian-style swordplay, specifically the styles which emphasized thrusting over cutting. As in England, the thrusting style was found to be the most effective of the time, and by 1590 the fighting styles of the Marxbrüder and Federfechter were almost indistinguishable (Castle, p.30).

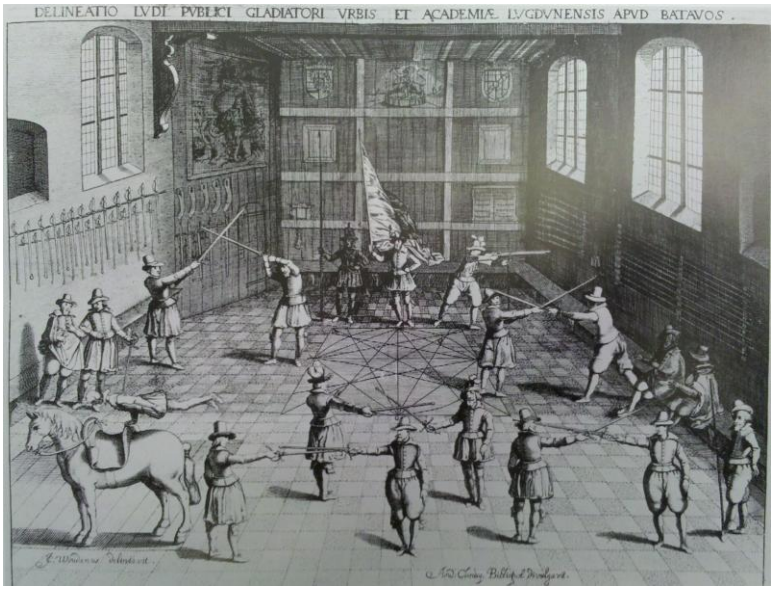


Figure 3: Late 16th Century engraving of the fencing school at the University of Leyden, in the Netherlands (Anglo).

3.4. Spain: The Verdadera Destreza

Spanish schools of combat were prestigious. Roman gladiatorial institutions had been maintained through the Middle Ages in Spain, and their masters were well-versed in all styles of combat.

Spanish swordsmen had to undergo considerable trial to gain the title of master. First they would face in sequence each of their examiners, each one a master in his own right. Following that, the applicant would face all of the examiners at once. The title of master swordsman was a noble one: once they passed, new masters gave solemn oaths in traditional Latin to never use their skills except for the “noblest of purposes” (Castle, p.32).

Whereas Italy and other nations had a variety of different schools of fence, in Spain there was only one: the *Verdadera Destreza*, which translates roughly to the "True Art." The father of the Spanish *Destreza*, was one Don Jeronimo de Carranza. Carranza was given the title of The First Inventor of the Science of Arms by his fellow masters; he believed the application of scientific thought to the study of arms was key to its progress (Martinez). Geometrical concepts were especially important to the Spanish school. Based on this, it is likely that Carranza's works, which began circulation around 1569, were influenced by Italy's Camillo Agrippa.

The heavy focus on geometrical thinking in Spanish treatises led many to view the Spanish style as too rigid. In reality the Spanish school taught geometrical concepts that were meant to be treated fluidly in combat. The singularity of the Spanish school meant that it developed rapidly, unlike the Italian schools which were held apart by socio-political strife.

Across Europe, schools of combat began as places to learn all forms of fighting, from boxing to staff combat. In time they developed into schools of sword combat exclusively. As fighting principles became more sophisticated, it became clear that a new weapon was needed, one distinct from the heavy, battering blades used on the battlefield.

4. A New Kind of Sword

In the late 1400s, it became clear that not all combat would occur on the battlefield. It was necessary to distinguish between battlefield and personal swords. The earliest examples of these personal weapons came to be known as "cut-and-thrust" swords. These swords, commonly used by foot soldiers and guards, were lighter versions of the heavy blades previously used by knights (Clements *Renaissance*, p.22). Personal blades became common accessories for lower class citizens seeking to defend themselves from the dangers of city life.

Lighter weapons became necessary for a variety of reasons. The lack of armor in an urban setting led to combatants relying more on dexterity. Another factor was the development of personal firearms, such as the wheel lock and matchlock pistols. Firearms made heavier melee weaponry and large armor a liability to its user. Heavier weapons took too long to draw—a heavy sword could not quickly respond to a threat from a firearm. In an attempt to counteract this disadvantage, lighter weapons had to be made. Long swords were narrowed down and became the first proto-rapiers. There were few differences with the rest of the design: the crossguards were still long and flat like the rest of the available swords, and attacks would still focus on the blade rather than the point (website: Clements "Questions").

One major adjustment to early rapiers was including rings on the crossguard. These altered how fencers would hold the blade and allowed the rapier to be handled with increased precision.

Fighting on city streets was considerably different from the great battles waged in war, and new techniques were developed to be more effective in this lighter, more flexible form of combat. Techniques were developed that led to the creation of the thrusting rapier, a highly mobile weapon.

5. Culture of the Rapier

5.1. The Mentality of the Duelists

The technicality of this new form of fighting was intriguing, and many began to study its intricacies. Schools of sword combat began to pop up, mainly in Italy and Germany. Knowledge of arms and combat became a major part of upper-class culture. Even Castiglione's *Book of the Courtier*, the guide to noble behavior in Renaissance Italy, states, "…I am of the opinion that the

principal and true profession of the Courtier ought to be that of arms…" (Castiglione §17). Masters of the art of fence arose: Italy's Camillo Agrippa and Nicoletto Giganti; England's George Silver; and countless other great minds across Europe. They wrote treatises, whole volumes of text on the various styles of fencing, each vying to find the best style, the perfect thrust.

Figure 4: An armed gentleman (Castle, p.25).

The earliest surviving written work on the art of fencing is the *Opera Nova*, written by Achille Marozzo circa 1536. Marozzo stated that cuts should be delivered in horizontal, vertical, or slanted directions and defense should come mainly from dodges. Thrusts were a feature of Marozzo's combat tactics, generally being coupled with a motion to repel the opponent's attack. These various moves, combined with positions necessary to execute them properly, were termed the 12 *Guardia*.

Italian mathematician Camillo Agrippa was the next to improve the art of fence, writing *Treatise on the Science of Arms with Philosophical Dialogue* around 1553. Agrippa's work

focused on applying geometrical problems to the art, such as better ways to position the sword. Agrippa's *Dialogue* shortened Marozzo's 12 *Guardia* down to 4. Lastly, Agrippa initiated the thought of having the point of the rapier hold more offensive ability, emphasizing thrusts over cuts.

It was not only the techniques of the swordsmen that evolved. Swordsmiths, too, sought to better their techniques and make more effective blades. The rise of thrusting styles led to a shift in how swords were made. Less emphasis was put on the edge of the weapon. The swords had to be light, yet sturdy enough to parry and riposte as such techniques became popular.

5.2. The Tradition of the Duel

Rapiers rose to prominence during the late sixteenth century, when they were commonly used weapons in duels. The most common duels were fights for honor rather than for life. Rules of etiquette and fair combat were established. While often depicted as violent fights, duels were commonly non-lethal, and a challenge could be declined. Participants of a duel consisted mainly of four people: the two combatants, and their "seconds," people who would act as judges or sometimes fight in place of a challenger if necessary (Baldrick).

