HISTORICAL EVOLUTION OF ROMAN GLADIATORIAL ARMS AND ARMORS: 300 B.C. - 450 A.D.

An Interactive Qualifying Project Report

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Abstract

In ancient Rome, gladiatorial combat was one of the most popular spectator sports of the Roman Empire. Over the course of 800 years, gladiatorial combat evolved from a sacrifice for deceased ancestors in a display of combat, to a political and social tool that used many lives to gain admiration. This project's purpose was to look into the historical background of gladiatorial combat in the Roman Empire, and to analyze the armor, weapons and combat of combatants. We were also tasked with replicating one piece of armor or weaponry used by gladiators. For this project, the weapon chosen was the Gladius, one of the most popular and iconic weapons among gladiators.

Acknowledgements

We would like to thank Professor Diana A. Lados and Mr. Tom H. Thomsen, who aided us in our research and progress in this IQP. We would also like to thank Joshua Swalec, who taught us how to safely use the forge and all of the necessary tools in his shop, as well as blacksmithing techniques. Additionally, we would like to thank Dr. Boquan Li for his instruction on how to mount, grind, and polish our samples for further analysis. Thank you.

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1. Introduction

This project is a part of the Historical Evolution of Arms and Armors Interactive Qualifying Project series. The primary purpose of this project is to examine the evolution of the weapons and armors of the gladiators in Ancient Rome, in terms of design, materials and manufacturing process, within the historical context of the gladiatorial combat in Ancient Rome. A secondary goal for this project is to recreate a Gladius using the same or similar methods as what the blacksmiths in Ancient Rome used. The last purpose for this project is to update the online database that was developed for the previous iterations of this project series with the information gather during this project.

The gladiators are one of the most iconic combatant figures in recorded history. They began as ceremonial gifts, or munera, to the deceased members of the higher class of Rome. Occasionally, the SPQR – Senatus Populusque Romanus, or the Senate and People of Rome – would wait to commemorate their deceased, so that they could raise enough money for a more spectacular munera. The gladiatorial fights were also postponed until the munera was more politically advantageous, such as closer to when elections would occur. These gladiators would fight each other, or even wild animals, such as lions, tigers, hippopotamuses, elephants, rhinoceroses, and other beasts.

Although these fights began as a way to celebrate the life and passing of Roman citizens, it eventually turned into one of Rome's most popular spectator events. They began as fights to the death between pairs of convicted criminals, or enemy prisoners of war. Eventually they turned into any willing participant, ranging from criminal to consul. As the fights gained popularity, schools, or ludi, arose in order to train potential gladiators in their art of combat.

Following this gain in popularity, the combatants were no longer forced to use a certain weapon, but rather they were allowed to choose which weapon they wanted to fight with.

2. Historical Background

2.1 Overview of the Roman Empire

This section acts as a brief overview of the Roman Empire. The Roman Empire was a period of Roman dominance between 30 B.C. and 476 A.D. Augustus Caesar was the first Emperor of Rome. This was the nephew of Julius Caesar, who would act as Rome's informal 'Dictator' due to his supreme political and military control at the time (Mark, pp. 2). In the time of his rule, the city of Rome was almost rejuvenated and, as quoted by Augustus himself, to have been "found Rome a city of clay but left it a city of marble". It was also during Augustus' rule that long-term peace was held. From 31 B.C. and for more than 2 centuries, Rome was not directly affected by war, which in turn led to displays of combat to honor the warrior traditions of the Roman army through artificial battlefields, which were used for public amusement (Hopkins par. 4).

Augustus' rule brought about the Pax Romana, or Pax Augusta, which was a period of peace held for about 200 years. Following Augustus' rule would be his heir, Tiberius, who lacked the strength to properly govern the city. However, his rule, followed by the three following emperors of Rome, would expand the territory of the Empire over to Britain, and continue the period of piece established by Augustus (Mark, par. 4). The succession of emperors, from Tiberius to Nero, was known as the Julian Emperors.

Though these emperors' actions brought expansion and progress to the Empire, Caligula and Nero were examples of erroneous action within the empire. Caligula, for example, was susceptible to foolish action and insanity, including nominating his horse to council and declaring himself (Morey ch. 24, sec. 2), while Nero's reign eventually became tyrannous and partook in many unfavorable activities, including crime, extortion and persecution of Christians (Morey, ch. 24, sec. 4). The state of peace was broken by Nero's suicide in 68 A.D. and was followed by the Year of the Four Emperors.

During this period of turmoil, the emperorship of Rome was contested at many points, spanning over the course of four rulers. Galba, the 6th Roman emperor, was assassinated shortly after assuming his role. The Praetorian Guard found him unsuited for his position and his seat was immediately filled by Otho, the 7th emperor. Otho's rule was contested by Vitellius, who started a civil war, leading to Otho's death and Vitellius' rise to the throne. Vespasian would then take over, following the poor qualities shown by Vitellius. Vespasian would take his seat as emperor one year following the rise of Galba (Mark, par. 5). Vespasian's rule lasted from 69 to 79 A.D. , in which the growth of Roman spectacles, the destruction of Jerusalem in 70 A.D., and an increase in the Roman treasury. During his reign, the Flavian Amphitheater, which housed mostly gladiatorial shows and beast combat, Circus Maximus and other spectacle-based buildings and areas were constructed (Morey, ch. 25, sec. 2).

Vespasian's rule was followed by his son, Titus, who was declared as the "delight of mankind" due to his immense popularity. His reign lasted until 81 A.D., which was filled with his kindness, but was also marked by the destruction of Herculaneum and Pompeii by the eruption of Mt. Vesuvius. Following Titus was his brother, Domitian, who ruled over Rome in a

tyrannical manner, which greatly contrasted the more jovial rulings of Vespasian and Titus (Morey, ch. 25, sec. 5).

After the assassination of Domitian, ending the Flavian line of emperors, the reign of the Five Good Emperors followed. Nerva, Trajan, Hadrian, Antoninus Pius and Marcus Aurelius were able to bring about and continue a section of "prosperity" in Roman history. This period lasted from 96 to 180 A.D. However, it was after this period of prosperity that the Empire would begin its descent. From 180 A.D. to 268 A.D. the throne of emperor phased between multiple emperors, such as Commodus and Gallienus, who were seen as weak and brought ill will to the empire, along with attacks and invasions from numerous other countries and civilizations such as the Persians and Franks, who posed a threat from the North and West, respectively (Morey, Ch. 26, sec. 2, 3).

