# HISTORICAL EVOLUTION OF THE BOW: LONGBOW VS. CROSSBOW

An Interactive Qualifying Project Report

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## Abstract

The history of medieval ages was a very important and crucial time frame for Europe and specifically England. In this period the English army had improved and developed rapidly using new arms and armors. The history of the bow and arrow during the medieval period seemed very interesting to us. The medieval ages started around 1500 years ago in North Africa and southern Europe. The bow and arrow was introduced during the medieval ages, and then enhanced by the English and Welsh, who created the longbow. We focused on the evolution of the longbow and crossbow. These arms represent an important period in history. We will make a sample crossbow as an illustration of the weapon. The material properties and the techniques of making of the crossbow are also demonstrated in this report.

## Acknowledgements

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# 1. Introduction

This report explains all of the work, research and experiments that were done in this project. The project is part of the Historical Evolutions of Materials Arms and Armors, an Interactive Qualifying Project. The purpose of this project is to fully understand, experiment and examine the evolution of the longbow and crossbow that were used in medieval ages in Northern Europe. The report at first focuses on the history of this region. During the medieval period England was embroiled in conflict with several problems like continuous internal and external wars, succession problems, and disease. England never achieved true stability in this time period. After describing the history of the region, we will focus on the design, materials and manufacturing process of the crossbow and the longbow during the medieval time period. We will also discuss the cultural and technological development of northern country based on these weapons. Another goal of this IQP project is to make notes on the building and construction of a sample crossbow. These two weapons are compared to each other to figure out the difference in endurance, range, properties and power. We will also analyze the material properties of the sample crossbow. The final and last goal of this project is to update the online material on the Historical Evolution of Arms and Armors website that has been created and updated from the previous projects over the past years. The website will be updated in design and also data, by uploading the project materials on the website and creating a new design for this website.

This focus of this project is to attempt to answer the following questions about longbow and crossbow:

- What materials were originally used to make the crossbow?
- What materials were traditionally used to build the longbow?

- What are the properties of the material used?
- How did the creation of these weapons change the face of Northern Europe?
- What manufacturing processes and materials can we use to make replicas of these weapons?

Finally to make it easier for the reader to understand the construction and building process of the longbow and the crossbow, our team will demonstrate the working process step by step in photos.

# 2. Review of England History 600 AD-1485 AD

England's middle age can be divided into three different periods.

- The Early Middle Ages, 600 AD-1066 AD
- The High Middle Ages, 1066 AD-1272 AD
- The Late Middle Ages, 1272 AD-1485 AD

This chapter provides a review of each time period and the important events that took place within each time period. (Middle Ages Timeline)

## 2.1. The Early Middle Ages: Dark Ages

Under the Roman Empire England was part of Britannia and its fall led to England's release. During its time as part of the Roman Empire the English economy was spent in the creation of a large military founding and in support for the complex network of towns, roads and villas to further the control of the Roman Empire. During the last stages of the Roman Empires troops were withdrawn from Britain and without the Empire's support the English economy collapsed. (Medieval England)

During the beginning of the Dark Ages in England many Germanic immigrants began to arrive, initially as a peaceful settlement. This immigration caused the appearance of new political and social identities, such as the Anglian culture in the east of England and a Saxon culture in the south. By the beginning of the 7$^{th}$ century these small colonies from both cultures grew and began to declare themselves kings, and started to collect tribute for conquered lands. These self-declared kingdoms were called The Heptarchy. (Medieval England)

During the 7$^{th}$ century the kingdom of Mercia rose to power under the command of King Penda. For the rest of the 7$^{th}$ century Mercia had control over a large region of England. For the entire 8$^{th}$ century Mercia and the rest of the kingdoms fought for the control of the land. By the end of the century, Vikings attacks began to grow in number and scale until the 9$^{th}$ century when the Danish Great Army invaded England and defeated the larger kingdoms of East Anglia, Mercia and North Umbria. (Medieval England)

In the middle of the 9$^{th}$ century Alfred of Wessex regained control by achieving a series of victories against the Danes. By retaking the permanent control of York from the Danes he cemented Wessex as the rulers of the Angelcynn, the Germanic peoples of England. By the end of the Early Middle Age, amidst problems such as no royal heirs and another Danish invasionn the Godwin family claimed the throne of England. (Medieval England)

### 2.2. The High Middle Ages

Seizing an opportunity created by the succession crisis, William the Duke of Normandy invaded England. He won at the battle of Hastings and gained control over the south of England. By bribing and coercing his Norman followers, he maintained control around the major English center of power and eliminated the former Anglo-Saxon elite. During William's campaign, several revolts took place that he routed before fighting into the northeast of England to establish Norman control in York.

The Norman lords used England as a strategic point to attack the south and north of Wales, expanding up the valleys to establish new territories. During William's rule, England formed the largest part of the Anglo-Norman empire, which was ruled by a network of Norman nobles with land holdings across England. The Norman noble's campaigns in the frontiers of Normandy caused England's wealth to reach a critically low state.

The Norman leadership was very unstable and caused another succession crisis, creating violent conflicts between the Norman's supporters. Under the revolts William II inherited the throne but faced several attempts to replace him with his older brother or cousin. When William II died his older brother claimed the throne but it was seized by his younger brother, Henry I.

Both brothers engaged in battle and the older brother Robert's defeat granted him a life in prison, but Robert's son, Clito, remained free to cause new revolts for the next years. In a stroke of bad luck, Henry's only son William died in the white ship disaster and his nephew claimed the throne. Henry's daughter Matilda caused civil war to break out between England and Normandy, resulting in a long period warfare later called the Anarchy. Matilda's son, Henry, agreed to a peace settlement and became king in 1154.

Henry, as the Count of Anjou, was the first Angevin of England as an important duchy of Aquitaine by marriage. Henry reestablished royal authority and reconstructed the royal finances by claiming power in Ireland and promoting an Anglo-Norman colonization for the country. Henry proved to be the ruler England needed, strengthening England's borders with Wales and Scotland, and frugally used the country's wealth during The Seven Years War against their arch-rival France.

Succession arrangements created a problem once again, caused by revolts led by Henry's children. In the end Scotland and Wales defeated Henry and his son Richard succeeded to the throne in 1189.

Due to his position in France and his service in the Third Crusade, Richard had to give the throne of England to his brother John. He was unsuitable for the throne, and in 1199 lost Normandy and a great part of Aquitaine to France. John's efforts to regain control of his position caused friction between the English barons. He tried to maintain peace by signing the Magna Carta. However, during the First and Second Barons' War, the king was captured.

John's son Edward defeated the rebels between 1265 and 1267 and restored his father to the throne. (Middle Ages Timeline)

## 2.3. The Late Middle Ages

Edward I became king and rebuilt the status of the monarchy, rebuilding and expanding key castles that were ruined. Edward mobilized a huge army against the princes of North Wales. He defeated the Welsh and began an English colonization and built castles across the region. Edward led several campaigns in Flanders, Aquitaine and Scotland, but he did not accomplish victory and the cost of the campaign created tensions that almost caused a civil war.

Edward II inherited the war with Scotland and encountered great opposition to his rule due to his royal preferences and military failures. The Despenser War in 1321-22 created instability and Edward was overthrown and possibly assassinated at the hands of his French wife Isabella and the rebel Baron Roger Mortimer. They ruled together for only a few years before being overthrown in a rebellion led by Edward III.

Edward III restored the royal power but during the 1340s the Black Death ravaged England. The dead caused by the epidemic and the plagues that followed it affected England for many years. Meanwhile Edward was under pressure from the French in Aquitaine who made a challenge for the throne. Over the next century the English force fought in many campaigns that became known as the Hundred Years' War. Many English elites, including Edward's son the Black Prince, were deeply involved in French campaigns and administrating the new continental territories.

Despite the rebellions that occurred due to the high taxes to pay for the war, Edward's military successes brought seized wealth to many parts of England and enabled considerable infrastructural work.

Richard II, Edward's grandson, confronted political and economic problems resulting from the Black Death, such as the Peasants' Revolt across the south of England in 1381. In the next decades, Richard and a group of nobles competed for power and control of France until Henry obtained the throne with parliamentary support in 1399.

He ruled as Henry IV enforcing political and religious conformity. His son Henry V restarted the war with France and came close to achieving victory before his death in 1422. Henry VI became king at only nine months of age, causing the political and military situation in France to fall.

Several bloody civil wars, later called the Wars of the Roses, happened in 1455 due to the economic crisis and poor perception of the government. Edward IV, leading a group known as the Yorkists, removed Henry from the power in 1461. By 1469, Edward, Henry and Edward's brother George fought for power. In 1471 Edward killed most of his rivals. The throne was passed to Edward's brother Richard upon his death, who ruled as Edward V referred to by the people as Richard III. Henry Tudor VII, aided by the French and Scottish troops, returned to England and defeated Edward in the battle of Bosworth in 1485, ending the majority of fighting, although rebellions against the Tudor dynasty continued for several years. (Middle Ages Timeline)

## 3. Soldiers of the Middle-Ages

Basic medieval infantry consisted mainly of pikemen or other foot soldiers using polearms. Their training was brief or nonexistent, with peasant soldiers often having no training or equipment besides their own belongings. In the later medieval period, soldiers were mainly freemen professionals with a higher standard of equipment.

Infantry were the mainstay of an army, battles being regularly decided by infantry charges and duels. Pike infantry also served an important role as a deterrent against cavalry charges, which could otherwise run down both infantry and archers.

Cavalry were not often used in open warfare in the middle ages due to being expensive to train. Due to upkeep costs of arms and horses, cavalry were usually noble-born knights, further limiting how often cavalry were used in battles.

In the early middle ages, a law was passed that required all peasants to keep a bow and arrows for self-defense. Boys over 15 were also required to practice archery every day. This training allowed England to field a large number of archers at battles.

### 3.1. Recruitment of Soldiers

In the early medieval feudal system, a man would be given a minor noble title, a knighthood, and some control over the surrounding lands. These knights would be responsible for obtaining a suit of armor; governing the surrounding lands; and, in the case of war, being able to mobilize both themselves and a certain number of soldiers.