Rules of a duel were most commonly to "first blood," in which case combat was considered complete when one participant received an injury, no matter how minor this injury was. First blood was preferred because it allowed both parties to save face without endangering either combatant more than necessary. First blood was not always the choice, and it was not uncommon to have a fight go to the death. In some cases, the first blood strike was a fatal blow (Baldrick).

These rules were by no means absolute for any specific duel. To law enforcement, the difference between a duel and two men attempting to kill each other was difficult to distinguish. Eventually, the Irish *code duello* was written as a guideline for all varieties of duel. It arose in Europe during the 17th century, around the rapier's fall from popularity as a weapon (Baldrick).

As duels were a matter of honor, most duels were carried out among nobility or similar high-class society, where honor or reputation would be a valuable thing to lose. Combatants generally preferred weapons of finesse rather than those which emphasized brute force. The rapier's ornate design, relative difficulty to wield effectively, and reputation for highly skilled masters made it a highly valued weapon for dueling. For much of the late 16th and early 17th centuries, rapiers were considered a fashionable choice among noblemen. Many decided that it was too unwieldy on its own, and often coupled it with a second defensive weapon such as a dagger, cloak, or buckler to keep guard during an attack. The rapier as the choice dueling weapon was short lived, and was soon replaced with similar weapons based on its design such as the foil, short sword, or flamberge. In time, gunpowder weapons became more prominent and overtook melee weapons as dueling instruments of choice before dueling was outlawed altogether (Baldrick).

6. Combat with the Rapier

The rapier was not used the way it is normally portrayed in the movies. The rapier was a thrusting weapon, not a cutting one as is commonly depicted. Also, attacks were not usually blocked, but were instead dodged. When incoming attacks were blocked at all, a dagger, a buckler, or a cloak was used.

The rapier was used mainly to thrust. There were three types of thrusts. The first was the *imbroccata,* which reached over the opponent's sword, hand, or dagger. It travelled in a descending direction and was delivered with the knuckles up. The second kind of thrust, the *stoccata*, went under the opponent's sword, hand, or dagger. The third strike was known as the *punta riversa* and was an attack from the left, outside the opponent's blade, either high or low (Castle, p.84).

There were two ways to cut with a rapier. *Mandritti* were cuts delivered from the right to the opponent's left side. *Roversi* were cuts delivered from the left to the opponent's right side. There are different kinds of *mandritti* and *roversi*. *Tondo* was circular and delivered horizontally. *Fendente* was vertical and downward. *Montante* was vertical and upward. *Sgualembrato* was oblique and downward (Castle, p.36).

Rapiers were not usually very sharp. "Rapiers simply could not dismember, decapitate or make strong cutting blows, nor were they ever intended to do so" (website: Clements "Questions"). Because the sword was not very sharp, one could grab or swat away the blade with their bare hand. This was still not very safe and would be safer if one was wearing a glove.

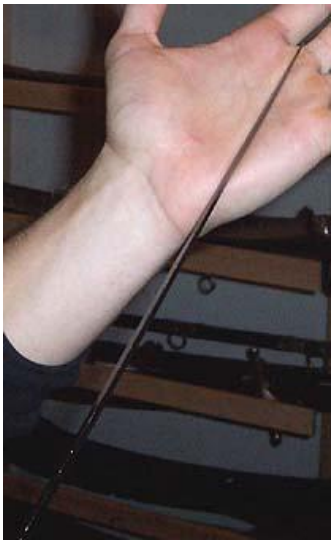


Figure 5: Rapiers were not cutting weapons (website: Clements "Questions").

When training, men had to be careful because if someone were injured, he could be blinded or maimed for life. "Blunted and unpointed weapons, originally called 'foyled' blades, were typically used that would not hurt if they hit too hard" (website: Clements "Questions"). The men would also agree on rules to make the sparring safer. Before fencing masks were developed in the 1700s, men had to be careful not to hit each other in the face because it could cause serious harm.

The modern sport of fencing was created in the late 1800s. It was derived from styles of fencing from the 1700s. The modern fencing styles were more directly derived from the smallsword than the early rapier. Modern fencing never used real swords. They were designed specifically to be safe in simulated dueling (website: Clements "Questions").

There are many differences between rapier fencing and modern fencing. In rapier fencing one could grapple with their opponent or grab their sword. In modern fencing these moves are illegal. A person is not allowed to use a secondary weapon or their free hand in modern fencing. There are no cutting strikes in modern fencing, whereas it is would be allowed in rapier fencing (website: Clements "Questions").

6.1. Stances

There were several wards, often called guards. The first was low ward, which had two variations. In the first variation, the fencer would hold his “sword arm almost straight angled forwards at around 45°, palm to the left with their points directed at their opponent’s face” (Hand). In the other, the arm was almost straight with the hand beside the right leg and the tip aimed at the opponent’s face. The second ward was the high ward. The sword arm was held up vertically with the palm to the right and the tip of the rapier pointed down at the opponent’s face. The third was the open ward. The arm was held up with the palm to the left and the sword held either straight up or angled slightly back. Another was the *punta riversa* ward where “the sword arm is held across the body with the palm upwards” (Hand).

6.2. Rapier and Dagger

The dagger was used to defend, not to attack. This was because one would have to get closer to their opponent to strike, which would be dangerous. There were two ways to hold the dagger. One way was with the blade down, with the guard near the pinky finger. “This type of grip is most efficient for guarding against thrusts or light cuts aimed below the dagger hand…” (website: “A Manual"). The right foot forward stance was recommended with this grip.

The more traditional way to hold the dagger was with the blade up with the guard closer to the index finger and thumb. The left foot forward stance was recommended with this grip. This grip made it easy to parry high or low thrusts and cuts to the left side of the body. Sometimes the dagger was used to attack the opponent’s blade directly (website: “A Manual").

Figure 6: A rapier and dagger duel (website: Clements "Questions").

6.3. Rapier and Cloak

Another item often used with a rapier was the cloak. The size and flexibility of the cloak had to be taken into account. Because a cloak was long, it would protect against cuts to the side. Since it was flexible, it would absorb the force of the attack. The cloak could be used to grab the blade or to knock a thrust to the side.

The cape or cloak was held by the collar or on the edge near the hem. While on guard, the cloak was to be held out and would hang down from the hand, but the fighter would have to be careful not to block his sight. Keep in mind that the reason the cloak protected was because of the flexibility, because if a hit landed on the cloak against a solid surface, like an arm, the protection was lost and the blade would cut through the cloak.

An offensive way to use a cloak was to entangle or knock away the opponent's blade. One could throw the cloak over the opponent's head to blind them temporarily, but the fighter had to be careful because he may then lose his cloak. A cloak could also be flicked at the opponent as a distraction (website: "A Manual.").