Rule of Rome continued to change hand, the Empire still in effect up until the late 5th century. It was at this point that the Western Empire began to fall, due to invasions from Goths, Huns and Saxons, as well as further conflict in 476 A.D. which lead to the fall of Romulus Augustulus. It was finally in 486 A.D. that the last Roman authority had fallen to invaders.

2.2 3rd Century B.C.: Origins and Development of Gladiatorial Combat

The origin of gladiatorial combat in ancient Rome dates back to 264 B.C. The exact origin of the tradition of munera is disputed. Nicolaus of Damascus, a Roman scholar from the 1st century B.C., believes the origin of gladiatorial munera to be of Etruscan descent. This was later supported by translations of terminology associated with the sport (lanista, the manager of the gladiator, and Charon, someone who accompanied the dead of the coliseum) as being of Etruscan descent, and the idea that the games were of foreign origin, leading to the wide held belief of the gladiatorial combat to be derived from the Etruscans. However, Livy, another Roman scholar, believed that the gladiatorial games were influenced by Campanian fights following the war in Samnium, where immediately following the war, combat was held between Roman and Campanian men. This battle following victory over the Samnium is what created one of the first gladiator categorizations, known as a Samnite.

In Figure 1, a Samnite is depicted, with a curved, square shield and a gladius. This was the standard gladiator armor early into the evolution of munera, which left most of the body unarmored.

Figure 1: A Samnite gladiator.

The first recorded gladiator fight in 264 B.C. was held by Demicius Junius Brutus, to honor his father, who had died (Futrell 6). A similar munera was held in 216 B.C., in honor of Marcus Aemilius Lepidus, a consul (elevated political official) and augur (priest, interpreting the will of the gods), which spanned over three days and incorporated 22 pairs of gladiators. Another munus of note in 206 B.C. was that of Scipio Africanus, whose father and uncle were killed in the Punic Wars. These early fights demonstrated the initial definition of the games, which was to honor a fallen relative or aristocratic figure, one especially important in political and religious affairs.

The munus hosted by Scipio was also held on the same year in which he settled the Iberian front during the Second Punic War for Rome. This also suggests that the munera were shifting to celebratory purposes, to commemorate military gain.

Something of note with the munus of Scipio Africanus' relatives is that the combatants in the munus had volunteered themselves, both non-Romans and Romans. Examples of volunteers ranged from members of tribes to showcase courage, to members of the Corbis and Orsua families competing for the post of chief of the city of Ibes (Futrell 9). From this, we can see that people were beginning to use the munus less as an offering, but more as a proving ground or place of potential gain. It is with this battle that we see the original context of the munera shifting to a more profitable act. It is this "literalization of the fight for public office" that Livy finds "reprehensible" (Drutell 9).

Initially, the munus was a sacrificial offering to those who had perished, as an omen of respect and admiration, often coordinated by the person's offspring, as seen in the two munera above. However, as time progressed, the usage of the munera drifted further from homage and closer to a form of entertainment. This was potentially caused by munera being privately funded, which allowed sponsors to reap the benefits of a munus and further an individual's political agenda.

2.3 2nd and 1st Century B.C.: Growth of Gladiatorial Munera

It was in the early second century B.C. and on into the first century B.C. that gladiatorial munera became less and less religious in context. By this point, gladiator combat had become a common spectator sport. As a true spectacle of the Roman Empire, the conditions and training available increased, and allowed varying members of society to participate in munera. This also signified the evolution of the munera into a marketable affair in order to gain status and power within the Republic.

The size of the amphitheaters, for example, was indications of the popularity and rise in influence that gladiatorial games held. By 80 A.D., there were almost 100 games per day held in the Coliseum (Hopkins, pp. 6). The Coliseum was capable of seating 50,000 people, and was easily the largest architectural building of the time period, which further drew in more participants and spectators. This large display also fueled the Roman tradition of public killings, giving the opportunity to kill supposedly unfavorable people in a manner that benefited economically and politically.

The three types of people who generally became gladiators were slaves, condemned criminals, and prisoners of war. Prisoners of war were more than likely the first participants, as Roman victories would lead to more potential combatants. In essence, gladiatorial combat served as a warning to those who threatened to oppose Rome and its rule. One such example is proconsul Manius Aquilius, who in 100 B.C. threw Sicilian slave prisoners of war against animals, in a method of execution that would show the extremity of Roman punishment (Futrell 121). The same was done in 43 A.D., with Claudius' conquest of Britannia leading to many British captives fighting in the gladiatorial ring (Futrell 122).

Condemned criminals within the Roman Empire are another example of punishment used to provide spectacle to crowds. Such criminals who proved to be of "such strength or skill that they can fittingly be displayed to the people of Rome" were often moved to a *ludus*, or gladiator school. This was the lesser of punishments, when being compared to sentencing to the arena or beasts, and also provided a source of entertainment for the people.

Slaves were generally associated with the other categorizations of gladiator due to status as a gladiator removing most, if not all rights from the individual. However, the designation of a slave gladiator usually lies with the person being of slave origin, and subsequently being sold into a ludus. One of the most important slave gladiators was Spartacus, a man who gathered 60,000 to as many as 120,000 men, ranging from freed men to escaped gladiators, according to varying accounts, (Futrell 127-128) and was a rival to the Roman Empire itself. The war stretched on from 73 to 71 B.C., in which the slave army eventually fell. The Third Servile War is a prime example of the discontent with the gladiatorial system within Rome.

In 105 B.C., state sponsored gladiatorial combat made its rise, with state sponsored ludi training people to become gladiators. Following the slave revolts, state control increased, with the introduction of lanista (manager) who would be able to sell and hire gladiators to fight under him. This was meant as a form of discipline to gladiators, such that an uprising akin to Spartacus and his revolt would not occur again.

As the popularity of the arena grew, so did the methods of praising victors. Pompeii, prior to the eruption of Mt. Vesuvius, was littered with graffiti, denoting gladiators of favor, and sayings like decus puellarum and suspirium puellarum, which translate to " delight" and "sighed-for joy of girls" (Cartwright, par. 8). Looking at these phrases we can infer the popularity of the

fights, as well as the similarities of the combatants to celebrities or popular figures of more recent times. It reinforces the inherent positivity towards the fights, and almost idolizes the fighters, though their treatment as gladiators in the ring and outside of combat would point otherwise.

