

THE EVOLUTION OF MATERIALS IN ARMS AND ARMORS: MEDIEVAL ERA

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Abstract

During the medieval ages, the development of armor was ever-changing because of the constant need for better protection. This project is devoted to the evolution of armors during the medieval ages with respect to technology, warfare and different geographical locations. Our research was compiled and presented on a public website, hosted by WPI, for public access. We also made a simple piece of armor using medieval techniques.

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I. Introduction

The primary goal of this IQP is to study the evolution of armors of different civilizations and time period. Our team was broken down into two groups, each studying the evolution of armors on different time periods. Group one focused on the ancient times of antiquity while group two researched around the 1000s-1500s A.D., primarily focusing on Europe's High Medieval Era to the fall of the Medieval Era. We gathered as much information related to armors and technology through different books, online database, and consultation with curator experts such as Jeffery L. Forgeng in order to broaden our knowledge and scope of how armors developed. The information was then compiled onto a website for public access. The website serves to present our some of our research findings and our work.

The definition of armors that will be adopted for this project is from the American Heritage Dictionary and is as follows: A defensive covering, as of metal, wood, or leather, worn to protect the body against weapons. Due to the human physiology, defensive covering requires a combination of pieces worn together to create a whole defense. The pieces that will be considered in the composition of armors in this project are the helmet, cuirass, gauntlet, greaves, and shields. Each of these pieces covers a part of the human body; the helmet covers the head; the cuirass covers the chest and the back; the gauntlet covers the arms and hands; the shield is simply a hand held protective tool.

Armors were, however, more than a piece of protective tool. They were also considered as a work of art as they were often adorned with family crests and other designs. Furthermore they reflected the reputation and the lifestyle of the person wearing it. Peasants could easily

identify a knight and his origin through the family crest engraved on his armor just like the rank of the samurais could be distinguished by the type of armor worn and its design.

As society was making progress, so did warfare. Throughout history, the development of weapons and armors has been an arms race. Armors have evolved with the increasing need of human protection and weapons have evolved to break this protection. This has led to different developments in different civilizations. The differences between civilizations led to a plethora of different types of armors. The type of armor produced was dependent upon its geographical location, available resources and techniques developed in each civilization. By studying the evolution of armors, we can see the linear evolution of armors within a civilization and a parallel evolution of armors of different civilizations at the same time.

The Medieval Era were a fascinating time period known as the transition period which lies between ancient greatness associated with the Roman Empire and modern greatness associated with modernity. Historians view the Medieval Era as a fruitless and unprogressive period. This is not necessarily true but on the other hand, they were no golden epoch that we should seek to return. In general, the Medieval Era were years of extreme hardship, of chronic war, of devastating pestilence, of recurrent famine, of prevailing ignorance and of degrading superstition. Only through the fires of fierce adversity and the waters of penitential discipline did they purge themselves of their enormous faults, and prepare the world for the higher and more widespread civilization of modern day.

There are many books and research done concerning armors, but many of those books usually only give historical and tactical information concerning armors. This project attempted to deviate from previous studies by focusing more on the scientific aspects of armors such as its

material composition, durability, protective capabilities, and metallurgy. There is a historic portion included in the project, but only to present the armors in their proper context of reality.

The project will focus on answering the following questions for the armors:

1. Date of use and the discovery of the armor
2. Civilization that made and use of the armor
3. Type of Armor: light or heavy
4. Number of pieces that comprises the armor
5. Material or composition of the armor and the resulting properties
6. Dimensions of the armor or its individual pieces
7. Weight of the Armor
8. Process used to build the armor
9. History of the armor

Studying geographical locations such as Asia and Europe during this time period will give us different perspective on how armors were used. We will be able to see the comparison of specs, technology, and effectiveness. Perhaps some of the armors will overlap or they might deviate throughout the progress of the civilization. The information will be used to create a common website with the Roman group. The website contains information about armors in general and can be a resource for other IQP groups in the future.

II. Background Information

II.1. Medieval Ages

The Medieval Ages covers more than 700 years, spanning from the 5th century to the 15th century in Europe. During this period, armors were prominent because of the internal conflict in Europe and Asia. Armors were therefore constantly used by soldiers to defend themselves from weapons like the sword, arrows, axe, mace, and lance. Generally, the whole body was covered by the armor from head to toe. Each piece was individually made and usually went through different shaping or processing method. Armors, in general, were very expensive to produce. Armors had to be made to measure and it had to perfectly fit the knights or samurai. An incorrect sizing could be lethal to the wearer if it prevented him to move properly.

II.1.1. European Government

The Medieval Age was an era ruled by the feudal system. The feudal system prevailed in Europe in countries like France, Germany, England, Scotland and Aragon: a large part of Italy. Other European countries were more or less influenced by it. The feudal system was the result of the perpetual struggle of civilization against barbarism. It emerged after the fall of the Roman Empire and is characterized usually by the presence of lords, vassals and fiefs. The king awarded land grants or “fiefs” to Barons in exchange for their militaristic contribution to the royal army as well as serve the royal court. The Barons, in turn, also divided their land among other men known as Vassals in exchange for military service and protection. The lowest classes of the medieval age were the peasants who lived and worked in a lord or noble land in

exchange for protection during times of war. The obligations and relations between lord, vassal and fief were the basis of feudalism. The vassals, the Barons hired and used young trained men to enforce the law and deal with unruly conduct. These men were known as knights.

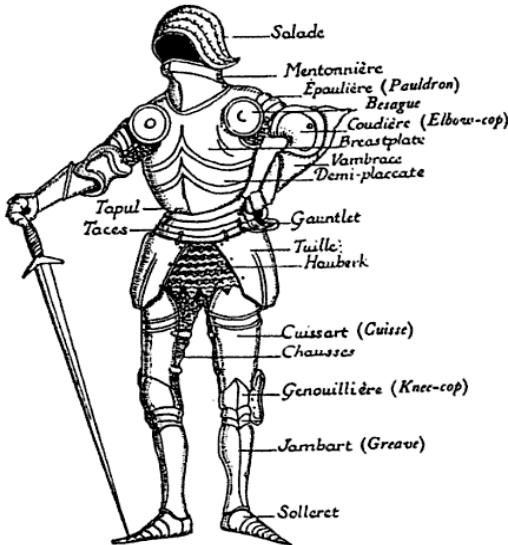


Figure 1. Typical European Armor.(Newman, 2001)

II.1.2. European Knights

Knights used to enforce the law and deal with unruly conduct of peasants or outlaws. They were not just men wearing full plate armors, they were men who had taken an oath to protect their land and provide service to the nobles. Their military training usually began when they were about 7 years old. They first served as a Knight's attendant, known as page, and then as a squire before being dub "Knight". Over time, they would learn how to wrestle, ride horses, and fight with arms with the knight they serve as their teacher. It was also common for Knights to collect wealth over time for their services to the nobles and Barons. The wealth collected allowed them to pay for the supplies necessary to carry out their own military campaigns and

have their own men-at-arms. Before long, they were part of nobility class all to themselves and glorified by the public.