Soldiers were peasants, often with no prior experience or equipment. Peasant soldiers would bring whatever weapons they had at hand, sometimes this was a bow or other hunting equipment, but usually it would be an axe or other household tool.

Mercenaries were also not unheard of. Mercenaries would be employed to shore up armies or skirmish with the enemy. Two of the more famous mercenary regiments of the period were Swiss pikemen and Genoese crossbowmen. In the mid to late Medieval period, the majority of troops were professional soldiers-for-hire, men with their own weapons, training and at least a helmet.

### 3.2. Training

Knights were expected to attend tournaments, take care of their own arms and horse, and train in combat daily. In the early medieval period most infantry had little training, being peasants made to go to war. But as the period went on, infantry became more well trained, both by the army; themselves; and in the late Medieval period, by independent groups of soldiers. Peasant boys older than 15 were required by law to practice archery every day. (1252 Assize of Arms) The Catholic Church even allowed the practice of archery on Sundays, an honor reserved only for activities deemed traditional. This law served both as a form of self-defense in a tumultuous period in history and allowed men to begin training in a military capacity early on. This early training was also useful because the longbow of the time period had such a high tensile strength that it needed years of practice to master. A boy, or man at the time, of 15 would set out to train to be a longbowman and not become a professional until he was 20.

The effects of this are highly visible. Far from modern interpretations of archers, these men had to be very strong to be able to use these bows, some with draw weights of over 200 pounds. The results of their training are visible on skeletal remains today. Skeletons found on the shipwreck of the *Mary Rose* were identifiable as archers by their enlarged arm bones and increased joint area. (MaryRose.org)

Longbowmen had impressive range and power, being able to knock a knight off a horse under half a mile away. Welsh and other continental longbowmen were required to be able to shoot ten arrows a minute accurately, but England's longbowmen were trained to accurately fire twenty arrows a minute, making them the elite soldiers of the period.

On the other hand, crossbowmen training was short, as they could be made from infantry soldiers in a week. They would train in speed and accuracy and end up being able to rival longbowmen, using the mechanical power advantage of the crossbow over the longbow. Crossbowmen were also cheaper to outfit. Crossbows were faster to produce than longbows, and the soldiers could be outfitted in leather rather than pikemen's metal armor.

### 3.3. Tactics

The main purpose of infantry was to mount a large-scale charge against the enemy. Infantry typically used pikes, poles as short as ten feet with a metal spearhead. Infantry lines would often have pike 'duels' on the battleground, and pike length became an arms race between armies to give their soldiers an upper hand. Infantry charges would also be made with lines of heavy shieldmen, who would crash into each other and attempt to attack around each other's shields. These shield lines would also be used to protect archers from arrow volleys.

Infantry would form up in lines or boxes of pikemen to counter heavy cavalry charges. Infantry wielding swords, clubs or shorter polearms would be interspersed throughout these formations to dismount and kill or capture cavalry riders.

In the early to mid-medieval periods, cavalry would be held back to fill holes in infantry lines, or placed on the sides of the formation to flank the enemy. Later on, knights and heavy cavalry would be used to mount a destructive opening charge on the enemy. Improvements in saddles and the invention of stirrups allowed cavalry better control and allowed lances to become longer even than infantry pikes; though the concentration of infantry pikemen could still take down a cavalry charge.

Archers were used to fire devastating opening volleys at the enemy. A successful archer volley could devastate an army's infantry and allow for a much faster victory. After the initial volley, archers would take shots at individual infantrymen or cavalry. The longbow could kill through both infantrymen's light armor and a knight's fullplate, and the archer could be accurate enough to hit across a battlefield. However, as the crossbow spread, it became easier to employ similar power in greater, and cheaper, force.

Mid and late medieval crossbowmen had greater power than longbowmen and were able to deploy in greater numbers. Soon after the Battle of Hastings, it became obvious that it was more strategically and economically viable to deploy a large number of crossbowmen than an elite force of longbows.

# 4. The Longbow

In ancient times every warrior was known to use a different type of weapon. Each warrior would be called upon for special tactics in war. In war, there are many things to take into account; tactics, power, strength, stamina, training, and size of the army. In ancient times everything had to be made by hand. Weapons were mostly made from wood before the use of metal in weaponry became widespread.

The longbow is a large type of bow, usually between four and six feet tall. The weapon is roughly as tall as the person who uses it, and in some cases taller. The height of the longbow allows the user a fairly long draw. (Baker, Tim) But what was the use of the longbow? What is the history behind it? And how was it made?

## 4.1. The History of the Longbow

At first the longbow was primarily used for hunting. The longbow was invented by the Celts from Wales. The first recorded longbow was used by the Welsh in 633 AD, where it was said that Offrid, the son of the king of Northumbria was killed by an arrow from a Welsh longbow. (Trueman, Chris) The battle was between the Mercians and the Welsh more than five centuries before the longbow was used in English military. However due to the English military's major use of the weapon in the Middle Ages, the weapon is usually called the English Longbow instead of the Welsh Longbow. The longbow was a very powerful weapon during the British civil wars, and the range and accuracy was very impressive. The longbow saw heavy use in the English army, who required the weapon to be taller than 5 feet. (Hickman)

The English Archers Law required every man between the age of 15 to 60 years old to train with bow and arrows. This law was established in 1252 to ensure all Englishmen would become an expert with bow and arrows. The King Edward Plantagenet III took this law further in 1363 by making it an obligatory archery practice.

The skill needed to use a longbow took considerable time to develop. The English invested in the longbow heavily, considering a single longbowman to be worth as much tactically as ten ordinary soldiers. The longbow was the most important invention of the 13$^{th}$ century for the English military and it instantly changed the political face of Europe.

The longbow was made from wood, preferably English yew, a notably elastic type of wood that grows naturally in England. The bow was cured for four years to harden the wood and protect it from the elements. The longbow had a powerful draw weight of more than 200 pounds and a range that was said to be as far as half a mile with enough force to knock a knight off of his horse.

**Figure 1: Longbow**

England gave special bodkin arrows to their archers. Bodkin arrows were three feet long with a wide tip that was designed to break through chain mail. Launched with the longbow's force, they had the ability to break through even the highest quality plate mail.

The longbow was the strongest bow in the medieval ages. This was due to its length, and the properties of yew wood. It took a long time for a soldier to be able to get the most out of this weapon, but England was able to use its strength to an amazing effect.

**Figure 2: The Battle of Crecy**

## 4.2. The Battle of Crecy

One of the battles where the longbow showed its greatness was the largest battle of the Hundred Years War, the Battle of Crecy. In this battle the French army outnumbered England nearly three to one, but half the English troops were longbowmen. The French did not believe that they could lose, but the English created a blockade and fired arrows at the French, killing one every 4 seconds. [Burne]

Even the knights were brought down by the powerful force of the longbow's draw. The longbow caused a number of important technological advancements, and was a major factor in the advancement of Europe throughout the middle ages.

## 4.3. Design of the Longbow

The design of the longbow is very simple. Because it can be made from a single piece of wood, it was possible for an amateur bowyer to make a longbow in less than twenty hours. However the skilled professional bowyer who produced medieval English longbows could make a longbow in just a few hours, before having to sit and cure.


**Figure 3: Different types of wood used to make a longbow**

Yew wood was a good choice for making longbows because of its high compressive strength, elasticity and lightweight. Now longbows can be made from two or more pieces of wood and gluing them together. This gives the longbow the advantage of the properties of different woods.

English longbows were made from several layers of wood, glued together and shaped into a final form. The sapwood of the English yew was used to make the outer layers because of its ability to endure a dramatic amount of tension. The heartwood was used for the core layer of the bow, which experienced a greater amount of compression. The only problem with making a yew longbow was that it was very difficult to find unblemished yew. The wood of other trees, such as mulberry, osage, bamboo or bacote, were unsuitable and were phased out entirely. For this reason yew trees were almost extinct in northern Europe by the late 16th century.

# 5. The Crossbow

The crossbow drove massive change in how military tactics worked in ancient times. This new type of ranged weapon meant that soldiers could be trained quickly with a deadly new weapon using mechanical power instead of that of the wielder. Early crossbows were built by attaching a composite bow, a bow made of several different materials like wood, horn and sinew, at the end of a wooden stock. Unlike normal bows, the string was pulled back with both hands and locked into place with a ratcheting system. A mechanical trigger was connected so that the string would release when the trigger was pulled. Traditionally the crossbow fired a bolt which was usually shorter than an arrow and lacked the feather fletching.

The crossbow has a long history of its use, and went through many improvements over time. At is prime during the Medieval Age Europe, it eclipsed almost all other bows, and stayed in use until gunpowder weapons came into widespread use.

## 5.1. History of the Crossbow

While most people immediately think of Medieval Europe when Crossbows are discussed, the device was actually invented hundreds of years earlier. The earliest evidence shows that the Chinese had crossbows developed more than 800 years before they become widespread in Medieval Europe. [Meng, Chinese Siege Warfare - ZhugeNu] Two hundred years after the Chinese, the Ancient Greeks also created a version of the crossbow. It is not certain whether the Greeks developed crossbows separately from the Chinese or drew inspirations from their designs. [Campbell, 3] Types of crossbows continued to develop throughout Roman times but its prime was likely not until Medieval times, where it eclipsed the English longbow.

### 5.1.1. China – 6th Century BC

The oldest evidence of crossbows is found in Ancient China during the Spring and Autumn Period (771 BC to 221 BC). They were likely invented sometime in the 6th Century BC, and came into widespread use in the area during the end of that period. (TripAdvisers) These early crossbows were designed to be handheld, whereas many other early crossbows were designed to be mounted on towers or walls. In this time period the crossbow bolts and triggers were primarily made of bronze. Evidence of these bronze triggered crossbows was found in a couple of tombs in Qufu, Shandong. (Selby) These crossbows predate Ancient Greek crossbows by a large margin. We are unsure if the Ancient Greeks drew inspiration from Chinese crossbow designs or if they simply developed their own designs separately. The Chinese continued to improve their crossbow designs, inventing the first repeating crossbow. This design allowed the user to load, and arm an arrow in a single motion.