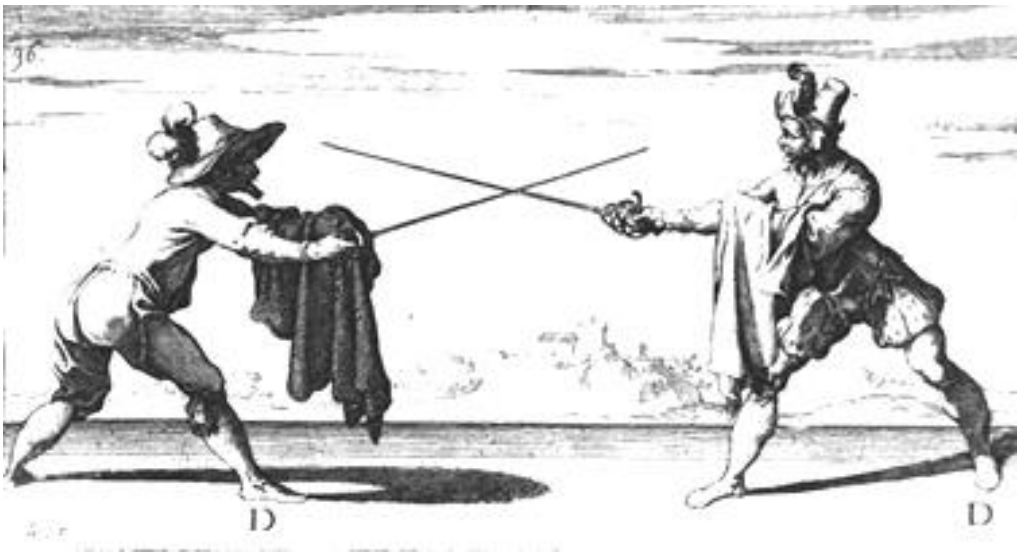


Figure 7: Rapier and cloak (website: Clements "Questions").

6.4. Rapier and Buckler

The third off-hand weapon was the buckler, a small shield meant to parry or trap the opponent's blade depending on construction. Bucklers were round with a diameter between twelve and twenty-four inches. They were made from materials that would neither break easily nor would damage a blade. The edge of the buckler was often covered with leather. There were two tactics when using the buckler. One was with the left foot forward and the buckler held out at about chest height. The rapier is typically grasped in an open ward. The buckler is then used to move the opponent's blade to the outside, which is followed by an attack. The other was the standard guard, with right foot forward, with the buckler held close to the body at chest height. It was still used to parry followed by a cut or thrust. The buckler could be used offensively also. Some bucklers had spikes to be used offensively. The smaller bucklers could be punched with and large bucklers could be used to strike the opponent with the edge (website: "A Manual").

Figure 8: Rapier and buckler (Castle, p.20).

7. Dimensions of a Rapier

An average rapier would be around 48 inches long with a 42 inch blade. The width of the blade would be approximately one and one-eighth inches at the cross guard and taper to the tip. Rapiers typically weighed between two and three pounds. There were a variety of cross section shapes, although a diamond-shaped cross section was most common (website: “Rapiers”).

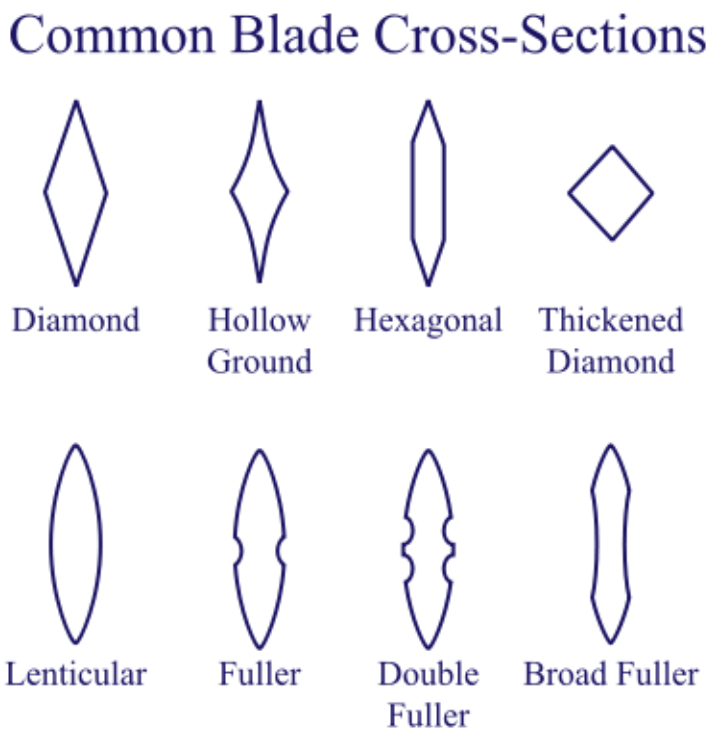


Figure 9: Various examples of sword cross sections (website: "Common").

Single fullers are common in rapiers. A fuller is a groove that removes material from the blade without compromising the blade's strength. The removal of material made the blade lighter. A fuller uses the same principles as an I-beam to keep a rapier strong. The web of the fuller resists shear forces on the blade and the flanges resist the bending forces.

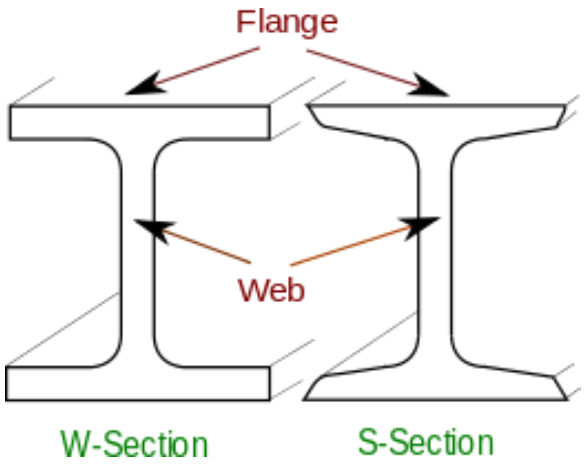


Figure 10: The cross section of an I-beam (website: "I-beam").

The most recognizable aspect of a rapier is its hilt. A hilt consists of a handle, pommel, and guards. The guards consist of a collection of rings or a cup that protect the hand. The guard is made up of two quillons that protrude perpendicularly from the sword. The knuckle and inner guards are metal rings that extend from the cross guard to the pommel (website: "What is the Rapier?").

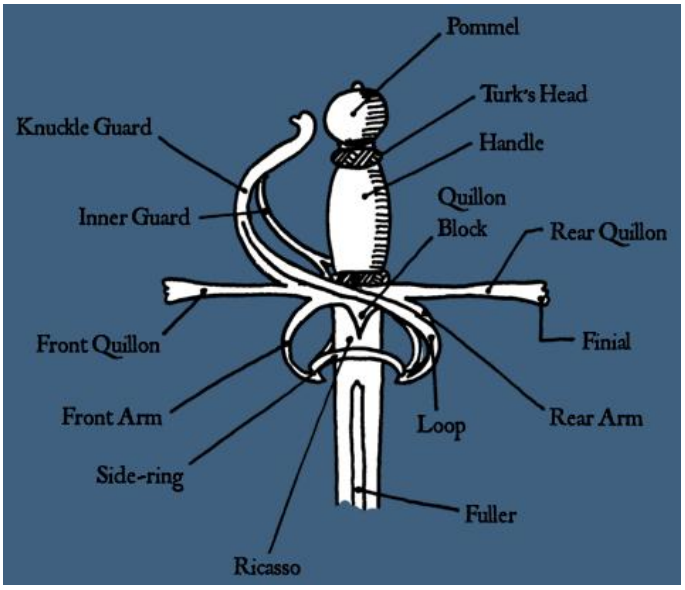


Figure 11: The parts of the hilt (website: "What is the Rapier?").