Knights, during the Medieval Era, were the main users of armors. As their social class was rising, they could afford better armors that reflected their social status. Therefore the armor became not only a protective material from the battle; it was also a source of a knight's social reputation and lifestyle. Knights would usually hire the best blacksmith to not only produce their armor but also to decorate the armor with elaborate designs. They would trim the armor with gold and sometimes even decorate the armor with jewels or beads. Often times, their armors were adorned with seal of the family they were serving or their own established seal if their status was well recognized. Armors were worn by the knights not only during battles, crusades or official ceremonies but also during jousting. Jousting was a popular activity held during times of peace so that the knights could remain in shape and retain their fighting skills.

The predominant armor in the early medieval Europe was the chainmail. It was the most common form of armor for Crusaders during the Holy Wars. The chainmail was great for protecting against cut but practically ineffective against blunt weapons. Up until the 14th century, however, mail started to lose popularity as plate armor became the new standard defensive for armor. The technique for making steel swords also came to play as well. These newly enhanced weapons could easily cut through mail and thus plate armor was strongly encouraged.

Typical armors for knights were:

1. **Helmet** - Served to protect the head.
2. **Greave** - A Greave is a piece of armor that protected the lower leg.
3. **Gauntlets** - Armor pieces that protected the hands, wrists and forearms.
4. **Pauldron** - Armor for the shoulder
5. **Sabatons** - Sabatons are armor for the feet

II.2. Metallurgy in the Medieval Era

The high Medieval Era was a time of war and suffering during which nations battled for control of land and assets. As a result of this constant period of conflict, certain technologies came to the forefront of metal production. Metal became the most precious commodity on the face of the planet and more specifically iron became the metal of choice. Iron was and is the most prevalent metal in the earth's soil; efforts to extract impure iron ore from the earth were increased and as a result iron production increased also. With the advancement of extraction methods such as water wheel power and more advanced mining, came the development of better and more efficient forging methods. The evolution of extraction methods fueled iron production during the Medieval Era, which required that forging methods improve as well. Iron possessed properties that all other metals did not. Properties which made iron the choice for weapon and armor production, two very important aspects of military conflict. Methods to obtain stronger, more resilient iron were developed to provide an edge against invading cultures. A strong relationship between the weaponry and armory was then formed; as one advanced so did the other. Different battle techniques had a strong effect on how both armor and weapons were developed and improved. The evolution of arms mirrored that of armor,

and the various production technologies throughout the period only aided in increasing the rapidity at which these two technologies progressed.

II.3. Blacksmithing

The Medieval Age was a world of metal and none other than the Blacksmith could artistically shape iron. This section will briefly discuss the trades of blacksmith and their tools.

A “Smith” is a term to describe one who works with metals usually by hammering. “Black” refers to the iron that the smith is hammering and thus they coined these types of smiths as “blacksmiths”. Many believed that medieval blacksmiths were all specialized in armor-making but that is misconception. In fact, armorers (blacksmiths who made armors) were generally located in large cities such as Milan or Insbrucks. A local town or village blacksmith would not have the skills or tools for armor-making. Although a local blacksmith maybe be able to manufacture some form of defensive armor, it would never reach the high quality of the specialized blacksmith.

A common blacksmith may not be able to produce great armors but they are still needed in their local towns and villages because of the various services they provide. They offered services in horseshoeing, repairing doors, farm tools, and other domestic uses. These handy blacksmiths are also needed by nobles and thus the blacksmith trade becomes well-respected in the community because of the importance in their craft.

II.3.1. Tools of a Blacksmith

- Hammers - A variety of hammers varying in size for shaping and finishing
- Swages - Tools, variously shaped or grooved on the end or face, used by blacksmiths
- Swage block - a perforated block of iron
- Fullers - A half-round set hammer, used by a blacksmith for forming grooves and
- Punches - Tools for making (usually circular) holes
- Drifts - Slightly tapered tools of steel for enlarging or shaping a hole in metal
- Bit - A tool for boring, of various forms and sizes
- Molds - Used for making popular and everyday items
- Table, stools, shelves etc

II.4. Mongolia

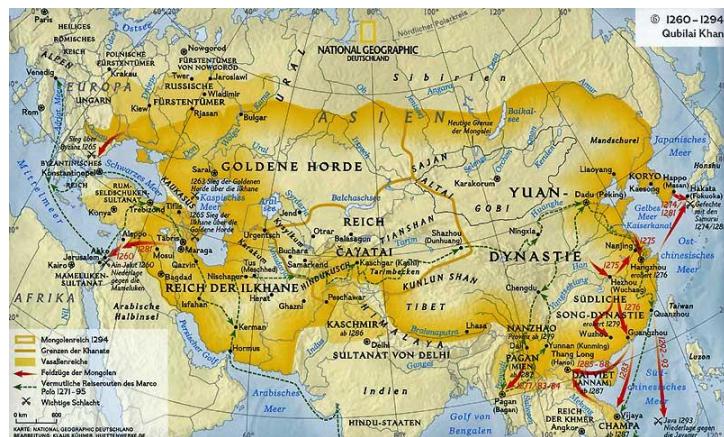


Figure 2. Mongolia under the Khans' rule.(Fletcher)

The late Medieval Era also marked the progress of technology, science, and literature.