**Figure 4: Chinese Repeating Crossbow**

In addition to hand-held crossbows such as the repeating crossbow, there were some stationary crossbows that were used for defense or siege. These included the Lian Nu crossbow, pictured in Figure 5, that shot multiple bolts with one pull of the trigger. (Meng, Chinese Siege Warfare - LianNu)

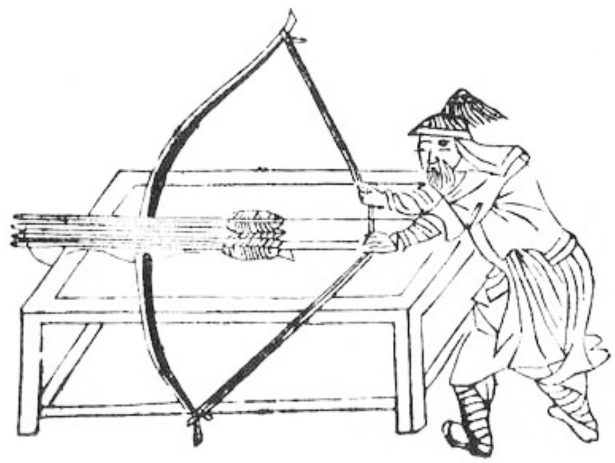

**Figure 5: Lian Nu Double Crossbow**

The earliest record of crossbows being in Chinese warfare was in the Battle of Maling in 341 BC. In this battle, the State of Qi ambushed the State of Wei with 10,000 archers, including soldiers wielding crossbows. Ambushed by the archers and attacked by Qi ground troops, the Wei lost all of their troops and their leader Pang Juan. This battle changed the course of the war, crippling the Wei.

While the Battle of Maling is the first recorded instance of Chinese crossbows in warfare, it is possible that they came into use even before then. (Webb) Bronze crossbow bolts were discovered in a burial site dating back as far as 6th century BC.

### 5.1.2. Ancient Greece and Roman Empire

Ancient Greece, while behind Ancient China, was still one of the first civilizations to use Crossbows. Some historians attribute some of the advances in Greek military technology to Dionysus I of Syracuse. In late 400s BC the Greeks developed the gastrephetes, or "belly-bow", and used them in the Siege of Motya. The gastrephetes was said to be invented by the Greek engineer Ctesibus during the 3rd century BC. (Corradi) The gastrephetes was pulled back by bracing it against the soldier's chest with one end, and pulling back on the crossbow string with both arms. This gave the gastrephetes twice the power of the normal composite bow that was pulled back with one arm.

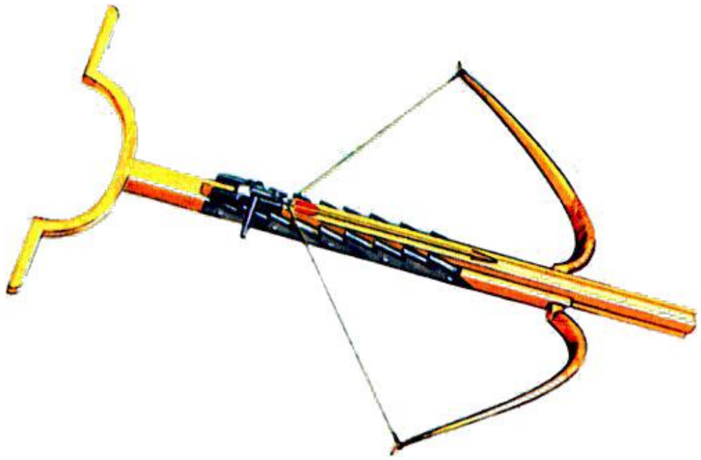

**Figure 6: Ancient Greece Gastrephetes**

The oxybeles, or “bolt shooter”, was created as a larger version of the gastrephetes, and was mechanically identical except for the fact it was much larger, and unable to be wielded on its own by foot soldiers. The oxybeles was developed as a siege weapon, but was soon after replaced with the ballista, a more powerful siege crossbow.

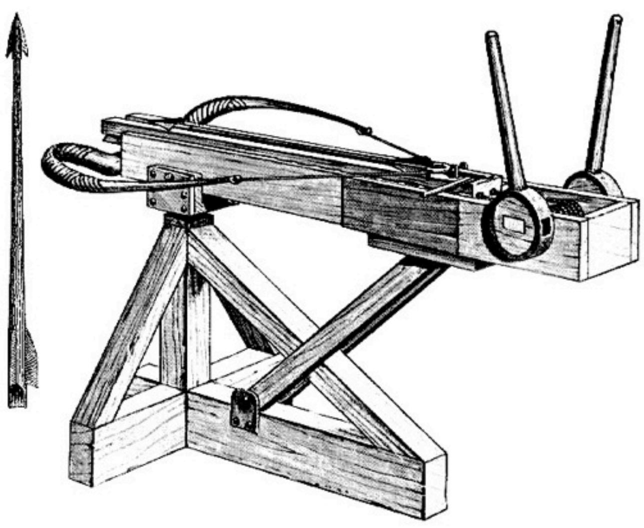

**Figure 7: Oxybeles Crossbow**

## 6. Comparison: Longbow vs. Crossbow

It is not very easy to compare longbow and crossbow together. There are many facts and points that each weapon has that make it difficult to decide which one is a better weapon. The crossbow had an important role in the late medieval period, it was the first hand-held weapon that could be used by an untrained soldier to kill or injure an enemy. The most powerful crossbow had a maximum range of 200 yards. On the other hand, Longbowmen were highly trained soldiers and could penetrate plate mail with the longbow, but were not as effective at long distances. It took a lot of time and spending to train a soldier to learn how to use the longbow, which meant that they could not be replaced easily.

The crossbow however, could be used by anyone, taking little practice to learn how to aim and handle the weapon. Crossbows were easier to aim than longbows and the Crossbowmen did not have to use a hand to hold the string back while aiming. This also gave Crossbowmen the ability to shoot immediately if surprised, as the crossbow could be loaded long before they needed to shoot. Crossbows required less upper body strength to operate than the longbow, but they could not shoot as frequently. Longbows could be used to shoot as much as five times more frequently than the crossbow.

Although it is impossible for any bow to be perfectly efficient, crossbows are particularly inefficient when compared to longbows. The reason for this is that the draw length of a crossbow is much shorter than that of a longbow. This means that even though the crossbow has more stored energy, the bolt does not have as much time to accelerate.

The table below was made from an experiment that was comparing a longbow and a crossbow that was spanned with a cranquin:

**Table 1: W.F. Paterson (1990) published data from Stephen V. Grancsay**

| Type of Weapon | Draw weight | Bolt weight | Speed of bolt | Difference |
|---|---|---|---|---|
| Longbow | 68 lbs. | 2.5 oz | 133.7 fps | Not much!! |
| Crossbow | 740 lbs | 1.25 oz. | 138.7 fps | Not much!! |

As you can see from the comparison table, there is not much difference between the crossbow and the longbow in speed. Taking the draw weight into account, it is noticed that the crossbow has a very great draw weight, but the bolt weight and the length of the draw cancel that large draw weight out. The problem of the crossbow could have been achieved with a longer draw length or lathe, but it would increase the weight of the crossbow.

To conclude, we can say that it is very complicated to compare these two weapons. Since untrained soldiers can use crossbow, and it much more portable, we could say that the crossbow was considered the best one by the people of that time.

# 7. Construction of the Longbow

The construction of the longbow was cancelled due to lack of time, and not having access to the necessary materials (mainly the right type of wood without any knots). The wood we were going to use to make the longbow is yew, which we ordered online. There are other types of wood that we could use such as ash, beech, lemonwood or walnut. Since we ordered the wood online and could not find the type of wood we needed in local stores, we encountered that the piece of wood we had actually couldn't be used to make the longbow. The grains had to be straight and free of any knots on the surface of the wood. The procedure to make the longbow is described in the following next pages.

The piece of wood has to be straight and knotless. In fact there cannot be any knots on the parts of the wood the bow is going to be made with. The outside or the back of the bow has to follow the grain of the wood. There could not be any broken grains on the wood. The following equipment and tools are what we would have used to make the longbow:

- Saw: To saw the pre-cuts of the stave
- Jack Plane
- Spoke Shave
- Rasp
- Files
- Sandpaper
- Knife

**Figure 8: Rasp**

**Figure 9: Spoke Shave**

**Figure 10: Jack Plane**

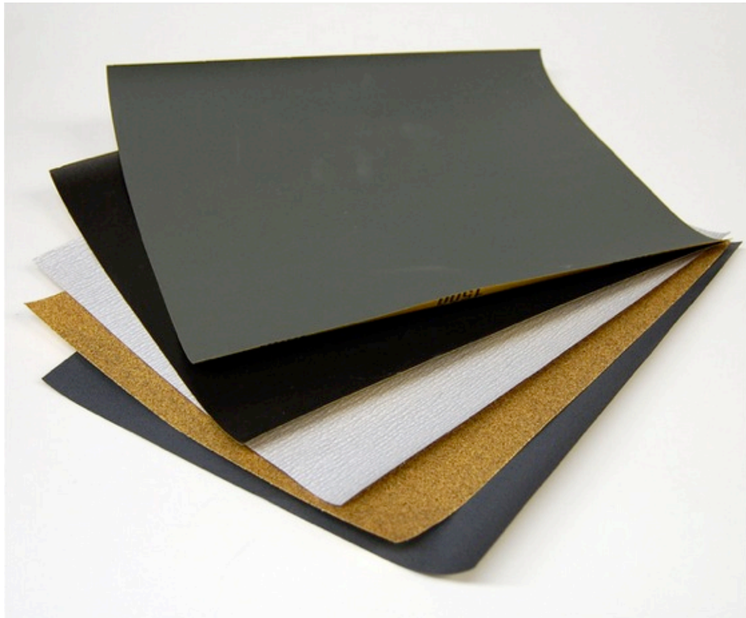

**Figure 11: Sandpaper**

**Figure 12: Files**

The only power tool that can be used is something to replace the saw with. The length of the longbow is usually between 150 and 190 centimeters (the same as the height of its user). The arrow is to be placed in the middle of the bow, the midpoint of the handle of the bow.