8. Manufacturing of a Rapier

8.1. Material

Rapiers were made by skilled craftsmen to be light and durable. Steel was the weapon material of choice due to its superior ductility and toughness. Steel was made by treating iron ore to remove impurities and add carbon. A blast furnace superheated the metal using coal and an air furnace. By pushing oxygen into the furnace it allowed the furnace to rapidly reach the metal's melting point. The liquid metal was separated from the impurities like sulfur, silica, and

phosphorus. These impurities would have made the steel prone to rusting and made the steel too brittle to use. This process also added the carbon to the iron ore (website: Clements "Questions").

Figure 12: A forge and bellows (website: "16th Century").

The ductility of steel made it an appealing material choice for weapons, allowing the rapier to perform its signature flex without breaking. Steel has a lower melting point and is more malleable than pure metals like iron, making it easier to work with. Steel weapons are more resilient when deformed frequently as a result of use and are less prone to shatter when a force is applied to them.

8.2. Forging the Blade

Once the processed steel was acquired, the craftsman would begin to forge the blade. Unlike most weapons of the time period, rapiers were not cast, anvil pounded, nor quenched (website: Clements "Questions"). A cast blade would be made by pouring molten steel into a mold of a desired shape. An anvil pounded sword's shape would be obtained by repeatedly heating and applying a force to the metal until the desired shape was obtained. Quenching is the

step after either casting or anvil pounding in which the heated blade would be quickly drenched in water to stiffen the entire blade. All of these methods left the rapier too brittle to use.

Due to the rapier's shape, the blade needed to maintain a higher level of ductility than other blades. A craftsman would need to slowly work the steel of a rapier into shape. This process involved heating the steel with a method similar to anvil pounding. However, instead of applying quick, powerful blows the steel was gradually pulled and pushed into shape. This method does not put as many stresses into the metal, which would result in weak points (website: Clements "Questions").

8.3. Treating the Blade

Once the basic shape of the blade was obtained, the edge of the blade was prepared for heat treatment. In this step, the blade would be shaped almost to a cutting edge. Once the blade was shaped correctly, it would be heated rapidly, such that only the outside of the blade was hot. Then it would be dunked in water. This way only the exterior of the blade would be affected, making the outside of the blade harder and allowing it to maintain a sharper edge that would not readily give out. Once the blade was sharpened to a cutting edge, it was deemed complete (website: Clements "Questions").

8.4. The Hilt

The handle was often made of wood with a pommel. The pommels were often decorative and made to secure the blade to the sword. They acted as a counterweight to balance the sword, making it easier to wield. The handle itself was wrapped with leather or cord. Similar to most other blades of the time, the hilt included a cross piece to protect the hand. However, rapiers commonly had ornate knuckle bows that extended down from the crossbars to the pommel.

These rings provided extra protection for the hand. They were often made from steel rods that were twisted and pounded together.

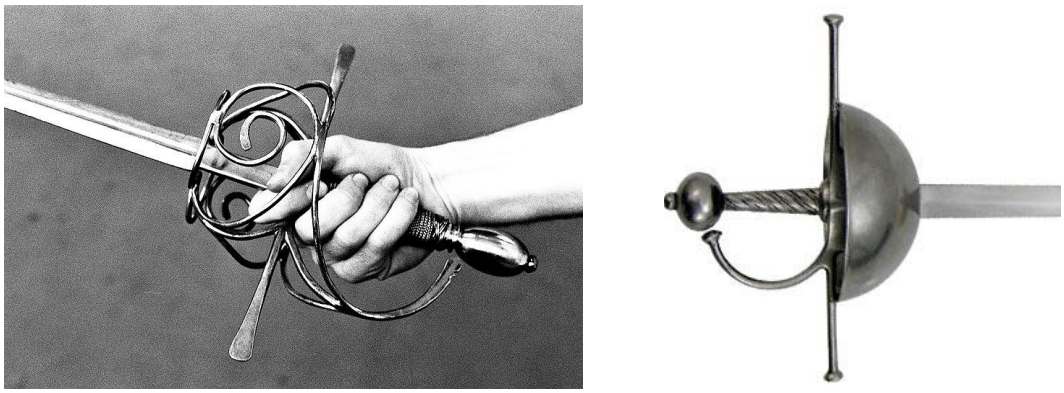


Figure 13: Examples of the two types of cross guards. *Left*: A ringed cross guard (website: "Rapier Hilt"). *Right*: A Spanish-style cup guard (website: "Mini Spanish").

9. Recreating the Rapier

The rapier replica was made with the help of Josh Swalec and Ferromorphics Blacksmithing. The process used in this project was similar to classical forging methods. However, modern tools and materials were added to the process. These changes were made based on the time constraint and the equipment available. The sword replication consisted of the following steps:

- Acquire or purchase materials needed for the sword
    - 4140 steel bar for the blade
    - Copper bar for the cross guard
    - Sheet steel for the knuckle guard
    - Steel rod for the pommel
    - Craft leather for the hilt
- Work the steel bar into a blade
- Bend the copper into the cross guard shape

- Cut the sheet steel into the shape of a goat's head for the knuckle guard
- Attach the guards and pommel to the tang of the blade
- Wrap the hilt with leather to provide grip

These steps roughly outline the process followed to create a rapier. This list states what needed to be done, but not how it was done. The details will be fleshed out throughout this section. Figures 14 and 15 are computer-aided design (CAD) models created to show the rough design for the rapier replica. The actual replica changed due to manufacturing and time constraints.

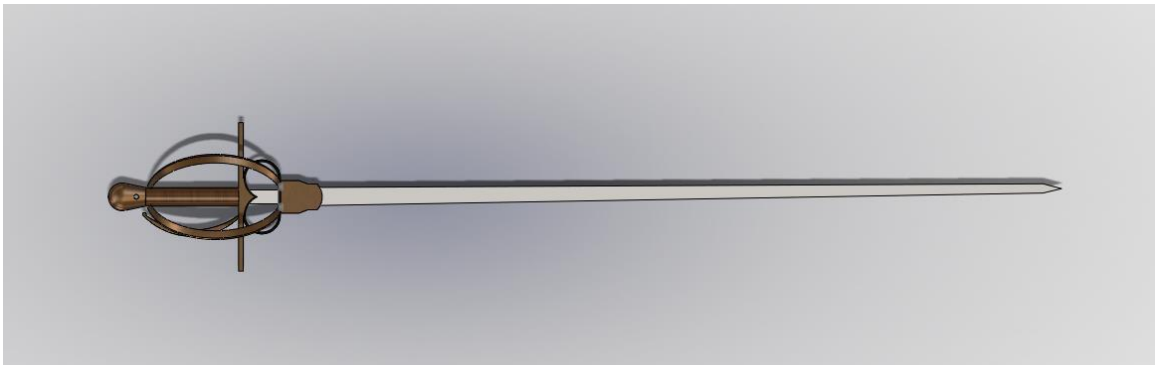


Figure 14: Solidworks assembly of the rapier replica.