Julius Caesar held two large munera in the early 1st century B.C. The first of these, in 65 B.C., was in commemoration of his father, who had died 20 years prior. The scale of the exercises was immense, with 320 pairs of gladiators in silvered armor. The Senate had forced a limitation on the number of gladiators available in Rome; Caesar had desired even more. The second occurred in 46 B.C., following victories over Gaul and Egypt. It was held at the tomb of his daughter who had died in childbirth eight years prior. The length of time between these spectacles and the deaths of their honored implies that the relatives acted more as an excuse for, rather than the purpose of, the munera.

One such gladiator was even an emperor. Emperor Commodus, who ruled from 108 to 192 A.D., had dueled in the arena himself. However, evidence shows many of Commodus' battles to be in very one-sided positions, or to protect the emperor by pitting him against animals and equipping him with bow and arrow (Cartwright, par. 10). Commodus was not truly participating in the sport, but rather showing off his skill in a way to gain favor, as well as to profit from the fights without any real risk due to the salary that he pulled from the Coliseum.

2.4 1st to 5th Century A.D.: Fall of Gladiatorial Combat

Resistance to the munera could be found as early as 65 and 63 B.C., in which anti-corruption laws were attempted, but ultimately curbed by Caesar, who was a very large advocate and proprietor of the games. The Spartacus Rebellions were also a major deterrent of the gladiator fights, though not halting the fights altogether.

It wasn't until the 4th century A.D., that Emperor Constantine the Great would convert the Roman Empire to a Christian nation. In the process of this transition, gladiatorial munera and ludi were seen to be not representative of the desires of Christianity. One of the first steps to the decline of gladiators was in 315 A.D., with a ban on child snatching in the arena, and further down, banning the gladiator munera in 325 A.D. However, this did not immediately affect the *muneara*, as a munus held by government in the 330s would break its own law. This did nothing as well to ban fights held during festivals.

This was handled by Valentinian I, who established a ban on the actual ludi, which curbed the official teaching of gladiatorial combatants. However, one of the crucial points that caused an effective end to the fights was in 404 A.D., when a monk looking to protest and separate fighters at a local munus was stoned to death by the crowd. The emperor at the time, Honorious, completely abolished the fights (Cartwright, par. 11).

3. Gladiators

The stereotypical Gladiator, as portrayed by Hollywood, has leather armor, occasionally, a brass helmet, and a short sword. This is demonstrated in Figure 2.

Figure 2: Russell Crowe in "Gladiator".

Initially, an actual gladiator had much less protection, and was armed with a dagger, rather than a sword. As the combat gained popularity, gladiators armed themselves more heavily, extending from a scutum, shield, to a hasta, lance. They also gained more armor; however, different types of gladiators had differing amounts of armor. This primarily depended upon the gladiator's individual popularity.

Of the dozens of different varieties of gladiators, some of the most familiar are the Andabatae, Catervarii, Equites, Essedarii, Hoplomachi, Laqueatores, Meridiani, Mirmillones, Ordinarii, Provocatores, Retiarii, Samnites, Secutores, and Thraces.

3.1 Types of Gladiators

3.1.1 Andabatae Gladiators

The Andabatae gladiator was restricted in his sight by means of his helmet. He was armed either with a gladius, fighting on foot and attacking blindly, or with a spear if he fought on the back of a horse. Andabatae wore body armor, but had an uncovered chest. Because they were fighting without being able to see, the Andabatae were typically used for comic relief of the audience (Famous Wonders).

Figure 3: Andabatae gladiator.

3.1.2. Catervarii Gladiators

Catervarii gladiators fought in a unique way. Not because of their weapons or armor, but rather because of their opponent. Rather than fighting one on one, the Catervarii fought in groups of several gladiators.

Figure 4: Catevarii gladiator groups.

3.1.3. Equites Gladiators

Figure 5: Equites gladiators on horseback.

Equites, as their name suggests, fought on horseback, rather than on their feet. However, if one gladiator were to fall off of his horse, his opponent would also fight on the ground, so that there would not be an advantage to either gladiator. The Equites had a large variety of weapons to choose when fighting. They could use a lance, called a hasta; a light spear, called a verutum, which could be thrown, as well as a gladius or spatha, a long, straight, double-edged sword. The Equites were also the first scheduled fight on days of gladiatorial games.

3.1.4. Essedarii Gladiators

Figure 6: An Essedarius gladiator.

Essedarii are similar to the Equites. These gladiators fought, not on a horse, but in a chariot. These chariots had only the gladiator and the driver in them.

3.1.5. Hoplomachi Gladiators

Figure 7: Hoplomachus gladiator.

Hoplomachi were the strongest and most armored type of gladiator. They fought with a gladius, but also carried a hasta, allowing the gladiator to have both a short range and longer range weapon. The armor included a helmet with a visor and a manicae, or arm guard, made from leather, as well as metal greaves on both legs. Because of the amount of armor worn by the Hoplomachi, they fought slowly and with gladiators that wore a similar amount of armor.

3.1.6. Laqueatores Gladiators

Figure 8: Laqueator gladiator.

The Laqueatores gladiators used a noose to capture their opponents, which was followed by an attack from their weapon.

3.1.7. Meridiani Gladiators

Meridiani gladiators fought in the middle of the day, after combats with wild beasts. These gladiators were very lightly armed. The name Meridiani directly translates from the adjective meridianus, meaning midday.

3.1.8. Mirmillones Gladiators

The Mirmillones were called so because they had the image of a fish on their helmets. Armed like the soldiers of Gaul, modern-day France, they typically fought against the Retiarii or Thraces as opponents.

Figure 9: Mirmillon gladiator.

3.1.9. Ordinarii Gladiators

Ordinarii gladiators fought in no special way, or under any notable circumstances, hence why their name is translated to ordinary.

3.1.10. Provocatores Gladiators

The Provocatores gladiators wore a simple helmet and basic armor. They were only armed with a regular-sized shield and a short sword, and fought only against other Provocatores.

Figure 10: Provocator gladiator.