Medieval Asia, especially, was far ahead of the western world in the field of science, communication and warfare development. Medieval Asia saw the supremacy of the Khans, who were responsible of the expansion of the Mongol Empire throughout Asia in the 13th

century. Genghis Khan controlled a very large part of Asia, an area which spanned from China to Europe. Mongolia was so large and powerful that it was called Pax Mongolica, similar to Rome's Pax Romana. Genghis Khan was also at the head of a huge army; the warriors were often times dressed in armors. The Mongol armors were derived from both the Chinese Style and the Middle East Style. The armors were either of scalar or lamellar variety, and were made from leather and iron. The Mongols, during the Medieval Era, were nomads and hence preferred light and low maintenance armors. This is why mail armor was rarely used; its weight and the effort invested into its repair were not in favor of the Mongols.

II.5. Japan

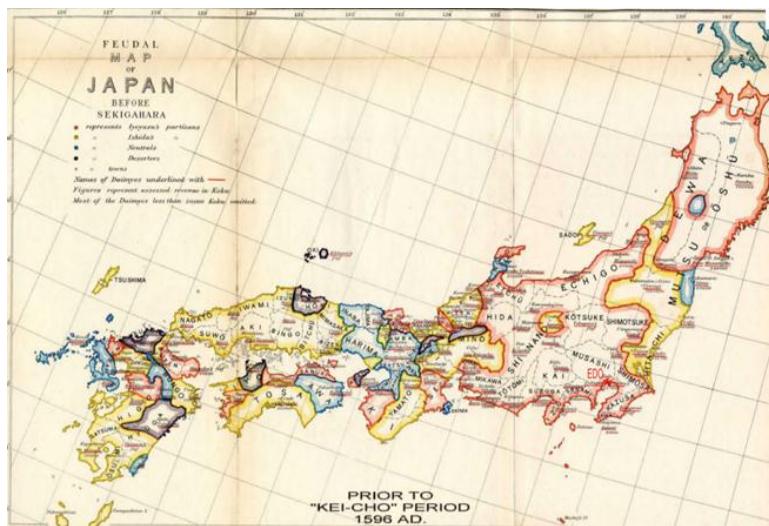


Figure 3. Map of Feudal Japan.(Murdoch & Yamagata)

In the Medieval Era, the Mongolians tried to invade Japan who was able to resist them. This was one of the major highlights of the Japanese history since the Mongols back then was a very powerful army to reckon with. In the battles that were led throughout the Medieval Era; we can see a progression in the physical properties of the armors used. Japanese armors were

very different from the armors used in other civilizations in terms of design and aesthetic. Japanese basic armors were similar to the Mongols', they were lamellar and depending on the social status of the warrior, the type of armor worn would vary. For instance, Japanese warriors from higher social class would wear the O-Yoroi while the foot soldier would wear the Do-Maru. The O-Yoroi is a type of Japanese armors with a more elaborate design than the Do-maru which is another type of Japanese armor. Just like in Europe where the armors were engraved with the family crests, Japanese armors were decorated with the crest of the clans.

Their armor, however, was quite different from a Knight's armor. Instead of being made of clunks of iron forged together, the armor of the Japanese warriors consisted of a metal breastplate that came in pieces which were tightly laced together in order to prevent the armor from falling apart. To make the Japanese's armor, many specialized craftsmen would lace together hundreds of lacquered metal and leather plates with colored silk cords to give the suit its distinctive appearance as well as its flexibility. The armor would then be covered with a layer of lacquer which prevented the metal from rusting. Lacing was considered the most difficult part job of assembling the armor. Japanese armor focused on aesthetics; therefore the armorers had to lace the armor neatly and carefully with color patterns which represented different clans.

Japanese armors allowed freedom of movement and excellent defense but could be overly heavy when fighting in rain. Another piece of Armor was the helmet which is made from metal plates riveted together. Higher class of Samurais had more decorative patterns and symbols on their helmets which also signified wealth.

From the late 1100s to the 1600s, Japan was known as feudal Japan. During this time period, Japan was under the control of the daimyos: the powerful regional families who controlled major portions of lands, and the military rule of warlords (shōgun). Poor farmers had to pay taxes to the daimyos for the right to farm their lands. Warriors known as the samurais pledged their allegiance to lords: the daimyos, and fought to protect their lands. Samurais were famous for their code of honor, the Bushido. Just like the knights in Europe, Samurais were a special social class on their own and had armors specially tailored for them.

II.6. Ottoman Empire



Figure 4. Map of Ottoman Empire.(In Encyclopædia Britannica)

The Ottoman Empire stretched from Eastern Europe to the Persian Gulf and Northern Africa, lasting from 1299 to 1922. In 1301, Uthman, an Uzbek of the Ottoman clan, overthrew the Seljuk aristocracy and proclaimed himself the Sultan of Asia Minor. (British Broadcasting

Corporation, 2009) The empire expanded westward, driving back the failing Byzantine Empire. Constantinople fell to Sultan Mehmet II in 1453 and became Istanbul, the capital of the Ottoman Empire. Istanbul lied on a large trade route and became extremely wealthy through trade. They expanded their empire to acquire more trade routes and slave labor. Since the Sultans of the Empire were not concerned with building infrastructure in their acquisitions, the only way their economy could survive was to acquire more territories to finance it. To accomplish this, a formidable army was maintained.

The army of the Ottoman Empire was different from those found in the kingdoms of Europe. Cavalry was the main constituent of their forces. Full plate armor was eschewed for lighter mail shirts or segmented plates. This reflected their preference for the more mobile tactics used in battle as well as the heat they had to deal with in local climes. (The Metropolitan Museum of Art, 2004) Also associated with the Ottoman Turks is the conical helmet, meant to be worn over a turban. There were also metalworking techniques unique to their arms and armor. One striking example is Damascus or watered steel, which was formed with alternating bands of hard and soft iron. This was imported from Persia and India, in the East. Another was gold inlaying, called damascening, which was present in the hilts of Turkish blades.(Grancsay, 1958)

II.7. South America

In South America and Mesoamerica, metallurgy and armor fabrication had not progressed as it had in Asia and Europe. There was no Iron Age in the Western Hemisphere. In the ancient empires of Aztec, Maya, and Inca, metalworking only consisted of gold and copper

alloys. Metals were either cold worked or cast, and the strength of the material was not of a primary concern; in fact, some bronzes were found with high levels of tin, giving them good aesthetic properties but poor physical properties. Metals were used mostly for ceremonial duties, with some utilitarian uses.(Hosler, 1995)