The first step of making the bow is to plan the piece of wood. We would start by carving out the basic design of the bow and cutting the wood to the size we need using a saw, hatchet or knife. For safety, we will leave extra wood on all sides. The second step is to remove the extra material from the back of the bow using the spoke shave, shown in Figure 9, until we get to the correct ring thickness. We have to be careful not to break the grain on the back of the bow. Third, we try to get the belly form done and remove the extra material from the front of the bow.

To make the notches at the end of the stave for the long string, we use a little round file, saw or knife. The notches have to be just deep enough to hold the string firmly.

The next part is very important. We need to bend the stave, but this needs to be done very carefully so that the stave gets used to bending during the tillering process. The tiller is just used as a stand to help make the bending operation easier. We would need to continue this process until the belly of the bow has a D-shape. Then we would need to begin testing to see if some part of the bow bends more than the rest. If any part did, we would need to remove material from everywhere but that place. After the bending process, and the sandpaper is used to remove scrapes and make the surface of the bow as smooth as possible.

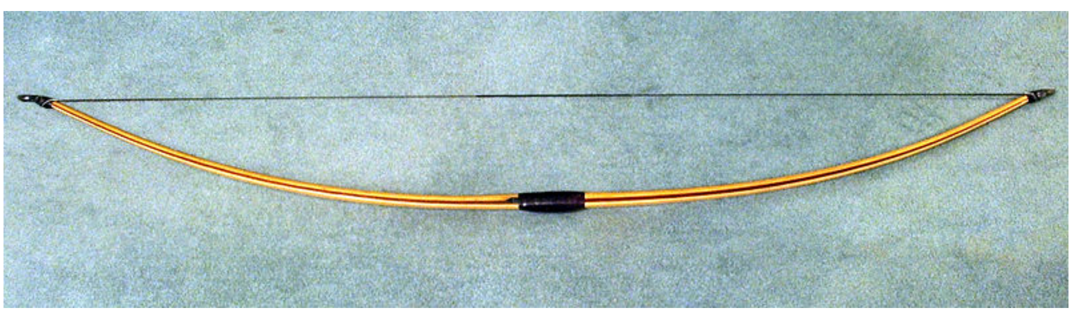

**Figure 13: The final look of a longbow**

# 8. Construction and Materials of the Crossbow

The research that was done about the types of materials that we should use for each part was done briefly, and we are waiting to make a decision about which materials will best match each part of the crossbow.

A usual crossbow has basically the following parts:

- Lathe or Prod
- Bow-string
- Stock (body)
- Trigger
- Nut and Socket
- Stirrup
- Groove
- Spring

For the first and an important part of the crossbow, the prod or lathe depending if it is made from wood or metal respectively, there are four possible options for the types of materials that we can use. If made from wood the prod can be made from yew or ash, which is the traditional way of making the prod. If metal, the lathe (prod) can be made from iron or brass (which is an alloy made with copper and zinc). The bow-string was traditionally made from hemp or flax. The stock is the wooden part of the crossbow, where basically all of the parts go together. This part is usually made, using hardwood such as oak. The trigger, nut and socket are made from aluminum, which is easy to shape, light in weight, and can be cut easily. This part of the crossbow and the spring are the most crucial and important parts of the crossbow, because the bolt release, spring power, and the precision it all depends on this part. There are many different trigger designs available that even provide a safety feature, so the trigger will be locked until the crossbow is locked in safety mode. The stirrup, is the part that is used to help ease the reload of the crossbow. It is used at the front of the crossbow as a place to place your foot to help reload faster and easier. To make the bolt move smoothly and easily, when the trigger is released, a bolt size iron or brass metal is cut and placed on the top of the stock, where the bolt is going to be placed. The spring is used to increase the nut and socket release power to be able to get a precise shot from the crossbow. The range and power is dependent on this spring.

To be able to understand the functionality of each part the following figures were designed, CAD illustrations are pictured below as Figures 14-18.