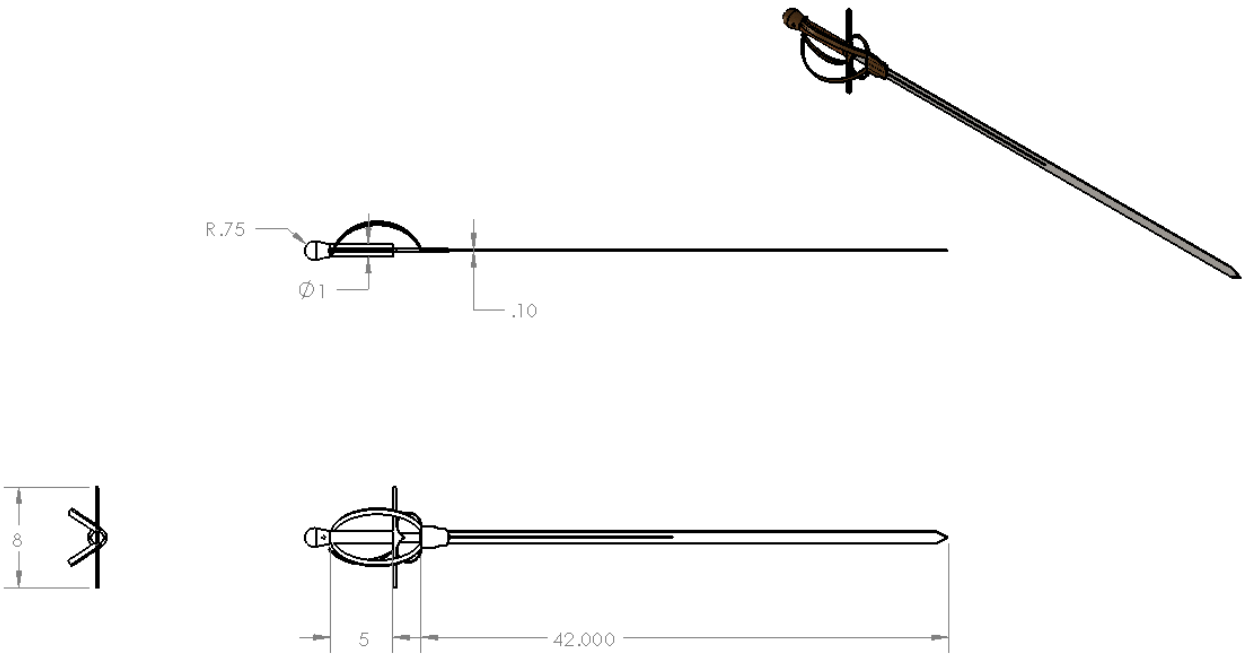


Figure 15: Solidworks drawings of the rapier replica with estimated dimensions (in inches).

9.1. Materials Used

Steel is now a readily available resource. Therefore, 4140 alloy steel was used instead of making steel out of the raw iron ore. The 4140 steel is an impact resistant material. Its primary alloying elements are chromium and molybdenum which are artificially added during its production (McMaster). The 4140 Steel was purchased online from McMaster Carr. Tables 1 and 2 show the properties of this steel.

Table 1: Steel Properties from the Distributer (website: "McMaster-Carr")

4140 Steel Properties	
Standard Specifications:	Multipurpose 4140/ 4142 Alloy
Hardness:	Rockwell C28-C32
Yield Strength:	85,000-130,000 psi
Also called "chrome-moly" steel because of its main alloying elements (chromium and molybdenum), which give it good fatigue, abrasion, and impact resistance. It is readily formed and machined in its annealed state and can be heat treated to increase toughness and wear resistance.	

Table 2: Steel Chemistry (website: "Simply Tool")

Weight Percentage of Elements in Typical 4140 Steel	
Carbon	0.42%
Silicon	0.30%
Molybdenum	0.20%
Manganese	1.00%
Chromium	1.00%

With the material for the blade established, the group looked for a material for the cross guard. A ¼ x ¼ square inches copper bar was selected to become the cross guard. Copper is soft and bends into the desired shape by simply heating specific areas. This material was selected for ease of manufacturing, not strength. Due to the fact that this is merely a replica, the copper hilt

will not need to actually take any force. Polished copper will look presentable. The copper bar was purchased online from McMaster Carr.

The pommel needed to have enough weight to counter balance the blade. A large rod of steel was found at the blacksmith's shop and used for the pommel. The goat head-shaped knuckle guard was created from a scrap of sheet metal found at the shop. The metal was flexible enough to bend without heating, but still held its shape. However, it would not properly protect someone because it is too flexible. For the purposes of a replica, the sheet steel was cost and time efficient. It will create the desired shape. The bar and sheet steel were both scrap metal and the students were not charged for their use.

The hilt had to look presentable and be comfortable to hold. The hilt was created using four components. Two of the components were purchased from Michael's Craft Store. A length of plywood facing was used to give the hilt a desirable width. A roll of suede lace was used for decoration. The other two hilt components were purchased at Dick's Sporting Goods. A length of tennis grip was purchased to make the hilt more comfortable. A roll of athletic tape was used to hold the other components of the hilt together.

The plywood facing was discovered while at Michael's. It had identical dimensions to the steel. It had rounded edges on one side that would create a desirable shape for the hilt. It was cut to create the two pieces shown in Figure 16.

Figure 16: Plywood facing for hilt.

The lace was chosen for its durable leather-like quality and its color. The red was the closest to WPI's school colors available, Figure 17.

Figure 17: Suede lace for hilt decoration.

Tennis grip seemed like a logical choice for the grip of the hilt. It was padded, sweat resistant, durable, and easily accessible.

Figure 18: Tennis grip for hilt grip.

The athletic tape was durable, red, and adhesive. It was a quick, reliable way to hold the hilt pieces together.

Figure 19: Athletic tape for hilt assembly.

The final budget can be seen in Table 3:

Table 3: Final Replica Budget Breakdown

Item	Use	Price
4140 Steel	Blade	$74.24
Copper Bar	Cross Guard	$10.63
Steel Rod	Pommel	$0
Sheet Steel	Knuckle Guard	$0
Plywood Facing	Hilt	$3.49
Suede Lace (Red)	Hilt Decoration	$8.99
Tennis Grip	Hilt Grip	$7.99
Athletic Tape	Hilt Grip	$4.99
	Total:	$110.33

9.2. Metallurgical Analysis of the Steel Samples

Four small samples were cut from the 4140 steel using the chop saw. Two of the samples were forged and the other two were not. The samples were used to determine the grain change along two different cross sections. One cross section is parallel to the cut; the other perpendicular. The chop saw and samples taken can be seen below.

Figure 20: The steel samples with quarter for scale. *Left*: Unforged steel. *Middle*: Heated and shaped steel.

A traditional anvil was used. However, a modern forge was used to heat the steel. A manual bellows was not used to add oxygen to the furnace in order to achieve the needed temperature. The forge used propane for fuel, which naturally burns at 1991ºC. This falls between 1700 and 2200ºC, the range at which 4140 steel is forgeable (websites: "About," "Alloy").

Figure 21: Blacksmith's work area with the blade heating in propane furnace.

While heating the steel, the students would wait for the steel to glow orange-yellow before applying the force needed to shape it. The following image shows the forge and anvil that were used to create the replica rapier.

Figure 22: Furnace heated steel on the anvil.