3.1.11. Retiarii Gladiators

Retiarii gladiators were likely the least armored of the gladiators, wearing just a short tunic. This disadvantage in armor was compensated for by his weaponry. He was armed with a three-pointed lance, called a tridens or fuscina, and a net, or a rete. The Retiarii would attempt to entangle his opponent,

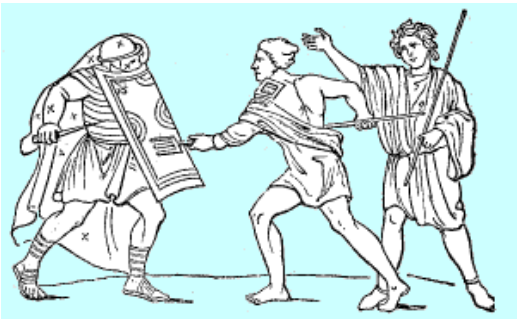

Figure 11: Retiarius gladiator facing a secutor.

typically a secutor or mirmillo, in his net by throwing it over his head. If he succeeded, the Retiarii would proceed to attack with his tridens. However, if the net missed, he was forced to run from his opponent and get his net back before his was killed. An example of this type of gladiator is demonstrated in Figure 11.

3.1.12. Samnite Gladiators

Samnites were one of the many gladiators named for an enemy of the Roman Republic. The distinguishing mark of the Samnites was their oblong scutum, or shield.

3.1.13. Secutores Gladiators

The Secutores gladiator is thought to have received his name from his combat with the Retiarii. When the Retiarius failed to secure the Secutor in his net, the Secutor pursued his opponent. The Secutores were favored by C. Julius Caesar. A letter from the great orator Cicero to Caesar reports that Caesar had at least five hundred Secutores at Capua! However, there is debate as to if the word should be read secutorum or scutorum. This change would shift the meaning of the phrase from having five hundred of this type of gladiator, to having five hundred shields.

Figure 12: Secutor gladiator.

3.1.14. Thraces Gladiators

Figure 13: Thraces gladiator.

Thraces gladiators were armed like the Thracians, another enemy of the republic, with a dagger, or a short sword, and a round shield. They typically fought against Mirmillones.

3.2 Gladiatorial Weapons

3.2.1 Hasta

The hasta was a long lance used by several of the gladiators. It was typically around 6.5 feet, or 2 meters, long with an iron head and a wooden shaft. Rather than being thrown, as it was within the Roman military, gladiators preferred to thrust with their hasta, keeping the opponent at a distance.

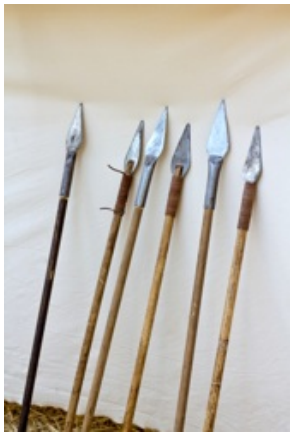

Figure 14: Several hasta.

3.2.2 Verutum

Similar to the hasta, the verutum was a spear used by gladiators. However, it was only about half the length of the hasta, only a little over a meter in length. It was not as substantial as the hasta. Therefore, the verutum was used more as a side weapon or for small skirmishes, as opposed to brawling with other gladiators.

Figure 15: Several veruta.

3.2.3 Tridens/Fuscina

Another variety of lances used by gladiators was the tridens or fuscina. As the name suggests, the tridens had three points, rather than the one that the hasta and verutum had. It was used by the Retiarii gladiators in addition to their net.

Figure 16: Retiarius gladiator with a tridens and rete.

3.2.4 Rete/Iaculum

Other than the tridens, the Retiarii gladiators used the rete or iaculum in combat. This weighted casting net was used to capture their opponents and make them unable to attack for a short while. During the time that the opponent was caught by the rete, the Retiarii would use his tridens to stab his opponent.

3.2.5 Scutum

The scutum was a shield used by gladiators as both a defensive and offensive tool. The scutum was a large rectangular shield with a curved front. A picture of this type of shield is shown in Figure 17. This massive shield was made of wood and reinforced with leather, eventually scuta even had their sides reinforced by metal. Its size allowed for it to cover most of

Figure 17: Scutum (front and inside).

the gladiator's body. As an offensive weapon, the scutum was used to shove the opponent back in an effort to gain distance between the two fighters, or even to stun the opponent for a second with the blunt force of a shield hit.

3.2.6 Spatha

The spatha is one of the many varieties of swords used by Roman soldiers and gladiators. It is significantly longer than the gladius, around 75 cm, and was typically used by the Equites and other mounted gladiators.

Figure 18: Spatha.

3.2.7 Gladius

The gladius is arguably the most iconic weapon of ancient Rome, as it was used by the Roman legionaries and gladiators. The gladiators were even named after this iconic sword! In general, gladii were around 27 inches long, with a blade between 20 and 24 inches. Because of this, the gladius was able to be wielded by on hand, leaving the other hand free for either another weapon, such as a hasta or verutum, or a scutum for defense. The gladius had a triangular tip, allowing the sword to be easily thrusted into an opponent. It also was able to cut and slash very well, primarily due to its concavity in the blade. Because the blade curved inward slightly, the gladius gained momentum as it sliced downward.

The appearance of the Gladius was different between gladiators of varying popularity. A criminal fighting for his life and freedom would have a simple sword, whereas a trained gladiator who is treasured by the people might have a more elegant and elaborate sword. The hilt of the Gladius occasionally had ridges for the fingers, but more often than not, it was left plain. The blade was generally left plain; however, it was not uncommon for criminal gladiators to have the phrase "Ave Caesar, mortituri te salutamus," which means "Hail Caesar, we who are about to die salute you" engraved on the blade of their Gladius in order to remind them of their impending demise. Scabbards for the Gladius were generally made of wood and covered in leather and decorated with brass.