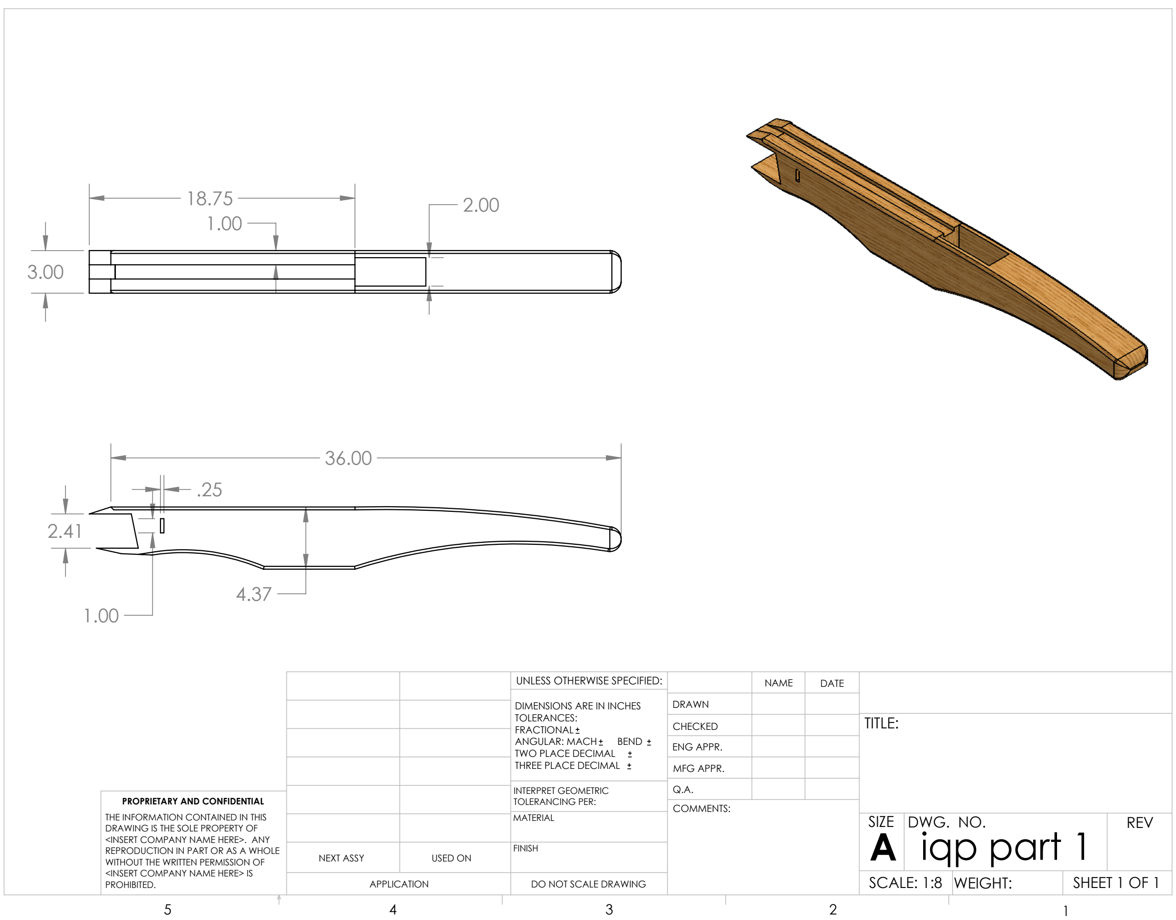


**Figure 14: Crossbow Stock**

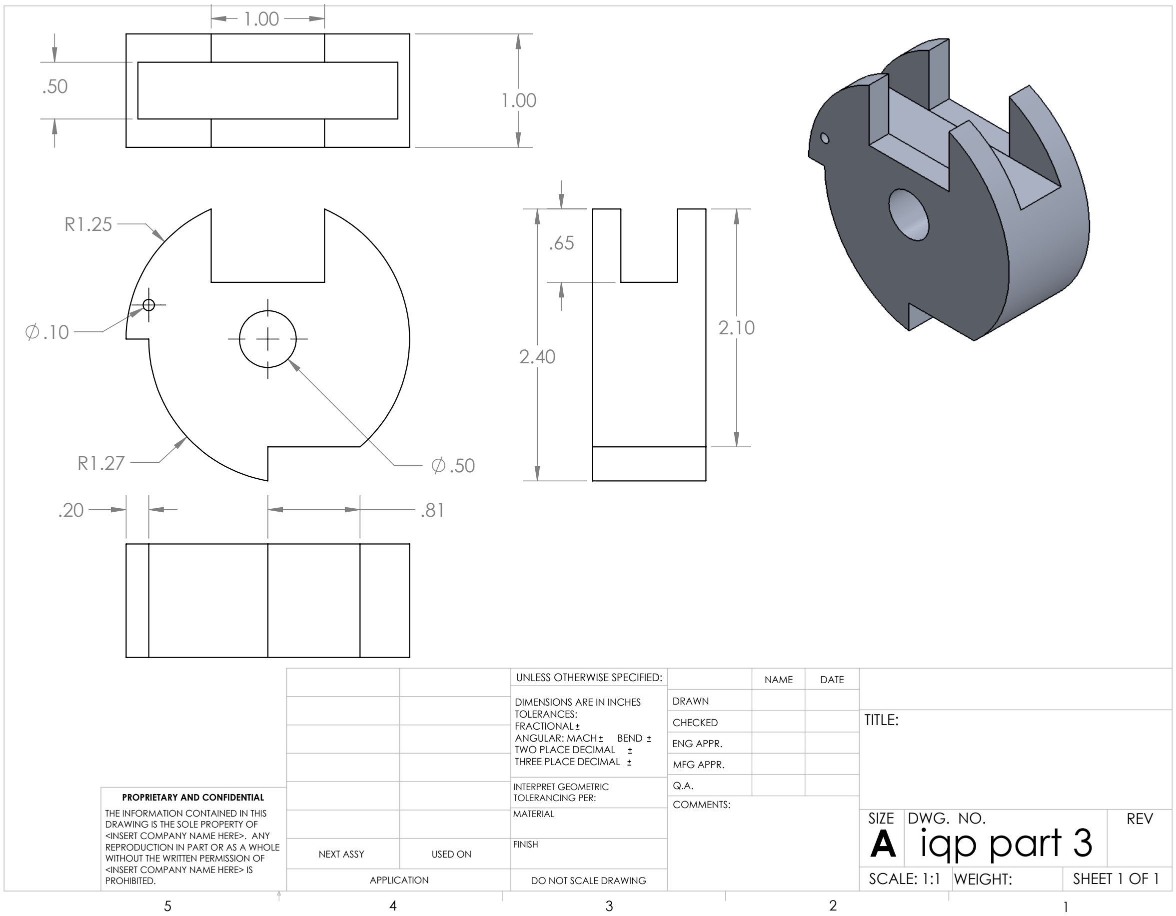


**Figure 15: Crossbow Trigger Mechanism**

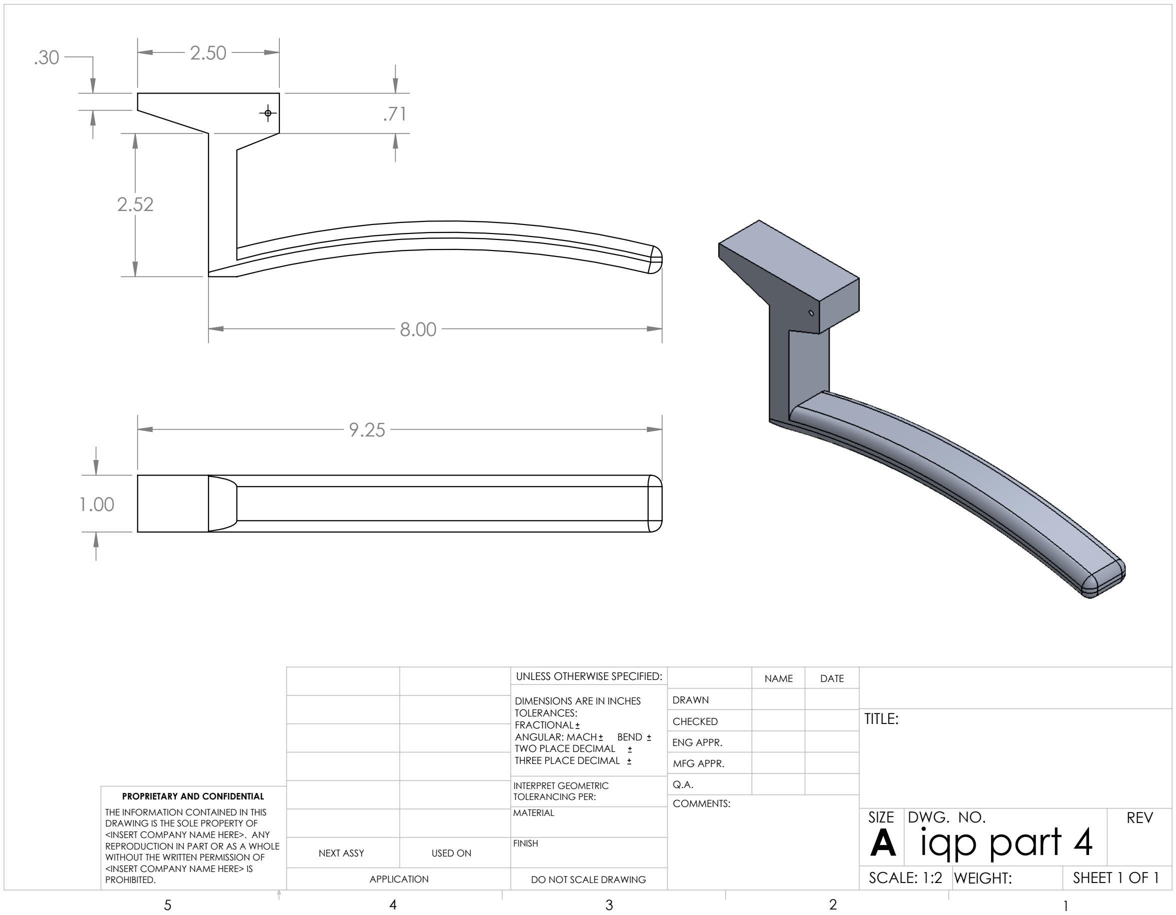


**Figure 16: Crossbow Trigger**

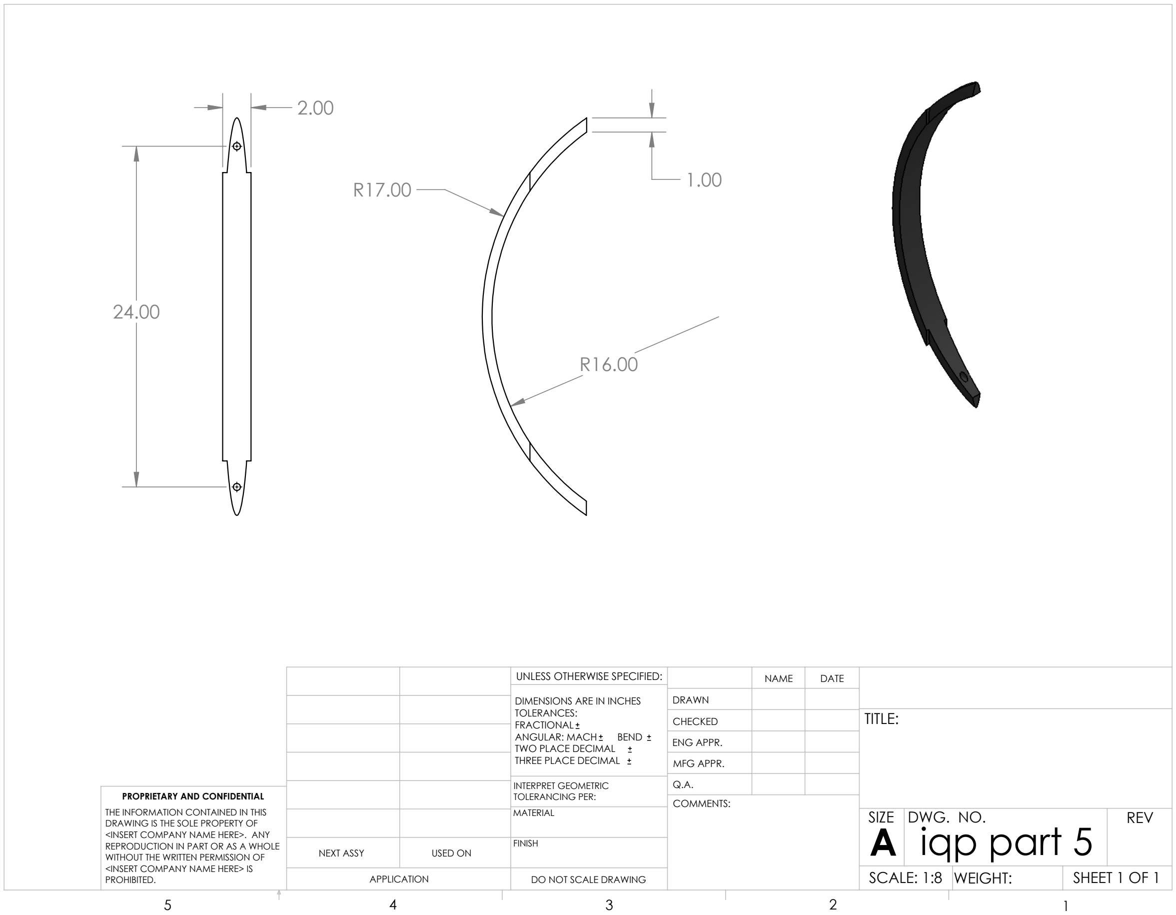


**Figure 17: Crossbow Bow**

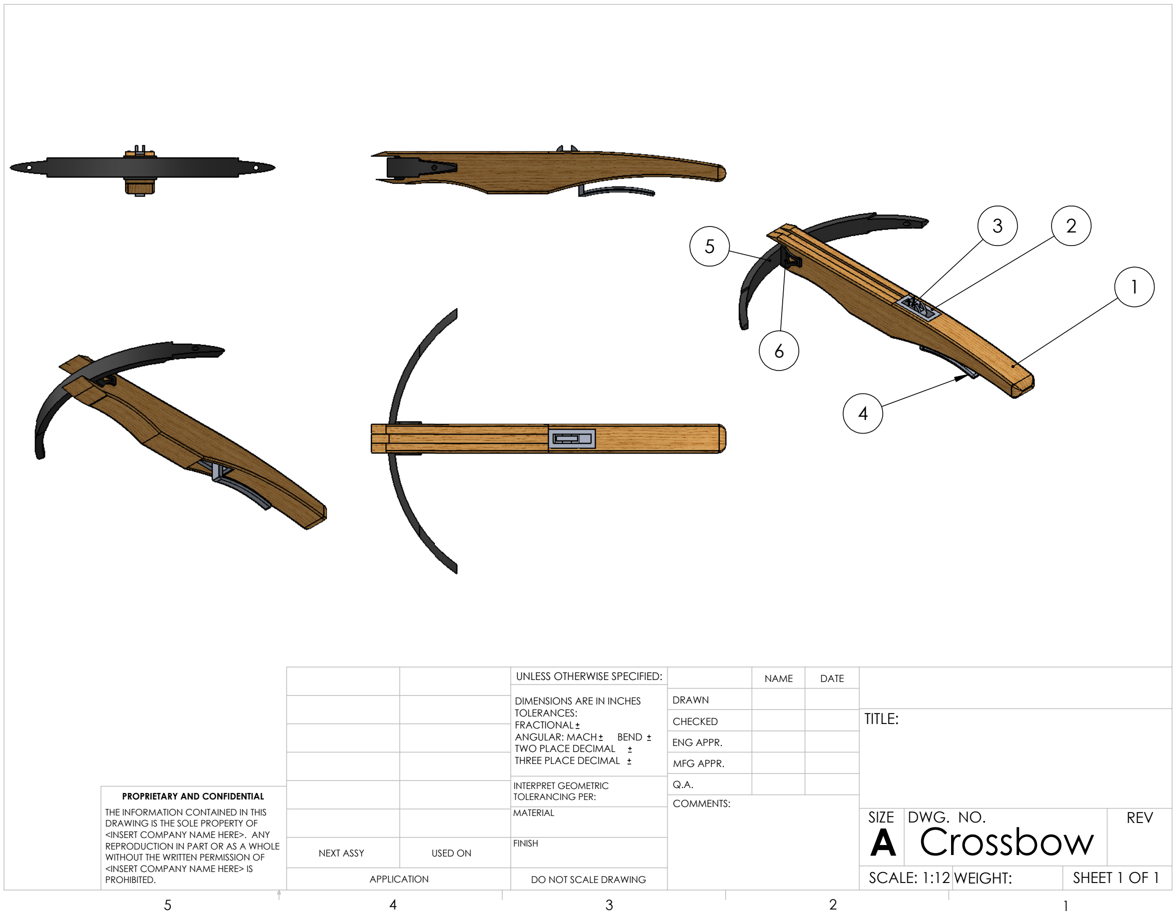


**Figure 18: Crossbow Assembly**

## 8.1. Materials Selection

Iron used in medieval times tended to be wrought or cast iron, a low carbon and high carbon iron respectively. Weapons would be made from either type of iron and then surface treated through carbon exposure, now known as carburizing.

Western smiths, such as those in Europe, seemed to favor taking low-carbon wrought iron and adding carbon to make steel, as casting was not developed until early in the 15$^{th}$ century. Wrought iron has as much as 0.25 wt% carbon, and would be placed in a carbon-rich environment to absorb carbon, by diffusion, and form steel.

We originally looked for a type of steel with 1 wt% carbon content, as iron will quickly absorb carbon up to a point around 3 wt%. But after failing to find a timely source of the correct type of steel, further research and consultation with Josh lead us to buy 0.5 wt% carbon steel.

European yew wood has been used for longbows since their rise, due to the elastic property of the wood. We have a staff of Canadian yew, which is recorded as having similar properties to European yew.

Period bowstrings were made from linen or hemp, with crossbow strings reinforced by leather. We purchased commercial bowstrings for use in the project for safety reasons.

## 8.2. Forging Techniques

We used hammers and the blacksmith's power hammer to flatten out our steel. The team sledgehammer techniques we used have existed as long as blacksmithing, and a waterwheel-powered form of the power hammer existed during the 14$^{th}$ century.

We used the power hammer to get the steel into the right general shape, then moved down to sledgehammers to better shape the piece. The way the sledgehammer shaping worked, with one person directing strikes, allowed for finer control of the shape of the bow.

## 8.3. Forging Procedure

This section illustrates the steps we took in the procedure in the forging of the bow for the crossbow. Josh presented all the steps and basic techniques to us in previous meetings.

### 8.3.1 Constructing the Metal Bow

#### Week 1

The first three steps presented below were used during the work session of our first day.

**Step 1: Starting the Forge**

In order to start the forge we first need to build a basket out of an entire newspaper, before lighting up the paper we removed all the used coal from the forge. After the paper is light up in the forge we put coal all over the paper making sure that the bottom of the forge is open so the air can come in. During this entire process we have to crank the bellow to burn out the paper and light up the coal. Once the forge is successfully on we can move to the next step.

**Figure 19: Turning on the forge**

**Step 2: Heating the metal**

The instructions for completing this step were really straightforward, put the metal inside the coal dome were is hot and crank the bellow to make it hotter. In this part we encountered a couple of problems. The first one was that due to the nature and dimensions of our metal piece, the heating process took a long time. The second problem was that once the metal was heated it was hard to hold it without burning ourselves.

**Figure 20: Heating the metal**

### Step 3: Hammering

After discussing for the best technique with Josh for the hammering of the metal, we decided to go with sledgehammering. As expected this proved to be an intensive amount of work for slow, but significant progress.

**Figure 21: Sledgehammering**

**Week 2**

In our second work session we changed both the heating and hammering techniques.

**Step 1: Propane forge**

Instead of using the common forge we used a propane forge. To start the propane forge we needed to open the propane tank and then using a lighter in the ventilation system, the forge will light up. The propane forge proved to be an important asset, as not only did we gain time, but we became able to heat a larger section of the tube at once. The only problem was that the metal did not stay hot as long as with the normal forge.