The steel was heated six inches at a time. Once the steel reached the preferred color, it was soft enough to make the steel malleable under the compressive force of the applied hammer strikes. The process by which the steel was moved in a desired direction was called peening.

Peening is the controlled application of force to move the metal in a desired direction. The hammer was used to repeatedly strike the steel at an angle, moving the steel outwards making the edges thinner and the bar longer. This left a bevel down the center of the bar, creating the desired diamond shape.

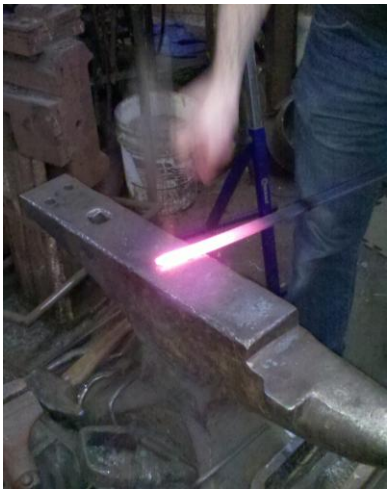


Figure 23: Peening the blade.

Repetitive heating of the steel would eventually weaken the strength of the blade. Unfortunately, the steel is a great conductor and does not retain heat for long. The steel remained hot enough to forge for about 30 seconds. Therefore, the steel needed to be struck rapidly and with purpose. This task was accomplished a few different ways. The student hammering needed to use the weight of the hammer to his advantage. This was achieved by almost flicking the hammer at the blade. Planning the next hammering before reheating saved precious seconds. Deciding whether to peen, straighten, or fix a section of the blade before reheating the steel saved time and produced better results.

Figure 24: Forging the tip of the blade.

The tip of the blade was created by striking the steel on both the broad and thin side. This narrowed the blade in both directions and lengthened the tip of the blade to the point shown below.

Figure 25: The tip of the sword.

In the end, the blade was rough and mimicked the desired shape. It was coarse and covered with scale. The scale was a result of oxidation, which occurs when the metal is heated. The scale was grinded off with an angle grinder and sanded until the steel regained its metallic appearance. Some of the blade remained marked due to mistakes made in the forging process that were too deep to grind away. The bottom eight inches were left untouched. This served as the tang, or the part of the blade that would become part of the hilt.

Figure 26: The forged blade.

The copper bar needed to be bent into a specific shape. The cross guard was designed to have a loop for a wielder to put his finger in and have two extensions to provide some protection for the hand and arm. In order to accomplish this task, a mounting platform was created. Two scrap pipes were spot welded to a sheet of steel using an arc welder.

Figure 27: The finished hilt mount. The copped was heated and bent around the pipes.

The copper bar was clamped to one of the pipes and pulled around the mount. An acetylene torch was used to anneal the copper at the turning points. The torch was turned up until it created a blue flame and was applied directly to the copper at the point tangent to the pipe as it was drawn around.

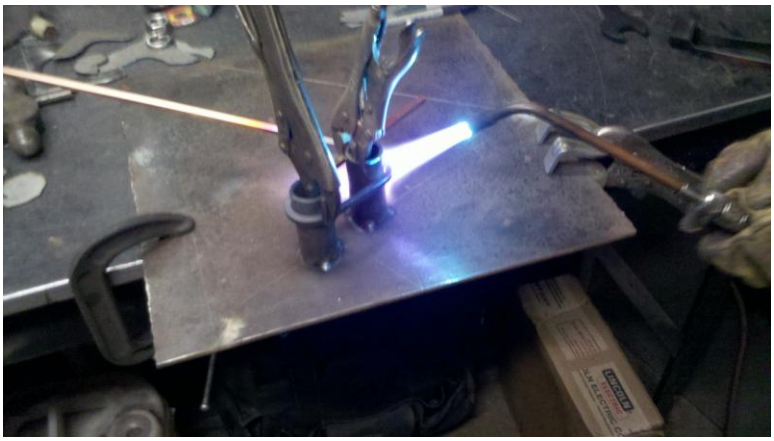


Figure 28: The hilt coiling process.

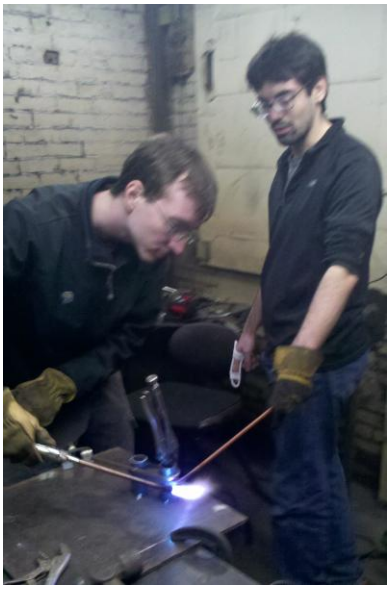


Figure 29: Using the acetylene torch while the copper is bent around the form.

Figure 30: The coiled copper.

This method proved to be effective. The whole process took less than 2 hours and created an evenly coiled cross guard.

The copper developed a little scale, but otherwise looked good.

Figure 31: The crossguard after being coiled.

The ends of the cross guard were then heated using a blowtorch to anneal the metal. The ends were then flattened and bent into ornate twists on the anvil.

Figure 32: Annealing of the crossguard.

This required a little practice on a piece of scrap metal. The process was not difficult; however, it did cause the coil of the guard itself to become a little misshapen.

Figure 33: The finished crossguard.

The knuckle guard was based on the shape of a goat's head with giant curled horns. This was done as a tribute to the WPI mascot, Gompei. The knuckle guard consisted of two pieces: the guard and the back connection plate. Both pieces were cut from a flat piece of sheet metal with a plasma cutter.

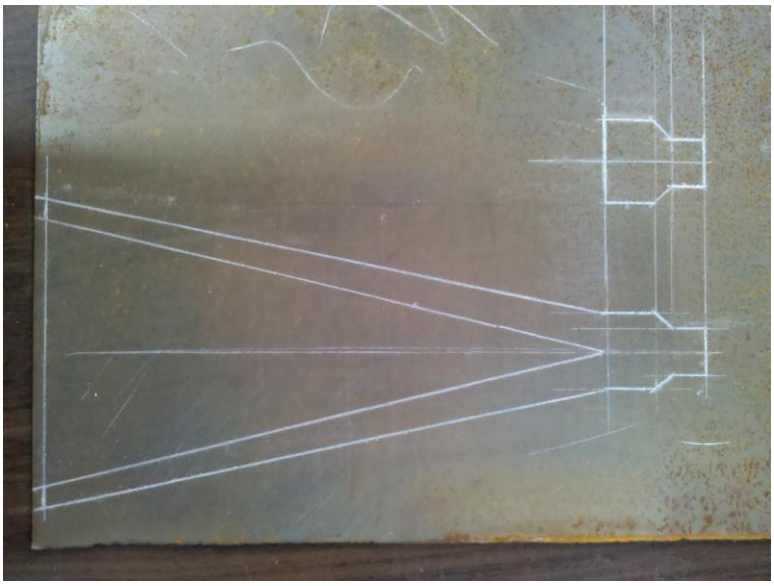


Figure 34: Sketch of the knuckle guards on sheet steel.

Figure 35: Back plate in the cutting process.