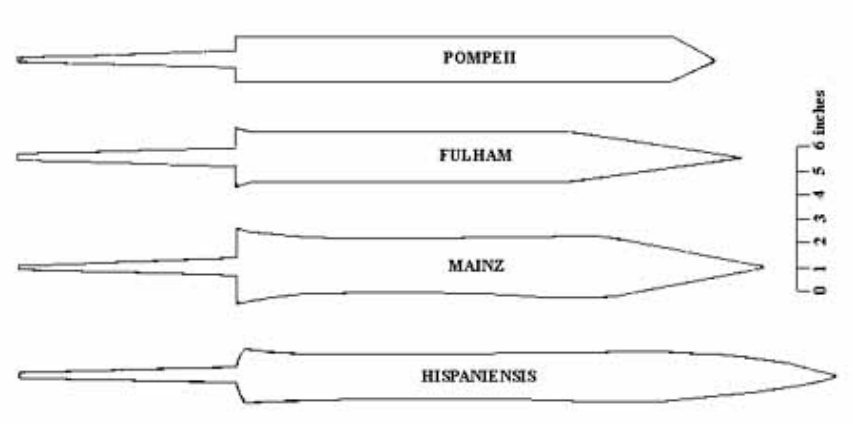

Figure 19: Various Gladius blades.

Though typically differentiated into two categories, Mainz and Pompeii Gladii, there are four main variations of the Gladius: the Hispaniensis gladius, the Mainz Gladius, the Fulham Gladius, and the Pompeii Gladius. Figure 19 shows the main differences in the blade design of these four Gladii. The Hispaniensis gladius was the original sword that the Romans liked. This Spanish version was the heaviest and longest of Roman Gladii. Additionally, it had the most prominent leaf shape in the blade. In addition, this version had the longest tip of the main varieties of Gladii. The Mainz Gladius is similar to the Hispaniensis Gladius in its prominence of the concavity in the blade; however this first revision of the Spanish version made the sword both wider and shorter. The next evolution turned the blade into the Fulham Gladius. This

version had a completely straight blade, a change from the previous two versions that had concave blades. This blade also had a long triangular tip, which became the signature aspect of this version of the Gladius, and was narrower than the Mainz Gladius. The Pompeii Gladius was very comparable to the Fulham Gladius, as it has parallel cutting edges and the triangular tip; however this version did not have nearly as prominent of a triangular tip at the end of the blade. The Pompeii Gladius was also the shortest of the Gladii.

4. Construction of Gladius

4.1 Background Process

In our recreation of a Gladius, we tried to use methods as close to authentic as possible. Before the introduction of the blast furnace after the year 1000, iron was smelted using bloomeries. To smelt iron in a bloomery, iron ore was placed atop heated charcoal. As the ore heated up, the iron particles inside would fall below the charcoal to the bottom of the furnace. These particles were joined by slag, the unwanted material. These masses of iron and slag make up blooms, for which bloomeries are named. Since these blooms contain both wanted and unwanted material, there had to be a way to separate them. Heating and hammering the blooms removed the slag, leaving the desired iron behind. This is where the term “wrought iron” comes from, since the iron mass has to be wrought from the combined mass of the slag.

To produce steel, the wrought iron would be placed back into the furnace amongst more charcoal. Heating the iron causes it to absorb the carbon in the charcoal, in a process called doping, and become steel. The additional carbon in the steel makes it harder than iron alone. By controlling the distribution of carbon and charcoal in the bloomery, smiths could control the consistency of the metal. While the metal was heated, it would become pliable. It is at this time that the metal would be hammered into the desired shape, in this case that of a sword. When the metal was sufficiently carburized and shaped, it was then quenched. Quenching the metal in water made the outside even harder. Throughout the entire process of working within the furnace, care had to be taken to prevent the metal from decarburizing. This could be easily caused by too much exposure to the air feeding the fire. Decarburized metal lacks the hardness

required for a sword. Although inconvenient, decarburization is conveniently rectified by exposing the metal to more charcoal, and thus more carbon.

The methods we use mirror these pretty well, but we skip forward to where the steel already contains a particular carbon-content in a convenient shape. As Roman blacksmiths would have done, we too are using a charcoal fed furnace to heat our metal. We are also hammering our steel into shape by hand, instead of using more modern tools.

4.2 Materials

Before the actual construction, the various materials required to form the blade had to be purchased. For the Gladius, the material used to form the blade was steel. This was generally a mix of high carbon steel in the center of the blade, with lower carbon steel along the edges. For our blade construction, we used a 4-foot bar of 1075 carbon steel, which had a carbon percentage of around 0.75 wt%. This is a medium-high carbon steel. A range of 1045 to 1095 carbon steel was recommended by Joshua Swalec, as it provided the strength of medium carbon steel and was a good approximation to the types of steel available to blacksmiths within the Roman Empire during the time period. This particular steel was also chosen due to its availability. The 1045 steel was much more readily available from multiple retailers, such as McMaster-Carr and Online Metals, while values above this were only available in sheets. However, the steel was not available in the proper dimensions required for our sword, therefore we decided to purchase the 1075 carbon steel. Other retailers also required the purchase of multiple tons of steel, which was far more than was required for this project. Figure 20 shows the CAD model of our reproduced Gladius.

Figure 20: Gladius CAD model.

4.3 Construction

In the initial reconstruction process, the metal was cut to 24 inches in length, and given an initial tip by heating one end of the steel and cutting the steel with a straight peen hammer. After the edge and tip were created, the basic form of the blade was created using a sledgehammer. After a portion of the steel was heated, one person would hold the section of the steel over the center of the anvil, and the other person would strike the steel while it was still hot enough to change its shape. This would cause the steel to expand outward, and give it the general shape of the Pompeii Gladius. This was done down the length of the blade for around 20 inches. After the initial shape was created, a smaller hammer was used to smooth out the blade and get rid of any major deformations caused by the sledgehammer process. This was also done in an attempt to create the bevel down the center of the blade; however most of the bevel creation would be done through the grinding process. A comparison of the initial metal bar prior to hammering, and the blade following forming can be seen in Figure 21. There is also a comparison shot between the worked blade and the surface-finished blade, which can be seen in Figure 22.

Figure 21: Initial bar vs. shaped Gladius.

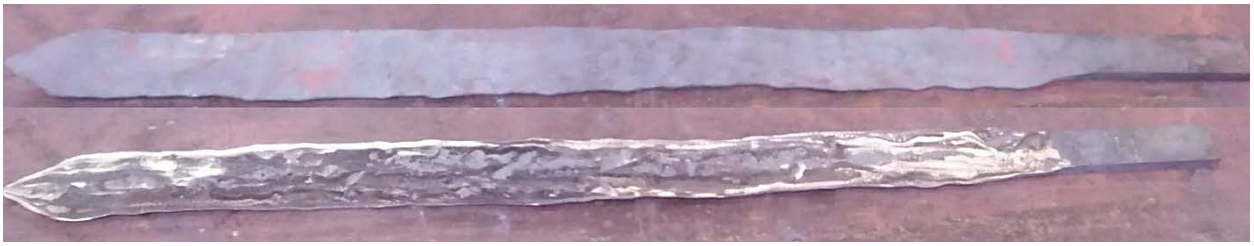

Figure 22: Comparison of worked (top) vs. surface-finished (bottom) blade.