**Step 2: Heating the metal**

As presented before heating the metal in the propane forge led us heat longer sections of the tube. The time frame in comparison with the normal forge was still the same but with the difference that the metal cool off faster. With Josh's assistance we solved the burning problem, since we welded a piece of scrap metal to one end of our metal so we can work and maneuver the piece easier without burning ourselves.

**Figure 22: Heating the metal in the propane forge**

### Step 3: Hammering

In order to obtain successful work progress we decided to use the power hammer. Using the power hammer showed to be a great benefit, not only we diminished our physical effort in comparison with the sledgehammering technique, but also decreased our working time.

**Figure 23: Hammering the metal in the power hammer**

### Week 3

We continued using the same process from before since it proved very effective. We only changed our heating mechanism; we decided to go back to the normal forge since it created a higher heat concentration in the metal.

**Figure 24: Final hammering**

**Week 4**

**Heat Treating**

The final step of the forge procedure for the bow of the crossbow was to heat-treat the metal.

The heat-treating technique we used for the metal was tempering. This technique will allow us to obtain the desire spring condition in the metal. Tempering has three steps; the first one is to heat the metal until it loses its magnetism; then it is quenched; and finally the metal is heated to temperature to achieve the desired tempering color and obtaining a specific metal property.

We started with the small piece that we used for the material analysis. The goal was to heat the piece to an orange-red color or until the metal piece was not magnetic, tested using a magnet. We repeated this process for the bow.

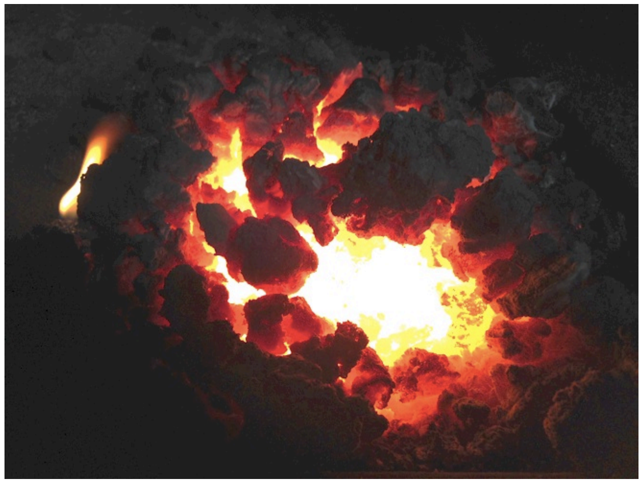
**Figure 25: Forge dome to heat the entire metal**

After this was completed we cooled the pieces in water, making them brittle, and proceed to grind down.  We do this in order to see the change in color that occurred in the metal.


**Figure 26: Grinding the metal**

The next step has to heat the metal to the desire temperature that for our case was 590˚F. Since we use a torch because this was the equipment we had, knowing when we reach this temperature was very difficult so we had to keep the torch moving at all time and see how the metal change color.

**Figure 27: Heating the metal with the torch**

The color we were looking for was blue, giving the steel more elastic and flexible. Other steel tempers are yellow, brown, purple, blue and gray. Gray is where the metal will get extremely hard, so we had to make sure and be really precise when heating the metal because the temperature difference between blue and gray is very low.

**Figure 28: Metal turning blue**

For the last step we let the metal cool down at room temperature. Then to test if we were successful in the heat-treating process we put the metal on the ground and jumped on it. The metal did not break; instead it bent and returned to its original shape. This proved that we had correctly tempered the metal, as the stress would have shattered it otherwise.

## 8.4. Manufacturing the Trigger

The next and most important step was to make the trigger of the crossbow. The trigger is the heart of the crossbow and is what makes it a unique design between firearms. To start, we chose a simple trigger design that consisted of a round nut and a handle.

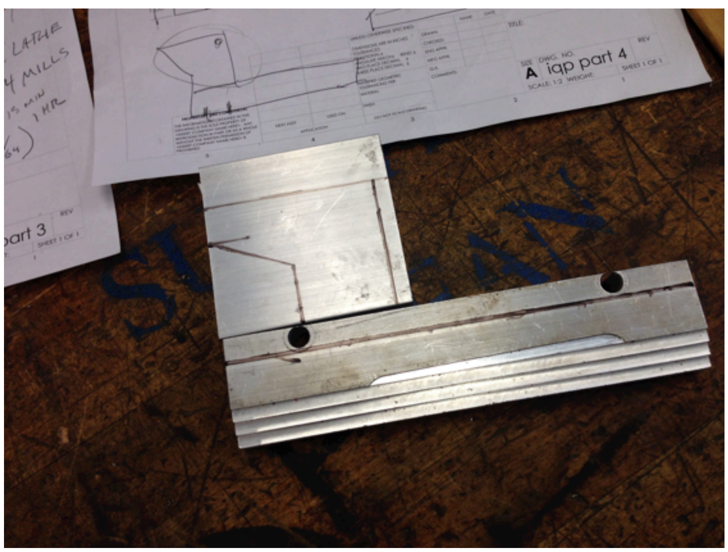


**Figure 29: Tracing the handle**

We found some small pieces of aluminum to make both parts of the trigger. The functionality is very basic and easy to understand. The nut will be placed inside the wood stock and screwed to the wood. The handle is set to not let the nut move at all until the handle is pressed upward, which would release the nut, and the nut will let go of the string.