Figure 36: Rough cutouts of the goat-head guard and back piece.

The cutouts were rough and sharp, so they needed to be filed down with the angle grinder.

Figure 37: Removing rough edges from the guard pieces.

Figure 38: Finalized knuckle guard cutouts.

The knuckle guard was then bent into shape. The ends of the horns were curled similarly to the cross guard. The tight curls were created over the anvil with the use of a hammer. The rest of the horns were bent over the anvil, but adjusted by hand. The cold sheet steel was ductile enough to be bent by hand. The connection plate was bent in half at a slight angle. This was done so that the ends would come in contact with the knuckle guard when put on either side of the blade. This way, they could be contact welded together.

Figure 39: The finished knuckle guard.

The pommel was created last. It was created from a piece of scrap bar. The end of the bar was prepped for forging by grinding down the burs on a table grinder.

Figure 40: Preparing the pommel for forging.

The rod was then heated and rounded to create a suitable pommel.

The pommel was then cut from the rod using an automated machine saw. A slot was cut into the pommel for the tang to go into. The pommel was grinded clean of scale before a notch was cut into it using an angle grinder.

Figure 41: The polished pommel.

The pommel was welded to the tang and the plywood facing was taped in place with a layer of athletic tape.

Figure 42: Beginning of the hilt construction.

The tennis grip was put on afterwards. The grip was wrapped around the hilt similarly to the way it would be put on a tennis racquet. Another piece of the tennis grip was put on the cross guard to provide some padding. Another layer of athletic tape was added to the hilt to hold the tennis grip on. The suede lace was added to keep the copper cross guard in place. The initial plan was to attach the cross guard by welding it to the blade. Unfortunately, the copper could not be welded with the materials available. Copper has a melting point too low for the arc welder work without melting it. The cross guard is held in place by the hilt and the welded on knuckle guard.

Once the assembly was complete, the edges on the sword were smoothed and the surfaces polished using increasingly fine sand paper.

9.3. Results

Upon completion, the process of forging proved to be a difficult endeavor. The blade has a slight bend in it. There are dozens of marks where stray hammer strokes hit too deep. The guards are merely for show and would serve limited purpose in combat. However, for a group of first time blacksmiths and with limited time and resources, the final product is a commendable replica.

Figure 38: Comparison of the CAD model rapier (top) and the hand manufactured rapier (bottom).

The samples cut from the steel were mounted, polished, and etched with the help of Dr. Boquan Li. The group used grinding trays to polish the sample surfaces to remove all material until the average roughness was smaller than one micrometer. Once the samples were polished smooth, an etching solution was prepared and applied.

Figure 39: Preparing the sample surfaces to be viewed under the microscope.

Etching the metal reveals its characteristic microstructure. According to the Buehler Sum-Met: The Science Behind Materials Preparation, Nital solution (nitric acid in methanol) was an appropriate etchant for steel. Using chemicals available in the Washburn lab, the team created a 3% nitric acid nital solution. The solution was applied to the polished samples with a cotton swab for approximately 30 seconds. With the samples polished and etched, the microstructures were viewed under the optical microscope as shown in Figure 40.

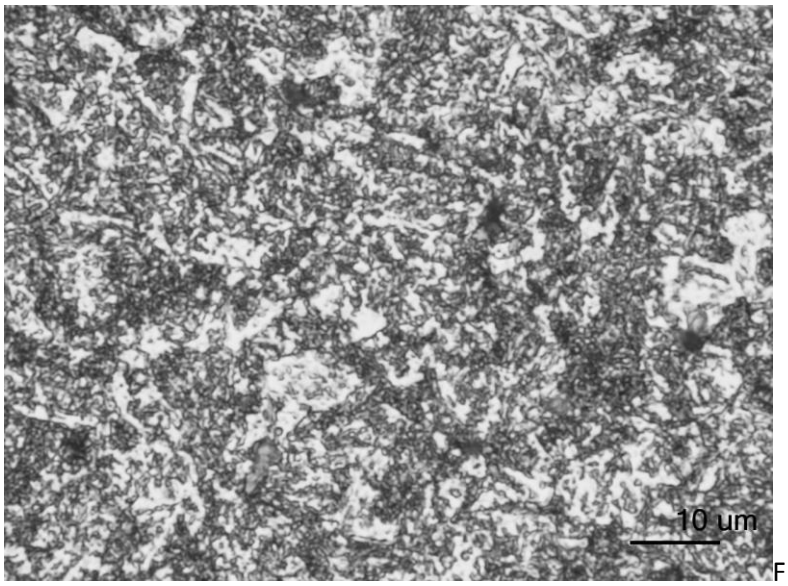
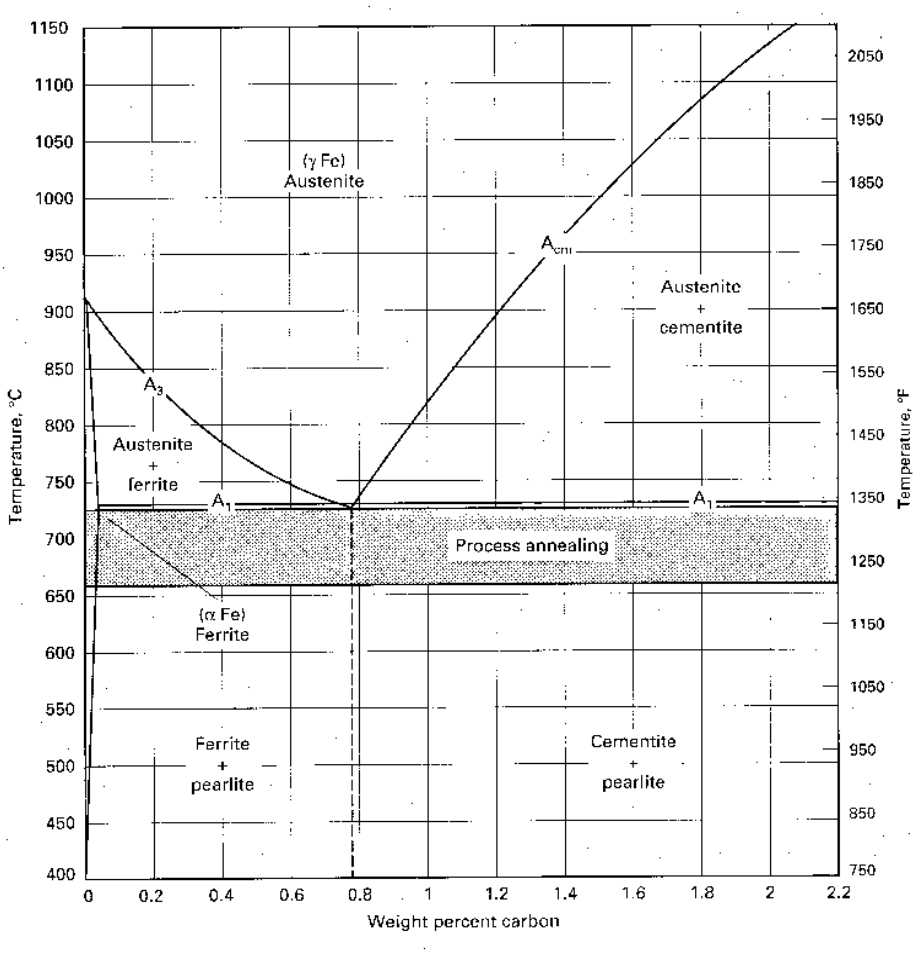


Figure 40: Microstructure of the unforged 4140 steel.

$$Cooling\ Rate\ of\ Purchased\ Steel = \frac{1550\ °F}{2\ hr} = \frac{0.215\ °F}{s}$$

The purchased 4140 steel was slow cooled. Due to this knowledge, the weight percentages of ferrite and pearlite could be calculated based on the Fe-C phase diagram. The carbon percentage in 4140 steel was found to be 0.42. This value was used to find the weight percentages of the constituent phases from the phase diagram. These percentages represent the ratio of proeutectoid ferrite to austenite in the steel before it drops below the eutectoid temperature (approximately 1340°F). Below this temperature, the remaining austenite transforms into pearlite (eutectoid ferrite and cementite).