The blade was then heat treated to give it increased hardness. The blade was set in the forge on a specialized tuyere to distribute the heat along the length of the blade. Normally, the tuyere would push air into a single point, but this specialized version pushed air to three locations simultaneously. Our blade was still longer than the new tuyere, so we had to shift the blade's position as it was heating to achieve an even distribution along the blade. When the blade was heated to a cherry-red color, it was then quenched. This took several attempts to achieve the desired results of a mostly uniform speckled pattern. Fortunately, setting the blade back inside the forge reset the treatment, so we could take as many tries as we needed. In its quenched state, the metal was hard but susceptible to cracking. It would require another application of heat to fix this.

Before the blade would be heated again, it was grinded down to give the blade a much lighter surface color. We would need a silvery surface instead of the black and speckled we currently had. To accomplish this, we took a grinding wheel to the blade by hand. We would return to grinding later to address the imperfections from shaping and the bevel. The grinded blade surface can be seen in Figure 23.

Figure 23: Ground blade surface.

The next step in its heat treatment was to heat the blade with an oxygen and acetylene torch. This was a departure from the historical process, but we could not afford to damage the blade at this time. The blade was heated by the oxygen and acetylene torch until the blade turned blue from the exposure. Seeing this color change is why we needed the blade to be grinded down first, else we would not have seen it as readily. This additional application of heat countered the

brittle nature of the metal, making it bend instead of break. The heat-treated blade can be seen in Figure 24.

Figure 24: Heat-treated blade.

After the blade was successfully heat treated, it had to be grinded down again. This purpose of this second round of grinding was to remove imperfections from the shaping process and create the bevel. We returned to the hand-held grinding wheel for this task, and we did our best to accomplish both of these tasks, primarily focusing on removing the imperfections. Some of these imperfections were in the center however, so the bevel had to suffer as a result. With the grinding concluded, the blade was finished. The completed blade can be seen in Figure 25.

Figure 25: Finished Gladius blade.

All that remained was the hilt. We decided to use a wooden hilt for its availability and simplicity. We were able to find wood in an appropriate shape and size for the grip and a small pommel. The guard had to be cut from a separate piece. With the hilt decided, we cut the back end of the blade to be ⅜ inches wide.

The hand-held grinder was used again here with a cutting wheel instead of a grinding wheel. With the back of the blade adjusted to fit the hilt, an incision was made in the wood to match. The hilt blade was then inserted into the hilt and glued into position. This method would not produce a connection built to withstand prolonged use of the weapon, but ours is a display model. Figure 26 showcases the tang created for the blade grip and the guard to be used for the sword. The finished blade can be seen in Figure 27.

Figure 26: Sword tang and guard.

Figure 27: Finished Gladius (dimensions are in inches).

5. Metallographic Analysis

5.1 Preparation of the Metallographic Samples

After our blade was completed, six samples were created. Each pair of samples reflected a different stage in the process of the blade construction: prior to working the metal (cold rolled and annealed), after forming the shape of the blade, and after heat-treating and tempering the blade. One of the samples in each pair looked at the microstructure normal to the length of the blade, and the other sample looked at the structure along the length of the blade.

The first step in preparing the samples for examination was to cut the samples to the appropriate size. A fine saw was used to cut the specimens down to an appropriate size. After the samples were cut down to an appropriate size, they then needed to be mounted. The two major methods of mounting are clamp mounting, compression mounting and cold mounting. Clamp mounting is a process reserved for thin sheets of metal or material when viewing their cross-sections. Cold mounting is the process of creating a cast around the part. This form of mounting requires little heat, generally only reaching peaks of 82 to 100°F, and is a fast method for preparing multiple samples. Compression mounting, the method that was selected for our specimens, is using compression to form a mold around the specimen, only exposing the face that is to be inspected. This was done using an automatic mounting machine. Each specimen was placed on the mounting platform, with the face that we wished to inspect facedown. An epoxy disk was then placed on top of the specimen before being lowered into the machine.
When the mounting machine is started, the specimen and epoxy are heated up to approximately 300°F. The mold was also compressed from the top. As the mold was heated up, the compression from above caused the mold to form around the specimen, leaving the bottom surface, which we

want to observe, open and unobscured. An example of one of our mounted specimens can be seen in Figure 28.

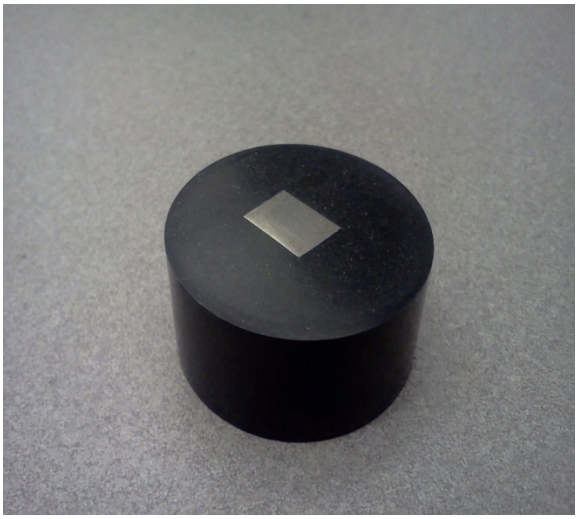

Figure 28: Carbon steel specimen mounted in epoxy.

After each of the pieces was mounted, the metal was grinded down to a flat surface. These were done using table-top specimen grinders. The process for grinding the metal was to start off using a very low grit value. The rough surface of the low grit would remove any deep imperfections in the surface of the specimen. Then moving further down the line, the grit was increased in increments of 200-300 grit. The initial grit value used was 180, followed by 320, then 600. With each progressive grinding of the surface, fewer and fewer imperfections in the surface remained besides the grain in the surface left by the rotation of the grinding wheel. This particular section proved to be the most time consuming process of the sample preparation, as pressure being applied to the samples had to be evenly distributed, and the rotation of the part while grinding had to stay consistent as the grit decreased, else the etchant will not be able to completely cover the surface. An example of the grinding process can be seen in Figure 29.