We used two small pieces to form the handle, and connected both pieces together with two screws. The holes for the screws were made using a drill to make special holes for the screws that would hold two pieces tight together. The shape of the handle was sketched out on the aluminum pieces and the shape of the handle was cut out using a table saw.


**Figure 30: Cutting the handle**

After finishing the last cut, we filled both pieces to get rid of sharp edges and some extra material to be able to perfectly connect both pieces together.

**Figure 31: Low part of the handle**

You can see the finished handle of the trigger in Figure 32. There were no complications on building this part, and everything worked out perfectly. This was a relatively easy part compared to the nut, which was the next part that had to be built to finish up the trigger of the crossbow.

**Figure 32: Final handle**

To make the nut, we started with a round 2-inch diameter piece of aluminum. We used a lathe to make a hole through the center, and a mill to cut the prongs in the top. After that, we used a saw to cut slots for the handle to catch in.

Historically, the handle would have been made from cast or wrought iron and the nut would have been cast in a mold. We machined the pieces as none of us had the necessary metalworking experience to forge them, and the metal we used was not conducive to the final shapes.

### 8.5. Building the Stock

We encountered some problems with the wood we planned to use for the stock of the crossbow. The main problem was that the wood had many knots and the strains were not straight lines. This meant that the piece of wood we had is weak and will not support the load from the metal bow and string. After consulting with the carpenter we went for another piece of wood.

We returned to the wood shop with the new piece of wood and a sketch plan for the stock as previously discussed with the carpenter, Ian. Before starting to work, Ian suggested that he would do the heavy cutting, as the machines would take long time to learn how to use and were dangerous.

We began drilling the case where the trigger mechanism will later be attached. At this point we had to do an alteration in the original design, since the handle of the trigger was larger than expected, we had to make the case larger so trigger mechanism will fit. The picture below shows how the machine operated.

**Figure 33: Drilling the trigger hole**

We continued to create the canal were the bolt will lie down. The first part was to calibrate the machine for the desired distance, halfway in the width of the stock; the procedure is shown in Figure 34.

**Figure 34: Calibrating the machine**

After the calibration process was finished we decided on the depth and the diameter of the canal. Ian did a first trace, but the canal was too small so we decided to do two more traces to obtain more depth.

**Figure 35: Making the canal for the bolt**

The next step was to cut the excess of the wood in straight lines in order to achieve a symmetric distribution in the stock of the crossbow.

**Figure 36: Cutting the excess of the stock**

With a saw specially designed for curved cuts, the bottom of the stock was cut. We achieved the desired design as shown in Figure 37.

**Figure 37: Cutting the stock**

After all the major cuts were completed, we used the belt sander to smooth each of the ends and the rough edges of the stock.

**Figure 38: Grinding the stock**

## 8.6. Final Pieces and Assembly

The final stock was finished with a coat of linseed oil, a varnish and sealing agent used in period. The bow was set in the groove we cut in the wood using a carpenter's hammer, though it was later removed to be tempered.

**Figure 39: Metal bow and wood stock**

Forging proved to be more difficult than we anticipated. In conjunction with the wood piece and aluminum mechanism, the final crossbow turned out to be harder to complete than anyone had predicted.

The final worked piece has some slight oxidation and hammer marks. The piece is also thicker than we had wanted, too thick to use standard crossbow strings. As the wood and mechanism parts were not made using historical techniques, they appear much more finished.

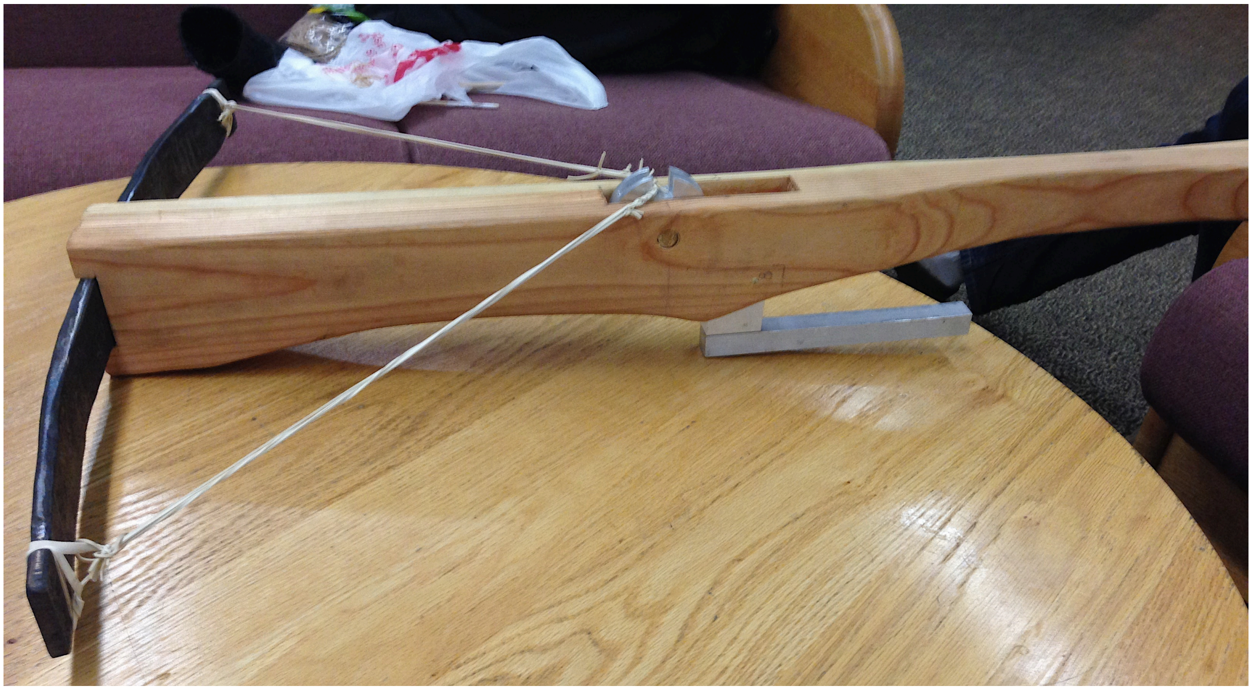

**Figure 40: The finished crossbow**

# 9. Material Analysis

We met with Dr. Li, one of the professors in charge of WPI's materials labs. He showed us the procedure to prepare our metal samples for microscopic analysis. We prepared two samples from each of the metal's three stages of work. We needed an initial, unworked as-purchased sample; a worked sample, from when we were done hammering the piece; and a sample that had been heat-treated.

## 9.1. Metallographic Sample Preparation

The first step was to cut down our sample into a size we were able to mount. We used a very fine circular wet saw to cut pieces off of our sample.

The second step was to mount the samples. This was done by a machine that took the sample and mounting epoxy and used high heat and pressure to fuse them into a one-inch diameter cylinder.

**Figure 41: Sample grinding**

The third step was to grind and polish the samples to a mirror finish. We were able to do this with input on the procedure from Dr. Li and the equipment in WPI's materials preparation lab.

After consulting independent research, previous reports and Dr. Li, we decided to etch the samples using a 3% nital solution – an alcohol and nitric acid solution. Samples were immersed in the etchant for 10-15 seconds and examined under an optical microscope using polarized light.

Our steel was cold-rolled at ambient temperature (25°C). The data sheet for this 1045 steel shows that it contains 0.42-0.5 wt% carbon, 0.6-0.9 wt% manganese and trace amounts of sulfur and phosphorous. The Fe-$Fe_3C$ phase diagram in Figure 42 was used to locate our alloy.

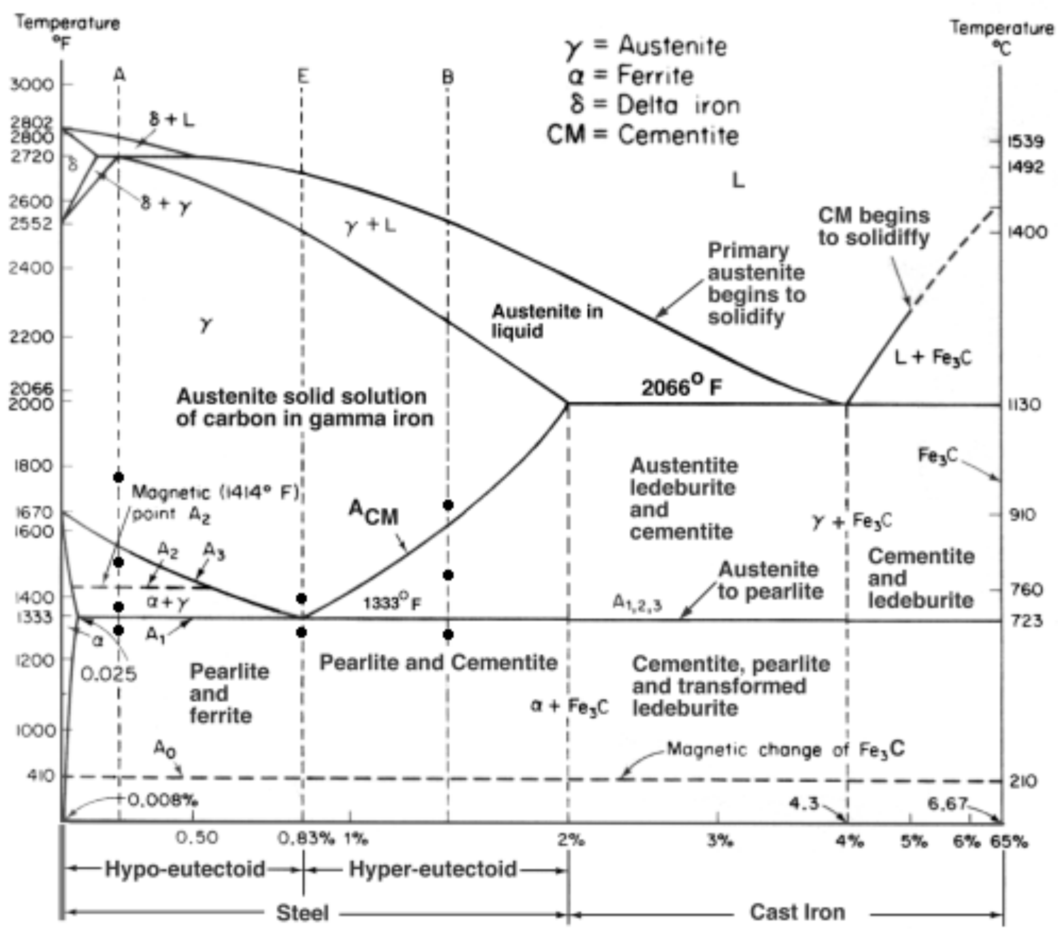


**Figure 42: Fe-$Fe_3C$ phase diagram**

During the post-working heat treatment, the temperature was raised to ~850°C and then the piece was quenched, forcing the metal to cool fast (the piece reached ambient temperature in an estimated time of 2-4 seconds), as shown in red on the 1045 steel TTT diagram in Figure 43.