II.8. North Africa

The use of armor in medieval Africa was concentrated in the north, particularly Egypt. The Malmuk Empire of Egypt lasted from 1250 until it was captured by the Ottoman Empire in 1517. The Malmuks fought against multiple enemies; the Mongols, Portuguese, and the Ottomans. Their infantry wore light armor, including mail, while the cavalry, the mainstay of Arabic forces, were more heavily armored, using a combination of mail and plate armor called *jawshan*.(Nicolle, 1998)

III. Metallurgy in the Medieval Era

In the following sections a summary describing the various aspects of medieval metallurgy will be discussed. Starting with extraction methods and ending with various steel production procedures, this section will provide a basic understanding of the kind of “science” that metallurgy really was in the high Medieval Era. Iron and steel production saw a dramatic increase in production as a result of the advancement of the forging and finery processes. This increase in production led to a growth in the frequency of conflict among nations. This growth was spurred by the end of the dark ages, and technological advancement grew to a heightened sense importance. Culminating in a discussion of the correlation between the advancement of

manufacturing processes and the evolution of arms and armor, this section will shed some light on the metallurgical impact on military conflict of the world in the medieval era.

III.1. Mining

In the Medieval Era, it was common for entire towns to be built around the discovery of veins of copper, silver, and other usable metals. Iron rose to the forefront of these metals. Nations saw how much more of this material there was in comparison to all others. These small discoveries of iron time after time, inspired efforts to develop full scale mining efforts to extract as much metal ore as possible. Metal mines of this period became the focus of powerful governments, as the need for growing states capital demands increased. Finding a mine meant finding wealth and funding for war and wealth. Ore extraction provided another option for the attainment of wealth and capital. Metal was then exported and imported between regions, depending upon need. Metal trade influenced metal production directly because of this affiliation with wealth. Difficulties arose however, when the metal sought after contained unwanted impurities. These impurities had to be removed so that the pure metal could be obtained. During the Medieval Era primitive separation methods could only do so much for removing the impurities from ore. Iron ore especially contained a large amount of impurities because of its ability to combine with almost every element. Most impurities could be crushed or hammered out of the iron ore, but small traces of these impurities still existed within the body of the ores. This physical removal process also required large amounts of man power. This animate source of power required capital to maintain and keep it running.

III.2. Water Wheel



Figure 5. Photo of a Water Wheel.(Miranda,Adriana, 2008)

The development of extraction and separation techniques began with the development of the water wheel. A water wheel consists of a large, wooden wheel with two circular discs that form a channel. In this channel there are flat wooden boards placed perpendicular to the direction of the channel walls. This creates pockets for the water to fill. Combined with a moving river this system then becomes mobile and generates power. The water wheel operates on a simple principle; the force of moving water against something flat will make it move. By repeating this process over and over and directing this force around a large circle, a large amount of torque can be generated by this water wheel. Thus the water wheel was able to generate power.

Rivers and streams were diverted into one source to increase the amount of power generated by a water wheel. This power source was used to power pumps that extracted water from freshly dug mine shafts which increased access to more iron ore buried deep in the earth. Water wheel power also provided a method for separating the ore. Trip hammers used in

forges were triggered by large cams connected to the shafts of water wheels. These trip hammers could bust up larger pieces of ore that could not be broken down by humans, thus increasing the amount of ore that could be removed and processed from any given mine. These smaller chunks of impure iron ore could then be hammered and ground down to even finer pieces by powered grist mills. These grist mills were often integrated into the water wheel powered system, which allowed quick transfer of iron ore product.

III.3. Forge Finery Processes

III.3.1. Crucible Method

Once the ore was processed into smaller more manageable pieces, methods to separate the impurities were used to isolate the iron. The ore was heated in large crucibles that were packed with charcoal. These crucibles were then heated to high temperatures and the charcoal slowly diffused into the steel forming high carbon steel or crucible steel. Large furnaces were required to heat these crucibles. As the various boiling points of the impurities were reached, the gaseous forms of those impurities were released from vents in the crucibles and burned up in the furnace. In this process it was seen that a large, spongy mass formed as a part of the steel after all the impurities were burned away. This mass was and is still called bloom, a combination of iron, carbon, and other metal oxides, such as silicon dioxide which is commonly known as sand or quartz.

III.3.2. Bloomery

The bloomery was the advancement of the crucible method as it allowed a substantially larger quantity of workable iron to be produced. This method was also known as direct reduction. (Lee Sauder, 99) Crucibles could only be made so large and their production was limited of course to their size. The principle fuel for a bloomery was charcoal, which is essentially wood or other organic matter burned down to the basic carbon element. All other impurities in the material are burned away until the pure carbon remains. This charcoal is then pre-heated in a bloomery, which was a large bricked, furnace called a cupola with a hole in the top for gas exhausting. The word for this type of furnace comes from the shape of it, as a cupola was typically a dome shaped structure on the top of buildings. This furnace design allowed for a small chimney that could be vented out of the smelting area easily.

The cupola had a hole in the bottom called the slag tap arch. This is where any impurities in the iron ore are removed as liquefied slag, the pure iron often times floats above the slag depending on slag composition. Slag is generally used as a waste removal mechanism in metal smelting, it also served other purposes, such as assisting in the temperature control of the smelting; and also minimized any re-oxidation of the final liquid metal product before the molten metal is removed from the furnace and used to make solid metal.(Brass, 1999) Slag floats on the surface of the molten metal, protecting it from oxidation by the atmosphere and keeping it clean.(Encyclopædia Britannica, 2011)

Iron ore was heated to remove any moisture and harden any impurities such that the impurities could be hammered out. Once processed, the iron is placed in the top of the furnace along with charcoal. To ensure that the iron coming from the bloomery is of the right

composition, charcoal and ore are introduced in a one to one ratio.(Tylecote, 1976) Inside the furnace, carbon monoxide from the incomplete combustion of the charcoal reduces the iron oxides in the ore to metallic iron, without melting the ore; this allows the bloomery to operate at lower temperatures than the melting temperature of the ore.(Tylecote, 1976) If the temperature becomes too hot, the liquid ore becomes cast iron ore and the furnace can freeze up. This phenomenon is due to the fact that cast iron's melting temperature is much higher than that of wrought iron and the furnace cannot maintain the high temperature required to keep the cast iron liquid. The ratio of charcoal and iron ore must be monitored to make sure the iron does not absorb too much carbon and become un-forgeable.(Tylecote, 1976)

The resulting wrought iron is easily forgeable and was hammered to remove any leftover slag that got into the bloom. This wrought iron is what was used to make armor and weapons. After constant hammering and reheating, any slag in the piece is removed and the composition of the metal being hammered becomes more like cast iron. The metal piece was then reheated just enough to allow it to deform when being hammered. The piece was then quenched and cooled once the final shape was achieved. Further shaping could be achieved with cold working the piece and hammering it into the desired shape without heating the piece. This method added even more strength to the piece, causing the steel to fuse under pressure.