Figure 29: Sample grinding.

Following grinding came polishing, which was a very similar process. The wheels used for the polishing process were 1 micrometer and 0.3 micrometers, and were very cloth like. It involved holding the sample against the polishing wheel in two-minute increments. As the piece became more polished, the defects in the surface decreased, and the surface was more reflective. The final polished surfaces were mirror-like.

The final step in sample analysis was etching the surface of the specimen. This involved using a nital solution (3% Nitric Acid and 97% ethanol). The specimen surface was submerged in the nital solution for approximately 5 to 7 seconds. The etching time varied between pieces. After the specimen was submerged in the etchant, the piece was washed with ethanol to wash off excess etchant. The etchant was allowed to dry on the surface before proceeding.

5.2 Microstructure Analysis

After the samples were properly polished and etched, we were able to examine the microstructure of the blade at various stages during the reconstruction. This analysis was done using the Fe-Fe_3C phase diagram, which is shown in Figure 30. This figure displays the types of alloys and the phases forming depending on carbon content and temperature.

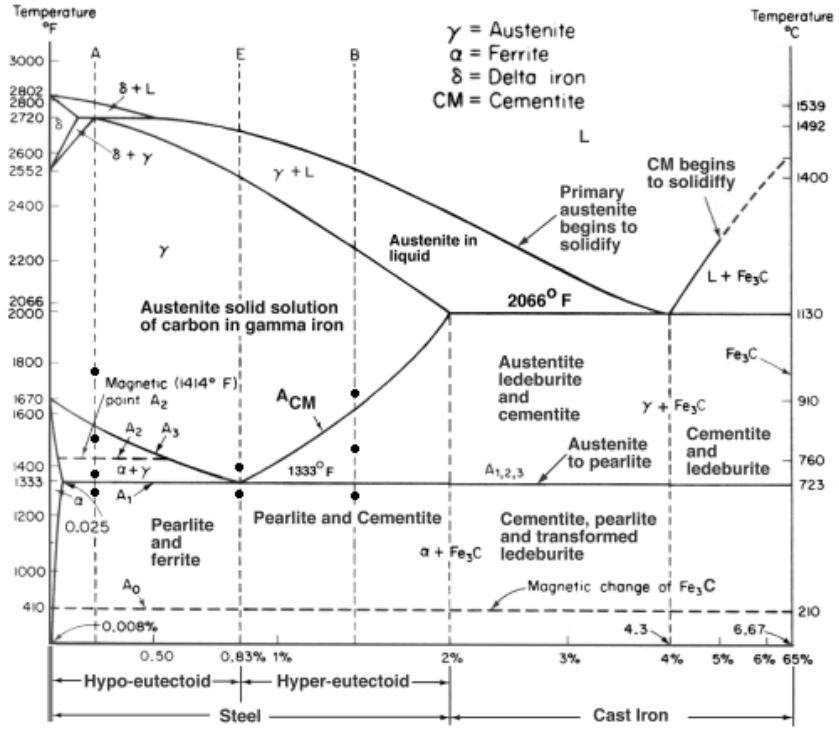

Figure 30: Fe-Fe_3C Phase Diagram.

The 1075 carbon steel is between 0.05 and 0.83 wt% carbon content, making the material hypo-eutectoid. During the construction of the blade, the metal reached the austenite phase briefly when heating the metal in the charcoal furnace, and formed other phases while cooling, including ferrite and pearlite.

The first sample to be examined was the unworked metal's structure (cold rolled and annealed). This microstructure can be seen in Figure 31.

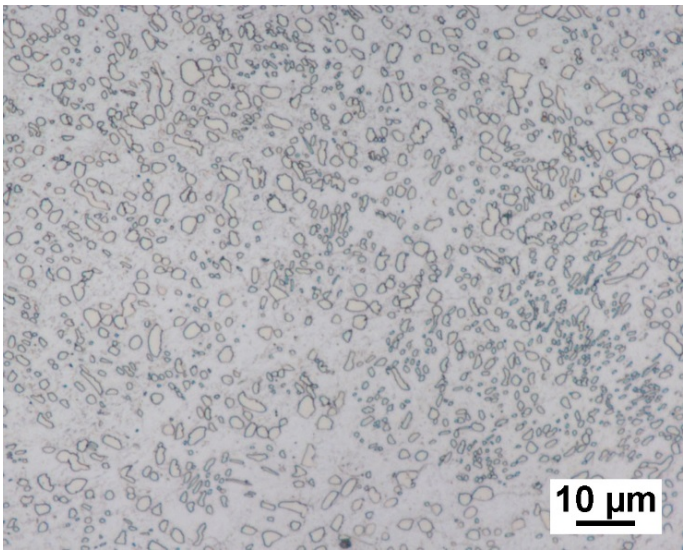

Figure 31: Microstructure of unworked AISI 1075 carbon steel (1000X).

In this microstructure, we can see the spherodized carbides, characterized by the round blobs, encased in a ferrite matrix, which is the white background phase. This microstructure is similar to some of the microstructures of similar carbon steels, such as the microstructure of the AISI 1074 carbon steel in Figure 191 of the ASM Metals Handbook, Volume 9. The ferrite matrix is relatively ductile and formable, and the carbides are brittle.

The second set of examined specimens was from the blade after hammering and forming, but before heat-treating and tempering. The microstructure of the worked metal can be seen in Figure 32.

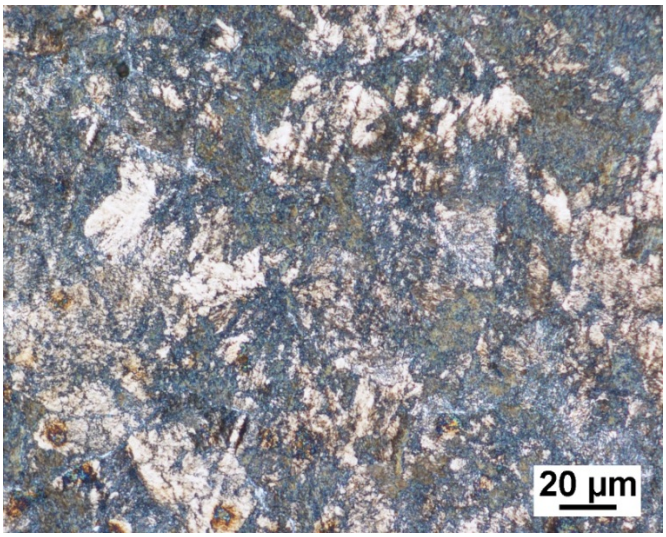

Figure 32: Microstructure of worked 1075 carbon steel (500X).