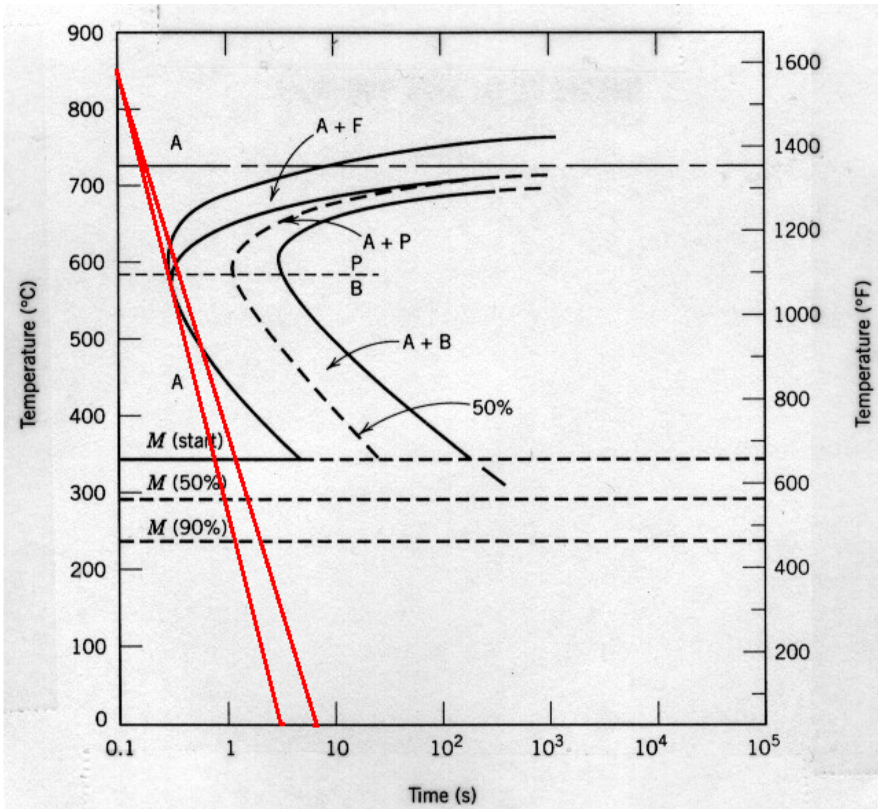


**Figure 43: TTT diagram for 1045 steel, marked with our estimated cooling lines**

Cooling rates were then calculated and used to determine the resulting microstructure. The start and end temperatures for the cooling rate calculations were 850°C and 40°C.

$$\text{Cooling rate } = \frac{850 - 40°C}{2\ Seconds} > \frac{850 - 40°C}{4\ Seconds}$$

$$405°C/Second > 200°C/Second$$

Based on the estimated cooling rates from the austenitic temperature, the steel should form martensite and bainite phases. This is different from the original microstructure of the material after cold rolling that was a combination of ferrite (white phase) and pearlite (the darker lamellar structure of ferrite and cementite) as shown in Figure 44.

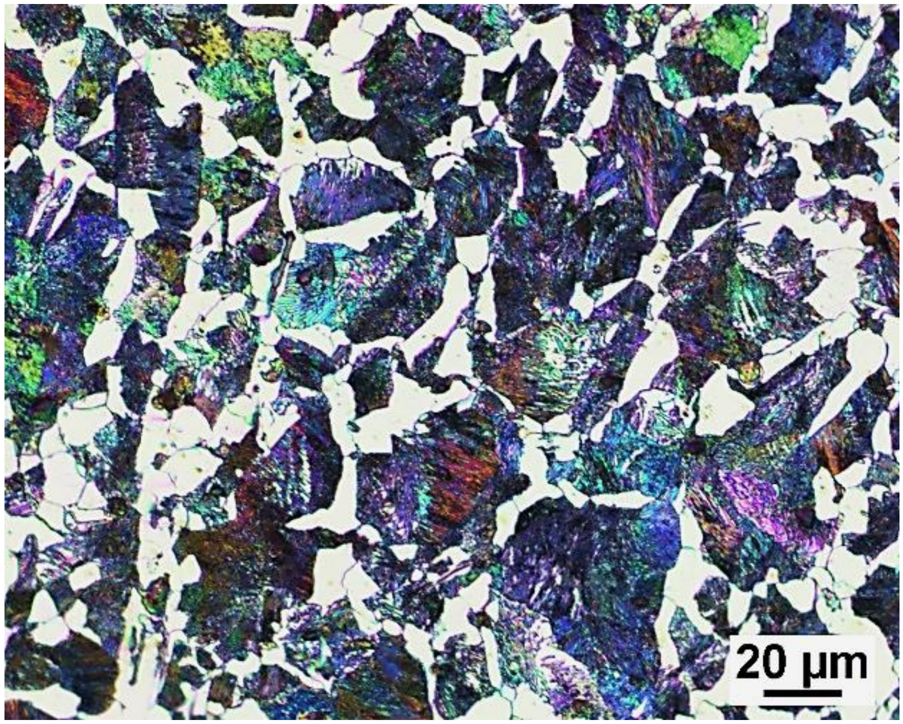


**Figure 44: 500x magnification of unworked steel**

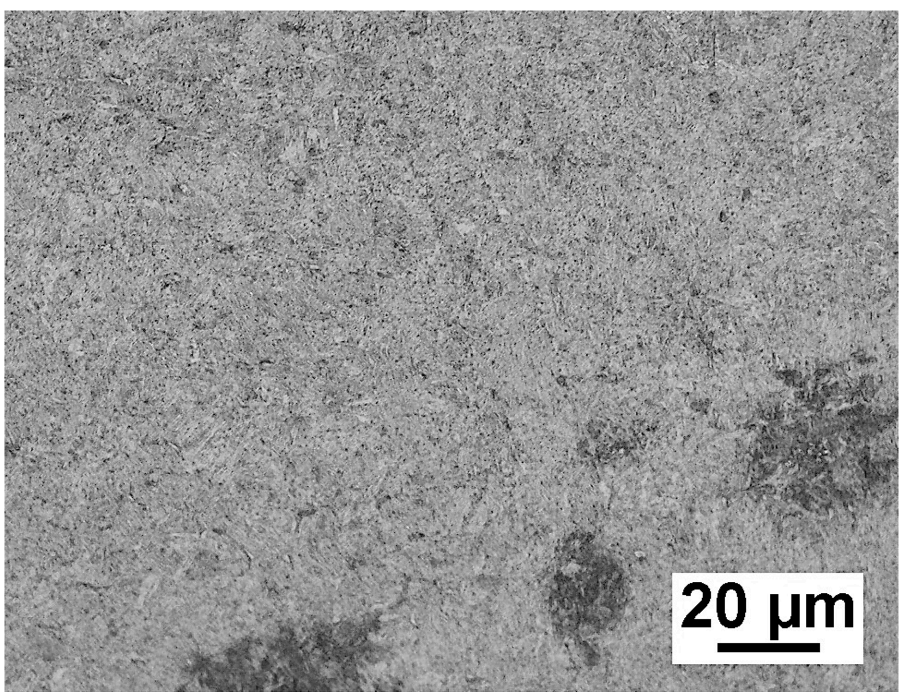


**Figure 45: 500x magnification of worked and heat treated steel**

Martensite is a hard and brittle phase that forms through a diffusionless transformation at very high cooling rates. Bainite form at lower cooling rates and has a similar appearance under the optical microscope. Our microstructure shows both martensite and bainite, as indicated by Figure 45.

To remove residual stress and enhance ductility, the material was finally tempered at 290°C for and then left in room temperature air to cool.

## 11. Conclusions

This report has looked at the history and construction of both the longbow and the crossbow. They were rival weapons for the latter part of the middle ages, but the crossbow slowly beat out the longbow. Unfortunately, no source can agree if there is a reason.

The crossbow could be trained on quickly and made even quicker, allowing a regiment to be trained over a fortnight. The longbow was cheaper, but the time it took to make was only second to the amount of time it took to train its users; though they were universally considered to be the elite archers of the world.

In the middle ages, a crossbow was a joint task between both a blacksmith and a carpenter or bowyer, while the longbow would only require a bowyer. In our case, while the longbow would have only needed a carpentry shop, the crossbow required three contacts in as many different shops. The bow was made at the blacksmith's, the stock at a carpentry shop, and the mechanism at WPI's machine shop.

Though we did not get into detailed blacksmithing work, this has been a good perspective on the kind of work that was done in medieval times. Both the hands-on experience of making the piece and the analysis and the theoretical side of the analysis have been a unique experience that we will all remember.

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