Europeans did not use blast furnaces but bloomeries. This process was used by all civilizations of the west, such as Greeks, Romans, Carthaginians and Celts. Several examples of bloomery industry were found in France and Tunisia. Scientists suggest that bloomeries were in use also in Antioch during the Hellenistic Period. In parallel, smelting in bloomery-type furnaces was popular in Kush and West Africa (Coke from Poland).

III.3.3. Blast Furnace

The blast furnace was the advancement of the Bloomery; it could produce iron on a much larger scale and in greater quantities. Iron makers of Central Europe succeeded in producing iron that would melt in the furnace and permit casting. This result they accomplished in a new type of furnace, built of masonry, which enclosed a shaft or vertical opening in the form of two truncated cones placed end to end, in a crude way, the lines of the modern blast furnace. The lower frustum came to be known as the boshes, the bottom, as the hearth. In this furnace, ore, flux and charcoal were charged in at the top of the furnace, while air, under very low pressure, was blown in at the bottom. The process is shown on the next page in Figure 6. This method was introduced into England about the year 1500.(Camp & Francis, 1920)



Figure 6. An illustration of the Blast furnace process.(Nikki Veldhuis, 2009)

Introduced from northern France, and operated by skilled, immigrant workers, the blast furnace was a much larger, and more permanent structure than the bloomery; and instead of a few kilos of iron being made, daily output was close to a ton. This meant a surplus of iron could be exported and sold by communities where these blast furnaces existed. The blast furnace

utilized more powerful water wheel driven bellows which could produce stronger gusts of air, thus increasing the temperature of the furnace. This meant that more iron ore could be processed at one time which facilitated a continuous production of iron. Ponds of furnace water had to be created in order to provide the constant energy the blast furnaces demanded. The “head” of the water gave the potential energy to drive the bellows that provided the blast, this was the term used to describe the amount of water required to move the water wheel. If the waterwheel was made larger, the larger the distance from the top of the dam to the mill had to match this as well or the larger the head.(Steven A. Walton, 2006)

The bellows of the blast furnace were typically a design of two large, wooden boards shaped like tear drops. These two tear drop shapes are connected by a leather membrane that allows the volume of air to increase and decrease as the bellows fill and empty of air. Other variations of bellows were in existence such as the Chinese piston bellows as designed by the Han Dynasty engineer Du Shi (Coke from Poland). A simple sketch of this design is shown be in Figure 7.

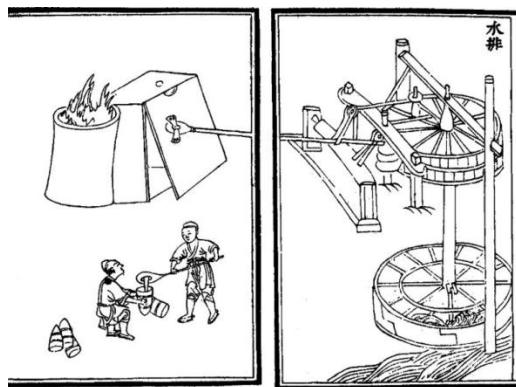


Figure 7. Furnace bellows operated by waterwheels.(Wang Zhen, 1313)

The bellows operated such that they drove on the upstroke and then heavy counterweights would compress them, forcing the air in the furnace at an even rate. The two bellows would operate out of sync, so that a more or less steady rate of air flow would be achieved.(Steven A. Walton, 2006) The technology of the blast furnace seems to be linked with the Cistercian Monks who transmitted the many metallurgical advancements of the period through the channels of travelling commerce who visited the monasteries and the advancement from the use of charcoal to coke as the fuel for the furnace. The Cistercians became the leading iron producers in Champagne, France, from the mid-13th century and up through the 17th century.

III.4. Iron

Iron is the most common metal known to man. It existed everywhere, in the soil, in the beds of bodies of water. This made it a valuable resource to manipulate into use. Iron however, oxidizes quite easily with water and air and pure iron never really exists in earth's atmosphere. This is why iron ore had to be processed before it could be used to make various items. Three major categories of iron are pertinent to medieval metallurgy. The first one is pig iron which is the intermediate from which all ferrous products are derived.(Camp & Francis, 1920) The second one is wrought Iron is an iron alloy with very low carbon content and includes fibrous inclusions, known as slag. The third one is cast iron or grey iron which is an iron alloy that is very brittle and was often used to make more desirable iron by adjusting the composition of melted ore. In medieval times a scientific method for ensuring the proper carbon content of iron did not exist, but rather an experimental control of material amounts

and air flow into the furnace as well as careful observation replaced discrete measures of products and processes.

III.4.1. Pig Iron

This classification of iron was used as an intermediate product in the creation of steel. In the solid form, pig iron represents a very complex mixture made up of uncombined elements, chemical compounds and alloys.(Camp & Francis, 1920) Carbon content was very important in determining the characterization of the pig iron. It occurs in pig iron in two forms, called graphitic carbon and combined carbon. The first being pure carbon, existing in the iron in the form of flakes distributed throughout the mass. Graphitic carbon forms in the pig iron during the process of cooling. Iron absorbs less carbon at low temperatures than it does at high temperatures. The presences of both graphitic and combined carbon strengthen and weaken the iron, respectively. Pig iron could also contain elements such as Silicon, Manganese, Sulfur, and Phosphorous. Materials that existed naturally as oxides of the iron changed both the composition and the characteristics or the iron in which these elements existed.