The iron-iron carbide phase diagram showing the region of temperatures for process annealing. Source: ASM Handbook, Vol 4, Heat Treating, ASM International, 1991, p 49

Figure 43: Iron-Carbon Phase Diagram (ASM).

$$Proeutectoid\ Ferrite = \frac{0.8 - 0.42}{0.8 - 0.02} * 100 = 48.7\%$$

$$Percent\ Austenite\ Before\ Eutectiod\ Point = \frac{0.42 - 0.02}{0.8 - 0.02} * 100 = 51.3\%$$

These calculations match the quantitative measurements on the optical images of the microstructure. The makeup was approximately 50 percent ferrite (white) and 50 percent pearlite, a ferrite and cementite lamellar structure (white and black).

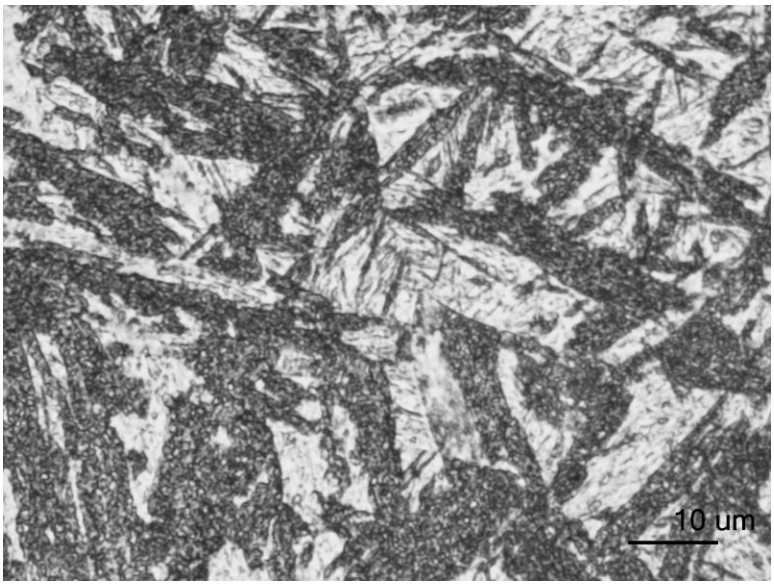


Figure 44: Microstructure of forged 4140 steel blade.

$$Cooling\ Rate\ of\ Forged\ Steel = \frac{1600\ °F}{10\ min} = \frac{2.67\ °F}{s}$$

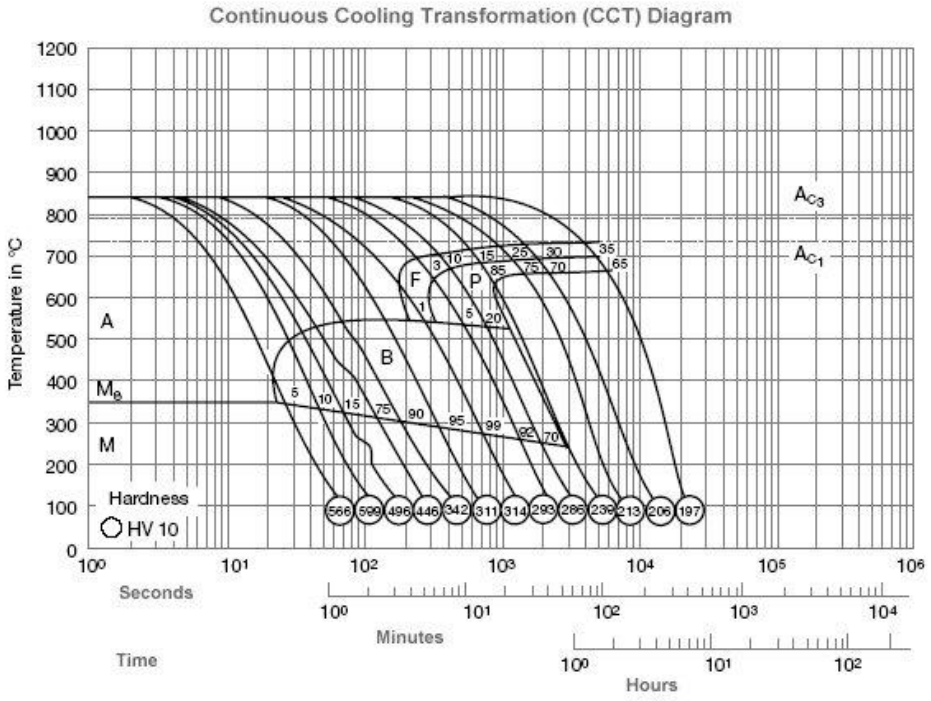


Figure 45: CCT diagram (website: "42CRMOS4").

The forged steel was cooled much faster relative to the purchased 4140 steel. As a result, the microstructure could not be predicted using the Fe-C phase diagram. The group used a Continuous Cooling Temperature diagram (CCT). Using the CCT diagram, the team used the cooling rate to evaluate the steel as having a bainitic microstructure.

10. Conclusion

This report has looked at the design and culture of the rapier weapon in a historical context. In its early years, the rapier was as common civilian weapon used in official business. Its lack of wartime use resulted in it becoming more of a fashion item over time. Nobility often carried ornately designed swords with hilts of precious metals embedded with gemstones.

Rapiers required skill to be wielded effectively. The style of combat using the long, thin blade became the subject of much study through many of the nations it could be found, with prominent fighting schools arising in Italy, Europe, Spain, and Germany. Each school sought a unique way to best employ this sophisticated weapon.

The light and quick design of a rapier was a perfect complement to the weapons of the era, gaining popularity at a similar time to early gunpowder weaponry, which rendered heavy weapons and armor not only obsolete, but a liability to the wielder. Public dueling among nobles and aristocrats meant that a weapon that promoted the user's skill over brute force was preferable as a status symbol. The weapon was not restricted to upper classes of society, and fencing schools that promoted the art of practicing with the weapon without the threat of major bodily harm to participants were available to average citizens.

The process of making the sword proved to be more challenging than was initially expected. Acquiring the resources, tools, and skills took much time and effort. The quality of the

finished replica pales in comparison to actual period rapiers in both style and form, highlighting the great skill held by the artisans of old. Coming out of this experience, the group has an increased respect for metal smiths both in the Renaissance period and today. This was a valuable learning experience.

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