In this specimen, we know that the sample was repeatedly austenitized, hammered, and air-cooled. Therefore, the resulting microstructure contained pearlite (the darker phase with lamellar structure of ferrite and carbide) and ferrite that formed at the prior austenitic grain boundaries during cooling. The structures seen in Figure 32 are similar to those in Figures 182 and 187 in the ASM Handbook, Volume 9, which illustrate 1060 and 1065 carbon steel that was also austenitized and air-cooled. The only difference between our microstructures and the examples found in the handbook were the etchant used; our solution was nital while the book primarily used picral to reveal the samples' microstructures.

The pearlite is expected, as this is formed primarily through slow cooling from the austenitic phase. Our metal is close to the eutectoid composition which explains the predominance of the pearlitic structure with some ferrite (ASM, pg. 178). The presence of ferrite adds to the ductility of the material, which makes it less susceptible to break.

The final sample analyzed was from the blade following heat-treatment and tempering, and the microstructure can be seen in Figure 33.

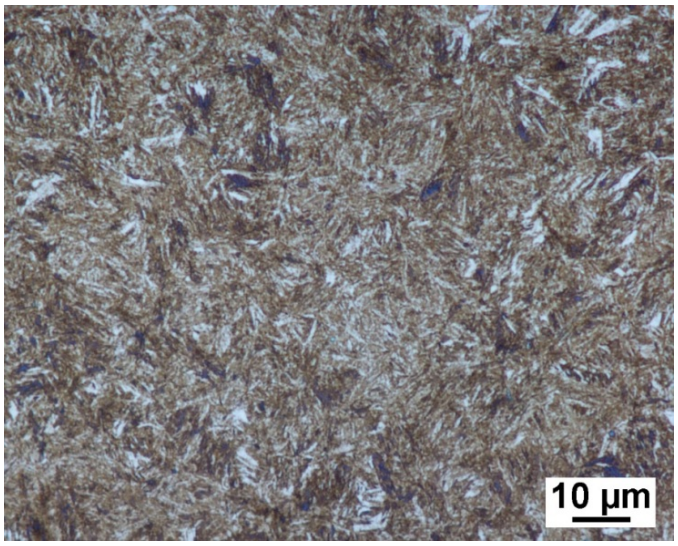

Figure 33: Microstructure of blade following heat-treatment and tempering (1000X).

The structure following the heat-treatment contains mostly martensite and some bainite phase. The forge generally reached a temperature of about 1300°F, and it took 5 to 10 seconds to completely quench the sample to room temperature. From this we estimated the cooling rate to be between 120 and 240°F/second or 49 to 150°C/second. As the cooling rate dictates the final microstructure of the material, for our cooling rate, the expected structure would be predominately martensitic with some bainitic phase. This can be seen from the cooling path of our alloy on the Time-Temperature Transformation (TTT) diagram shown in Figure 34. Subsequent tempering in the 700 to 900°F temperature range converted the martensitic structure to tempered martensite, which increases ductility of the material and reduces residual stresses. Our microstructure in Figure 33 is similar to those seen in Figures 141 through 144, showcasing tempered martensite in AISI 1050 steel (ASM, pg. 189).

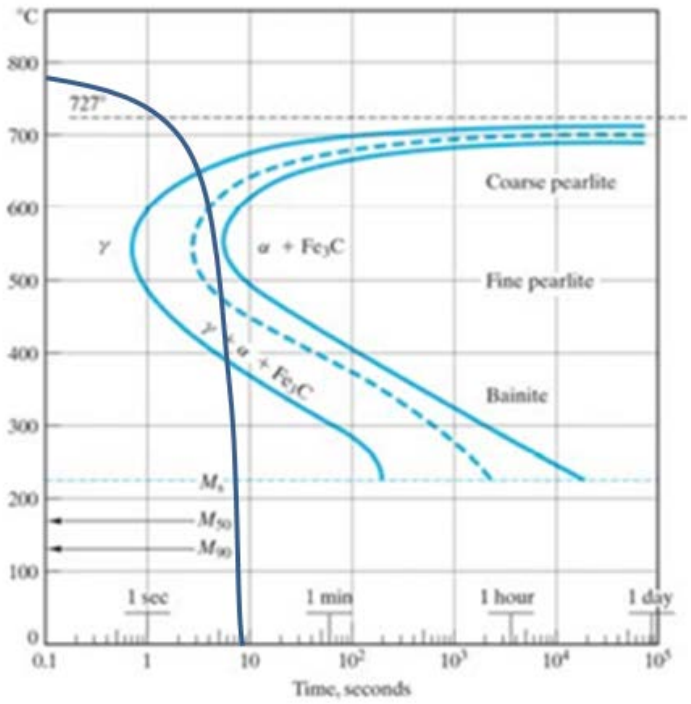

Figure 34: TTT diagram with predicted cooling rate.

From the analysis of the resulting microstructures of our metal at various stages, it was confirmed that all of the processing steps that the metal was subjected to, increased the strength, while also imparting ductility and increasing the sword's resistance to fracture.

6. Conclusions

Throughout this report, we have studied the history of Ancient Rome, as well as their obsession with the Gladiatorial Games. In considering the evolution of one particular gladiatorial weapon, the Gladius, we were able to determine that the gladiators were more adaptive as time progressed. Though all of their arms and armors changed as time evolved, the Gladius was an iconic weapon that was used in both the entertainment of the Roman populous and the expansion of the Empire through military conquest. This project's goal was to recreate the Roman Gladius through relatively traditional methods, such as metallurgy. Alongside the reconstruction, we attempted to learn more about the different metallurgical properties of their blades, such as the strength and ductility. Through the analysis of the microstructure of the blade at various points in its construction, we can confirm that the methods used in the Roman Empire strengthen the blade and guaranteed its spot as a versatile and ductile weapon. The Gladius will remain one of the most iconic swords of all time, having already secured its place in history.

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