III.4.2. Cast Iron

Cast iron is very brittle in comparison to wrought and pig iron; while this variation of iron exhibits very high carbon content, about 2.5-4%. Gray iron as it is alternatively called also contains Silicon at about 1 to 3% of the total mass of iron alloy. Modern metallurgy has shown that the silicon acts as a graphitic carbon stabilizer which means it helps the alloy produce graphite instead of iron carbides. Thus this iron is only good for applications where tensile strength is not crucial, or anything that is not arms and armor. Cast iron if accidentally obtained

was often used as filler to control carbon content in the liquid iron. Depending upon the application, cast iron was not desirable because the properties it exhibited are undesirable in high quality weapons and armor.

III.4.3. Wrought Iron

A type of iron that is made in an open hearth such as a bloomery, where strong gust of wind are introduced through the tuyere to reduce the starting material, iron oxide ore, into iron according to the reaction:

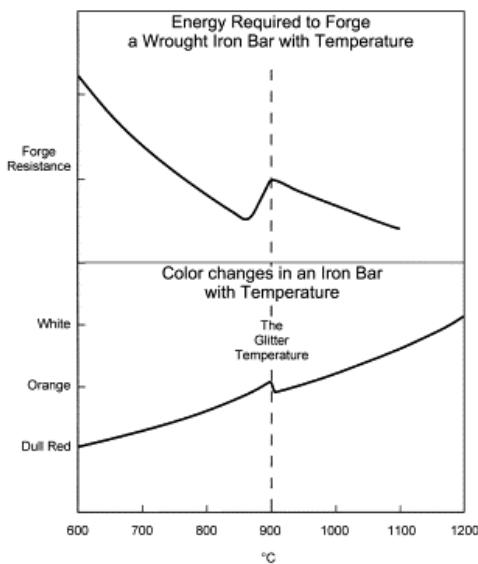


Figure 8. Color change and force resistance as a function of temperature.(Sherby et al., 1999)

The charcoal is supplied by wood and the temperature does not exceed 1000°C (much below the melting point of iron). The result is solid iron mixed with liquid slag in a mushy condition- bloom, but the end product becomes wrought iron once the liquid slag present in the bloom is hammered.(Oleg D. Sherby, Jeffrey Wadsworth, 2001) Wrought iron is given the name because the iron bloom is worked after being removed from the forge; the word

"wrought" is an archaic past tense form of the verb "to work", and so "wrought iron" literally means "worked iron". Wrought iron was often the raw material from which weapons and armor were made from.

Working iron required a knowledge of the color of iron as it is heated. The hotter iron is the brighter white it becomes, and proportionally the force required to forge the iron goes down as a result. Figure 8, a plot of color change and force resistance as a function of temperature shows this relationship. Skilled blacksmiths knew the slight variations in these colors and could manipulate the various parameters of the forge to obtain the desired iron. The blacksmith had many methods available to create a thorough understanding of the behavior of iron.

1. The observation of the color of the iron as it is heated for forging or for heat treating.
2. Determination of the strength of iron, characterized by the ease of forging, which is a function of temperature.
3. Determination of the strength and hardness of iron at ambient temperature. This was readily determined by scratching or bending the iron, and is dependent on the temperature of forging and on the cooling rate after forging.
4. Representing a more scientific method is the use of lodestone to measure the magnetic qualities of iron. A loadstone is a natural magnetic iron oxide mineral.
5. Ancient blacksmiths understood that iron had two distinct internal structures, a compact one and a less compact one.(Oleg D. Sherby, Jeffrey Wadsworth, 2001)

A blacksmith's shop was always a dimly lit one and this was so the blacksmith could discern the temperature of the iron from its color as it was heated. As shown in Figure 8 shows, the wrought iron became weaker or easier to forge as the temperature increased. Once the iron became a dark orange color at around 900°C two things happened. The wrought iron suddenly became stronger and more compact, and also the color changed strangely. This was the glitter temperature in which a sudden reversal in color change is shown in the middle of the diagram by the downward slope of the line. The temperature seemed to decrease as a result of this phenomenon. As the temperature was further increased the resistance to forging decreased again. This meant that at the glitter temperature the iron was of a different condition and thus a more compact, stronger iron was obtained. Once this method was repeated, the properties of wrought iron would change when the iron combined with different amounts of carbon. New temperatures were observed for the glitter effect as an effect of this variation.(Oleg D. Sherby, Jeffrey Wadsworth, 2001) By controlling these parameters blacksmiths were able to obtain different grades of wrought iron which could be used for various applications. Wrought iron however was not ideal in terms of strength and therefore was not utilized in armor and weapon production due to its high slag content.

III.5. Steel - The Difference

III.5.1. Steel

Any compound of Iron that contained between 0.15 - 1.35% of carbon, this low carbon iron was created from pig iron of higher carbon content.(South Yorkshire Industrial History Society, 2003) The lower carbon content gave this new steel better properties in terms of tensile strength and shatter resistance, the latter being a property that high carbon steel lacked

and as a result would shatter upon heavy impact. These properties made it a prime resource for weapons and armor because it was also easily forgeable.

III.5.2. Blister Steel

This was the first type of steel that was commercially produced in the late 16th century. The process took place in a cementation furnace, more of a kiln, in which wrought iron bars and charcoal were heated for up to two weeks, until the carbon had been absorbed into the surface of the iron. This long process produced a bar that had high carbon content on the surface and low carbon content in the center. This resulted in a blistered appearance to the bars, thus the name. Blister steel did not have much use in this form and existed merely as an intermediate step until processed into crucible steel or shear steel.(South Yorkshire Industrial History Society, 2003)

III.5.3. Shear Steel

Before the development of crucible steel, blister steel was forged by repeated folding and forge welding to mix the areas of high and low carbon steel. Shear steel was the lowest quality generally created and further folding and welding created double shear steel. Long regarded as ideal for blades and cutting edges, primarily because the slag trapped within the steel lead to a serrated edge without it being purposely formed.(South Yorkshire Industrial History Society, 2003)

III.5.4. Crucible Steel

This was a high quality steel created by melting blister steel in a covered crucible using a coal fire. After the slag was removed, the resulting steel had consistent properties throughout

thus making it ideal for use in weapons and armor. This was the predecessor of Damascus steel which utilized the crucible method of steel production.

III.5.5. Wootz or Damascus Steel

Damascus steel is legendary steel known to have originated in Persia during the Medieval Era. The method of their manufacture by blacksmiths of ancient times was believed to be a lost and forgotten art. Legends abounded that Damascus steels were first developed at the lost continent of Atlantis, and that they were brought to India when Atlantis sank. The Indian steel was widely traded in the form of castings, or cakes, about the size of hockey pucks, known as

wootz. The best blades are believed to have been forged by blacksmiths in Persia from Indian, which was also used to make shields, helmets, and armor.(Sherby & Wadsworth, 1997)



Figure 9. Two Damascus swords and surface markings.(Sherby & Wadsworth, 1997)

The exact procedures used by the ancient blacksmiths in making the surface markings on genuine Damascus steel swords shown on the previous page in Figure 9 are the result of a complex forging procedure called upset forging. The pattern is a swirlly distribution of proeutectoid carbides which are the white areas adjacent to eutectoid carbides and

ferrite.(Sherby & Wadsworth, 1997) In 1973 a study done by Stanford professors O. D. Sherby and J. Wadsworth, a procedure utilizing a rolling process, known as the “Wadsworth-Sherby” mechanism; in which the UHCSs were rolled and worked as they cooled produced the high strength steel. This mechanical working broke up the iron carbide networks as they were first forming during cooling, i.e. at a point at which they were still thin and not fully continuous. In this way, the iron carbide that formed upon cooling never had a chance to grow and create the thick networks normally associated with ultrahigh carbon steels.(Oleg D. Sherby, Jeffrey Wadsworth, 2001) This method is what gave the steel its superplastic behavior, when the steel was deformed well beyond its usual breaking point, usually over about 200% during tensile deformation. Such a state is usually achieved at high homologous temperature, typically half the absolute melting point.(Sharma et al., 144-147)

Persians making this steel during the Medieval Era did not rely on sophisticated metallurgical testing available to modern society. These people relied more so on the traditional procedures handed down from generation to generation. Along the way, different variations to the technique would occur but the overall procedure would remain the same, producing a high strength steel. Modern metallographic testing has shown that carbon nanotubes formed in the matrix of the steel. Today these nanotubes when present in a material are known to exhibit superior strength compared to the same material without them. Persians metallurgists did not know that this microscopic structure existed in the steel, which only added to the legendary stigma that Damascus steel had in the Medieval Era.

III.5.6. Japanese Steel

The Japanese swords are said to be strong, tough and sharp. The swords in Japan are made from a special type of steel called Tamahagane. Tamahagane is produced from iron sand known as satetsu in a charcoal bath, using a forge called tatara, made of clay similar. A tatara was a clay vessel about 4 feet tall, 12 feet long and 4 feet wide. In tatara process the steel produced is an inhomogeneous mass of bloom, called kera that could be sorted out according to carbon level. The lowest carbon steel is called hocho-tetsu, which is used for the shingane, (translated as “core-steel”) of the blade. The high carbon tamahagane and higher carbon steel, called nabe-gane, will then be forged in alternating layers, using very intricate methods to form the kawagane or, “skin steel”. The system of the two steels was then forged metals are forge welded, folded, and welded again, as many as 16 times. The folding removes impurities and helps even out the carbon content, while the alternating layers combine hardness with ductility to create toughness. (Kim, 2004) The forged steel was then coated in a layer of clay mixed with charcoal (Das, A. K., Ohbaa, T., Morito, S., Takami, G., Fujikawa, T., Yaso, M., 2009) which was a case hardening method to infuse even more carbon into the first few layers of iron.

Japanese swords exhibited a method of forge welding layers of carbon steel with differing carbon contents. This method was utilized throughout most of Asia in the Medieval Era. These blades were renowned for their ultimate strength as well as their extremely low weight. Japanese samurai swords had to be light as they were utilized in surprise ambush attacks. The higher quality steel created in the tatara process was never used in armor making, as often the less desirable iron produced was used instead. The tatara process was long and carefully manipulated. Iron produced in the method was surely to be used in weapon making

compared to armor making. In medieval Japanese warrior culture, a samurai was only as strong as his blade. This philosophy ensured that only the best iron was used for samurai swords.

III.6. The Conflicted Evolution of Materials in Arms and Armor

The medieval ages were a period of technological advancement in weaponry and armor. As the world stepped out of the period of the dark ages, a flourish of progress flowed out bringing with it a new era of military conflict. The development of armor all over the world ran parallel to the advancement of weaponry. Armor was most effective in melee combat. The Medieval Era marked a time period when melee combat was the dominant strategy in warfare. Thus a symbiotic relationship was born between arms and armor; when one advanced so too did the other.(Alvesteffer, 1999)

Around the 11th century, chain mail was invented and was used widely because it's deflective properties against swords. Military combat of the time was of the hand-to-hand type using swords or other edged weapons, so simply wearing a chain mail shirt reduced the risk of becoming mortally wounded. The problem with wearing just chain mail however, was the cost factor as it was very expensive and did not really offer enough protection to be worth the price. This is where we see the innovation of Asian cultures like the Japanese, who stitched together, laminated plates of iron. This provided a flexible suit of armor but still offered superior protection in comparison to the English style chainmail.(Alvesteffer, 1999)

Chain mail was the main type of armor used during the Crusades because iron production had advanced to the point where high quality iron was mass-produced in large bloomeries and blast furnaces. Mail was ideal for the travelling foot soldier because it was effective in combat but yet relatively light and very flexible. By the end of the 13th century, full

body chain mail was utilized in battle, often by the wealthy elite. Some blacksmiths even began to combine iron plates with chain mail for increased protection.

In the 14th century there was growing evidence that mail armor was inadequate against modern weaponry. Bows and crossbows had come into wide use because of their success against armored men in several large battles. The crossbow was a deadly new weapon that could even penetrate armored knights.(Alvesteffer, 1999) One formula developed for how thick plate armor had to be in order to prevent a longbow arrow from piercing armor is the De Marre equation, which was developed by a French physicist in the late 19th century. This of course was developed far removed from the Middles Ages but provided insight into the kinds of innovation that were going on with plate armor.

$$\frac{2W(V*\cos(x))}{d^3} = \frac{C*A*t}{d}$$

- W = weight of projectile
- d = diameter of projectile
- V = velocity of projectile
- x = angle of attack
- t = thickness of plate
- C and A are constants that account for projectile nose shape, projectile size, projectile damage, penetration, plate type, and obliquity angle of impact.
- When value on left side exceeds that on the right side, penetration will occur.

(Anne McCants, 2011)

Armorers understood that the metal had to be thicker. Massacres in the 14th century spurred the plate revolution that was characteristic of this time period. For the first time in the Middles Ages, iron armor was common among all soldiers. Chain mail simply lacked the ability to protect soldiers effectively against these powerful ranged weapons. To properly armor soldiers, iron production had to of course increase and during this period there is also a tremendous advancement in iron armor production.(Alvesteffer, 1999) Shock methods of military combat became popular, in that larger more blunt weapons were being used to inflict damage on the body over a larger area, a crushing method. Swords became larger and less sharp; axes, hammers and mallets of all types became larger and more grotesque in shape with spikes and rocks imbedded in their surfaces, which aided in inflicting more damage. In order to protect against these massive attacks to the body, strong plate armor had to be developed. Advances in iron production provided the means for stronger plate armor to be developed. Bloomeries and blast furnaces were growing in size and were able to pump out more usable, higher quality iron for use in armor and weapon production. This higher quality iron was used to make stronger, more resilient body pieces that could withstand the crushing blows of large bastard swords and wooden hammers.

Eastern cultures around the world however did not utilize ranged weapons like the west. Mongolian, Japanese, and Middle Eastern cultures utilized more lamellar style armor that combined chainmail with plate armor pieces, offering the best of both styles. This is because these armies chose to use more mobile styles of military combat such as cavalry tactics or guerilla style ground movement. Moving targets were far more difficult to hit with a bow and arrow. So their weaponry remained of the sharp, slicing and piercing variety. This affected the

development of weapons more so than it did armor. This is seen by the ubiquitous advancement in sword technology. Japanese and Middle Eastern cultures prided themselves especially on the quality of the steel in their blades. The weapons these militaries used came in constant impact and needed to be resilient. As was described earlier in the section on steel production in the Medieval Era, Damascus and Tamahagane steel were of great importance. Full body plate armor did not have the use in these cultures like it did in European cultures because it lacked the practicality that more mobile eastern styles of suit armor possessed.

In the 15th century, the process of strengthening iron by putting grooves in it became a wide-spread technique often referred to as “Gothic Style” armor. Blacksmiths and armorers were able to do this because the quality and strength of the iron that was being produced during this period increased. Steel was becoming stronger as blacksmiths discovered new techniques to create high carbon varieties that were both light and durable. This increased strength in the steel coupled with new weight saving techniques really boosted the practicality of full plate armor once again.

In looking at this particular relationship, it is seen that two different focuses arose during the Medieval Era solely based upon the style of military combat. In the west it was the shift from chainmail to full plate armor, where as in the east it was the meshing of the two styles that really spurred weapon production forward. The medieval period saw tremendous advancements in iron, steel, weapon, and armor production due to methods developed that not only created higher quality materials but also a larger quantity of these materials. This allowed nations to expand their militaries and thus providing them with numerous outlets to test various techniques and advancements. This growth also allowed for a large amount of

feedback to be obtained from those involved in battle, as often improvements to arms and armor were made at the behest of those who used it most, the soldiers.

Metallurgy in the Medieval Era was less a science and more an experience, a way of life. Blacksmiths and armorers lived and died by the quality of their work, ensuring that their names were well known within the trade, which brought them wealth and acknowledgement. Soldiers lived and died by the quality of their weapons and armor, relying on the quality of the steel to get them through battle. Nations thrived and decayed on the quality of the iron they used and exported, whether they were able to win decisive battles because their soldiers were able to survive the enemy onslaught. Techniques were kept secret, as it meant the difference between being successful and being dead. This is why much of early metallurgy is hard to uncover, and has to be searched out in the far corners of libraries and history books, and only then can one discover the impact that metal played on the evolution of arms and armor.

IV. Europe

IV.1. High Medieval Ages - The Chain Mail and Other Armors (1100s -1200s)

IV.1.1. Chain-Mail

Chain-mail being light, flexible and durable was the primary source of defense before the addition of plate armor before the transition period. The word mail comes from the Latin word “Macula” which means net or mesh. It is a suitable description for the intricate network of rings and openings of mail armor. Mail was first used as early as 8th century but never really came into use in Europe until the high medieval ages. They were designed as loose-fitting shirts, known as hauberk, covered with either bronze or iron scales. The mail could be fashioned into any part of the body for protective covering such as the hands, or feet. They were mostly notably used during the time of the Norman invasion of England in 1066 and the 12th century crusades. They were widely used because the rings were relatively easy to manufacture and did not require a high skill level. The process, however, of interlocking the rings is rather labor intensive.



Figure 10. German Mail Aventail 1280.(42 Royal Armouries Collections, Online)

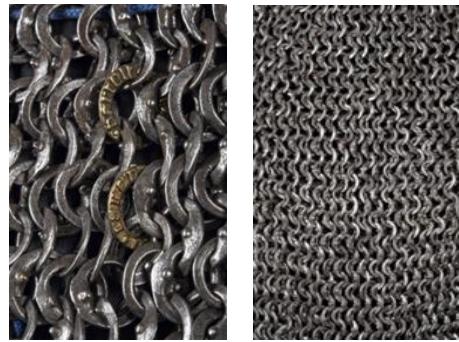


Figure 11. German Mail 1430.(Royal Armouries Collections, Online)

IV.1.2. Ring Making Process

The process of making mail ring was quite tedious and time consuming. First, sheets of metal were hammered so that they were thinned out. Next, the metal sheets would be cut into narrow strips and these strips would be heated and drawn through a conical hole to form circular wires. The strips would be continuously drawn out until wire reaches the desired diameter. Once the wire is drawn out, it is wrapped around a rod to form a series of coils. Finally, a chisel or saw would use to slice along the rod and open rings are then formed.

To form the mail shirt, each of the open rings would join to four or other six rings until the desire size is reached. In order to tighten the rings together, a rivet would be used to link each ring. This process is done by flattening the open ends of the ring and punching a hole at each of the extremities. This allows a rivet to be inserted through both holes. This long process was expensive and therefore regular soldiers could rarely afford this equipment. Figure 12 illustrates the process of making rings.

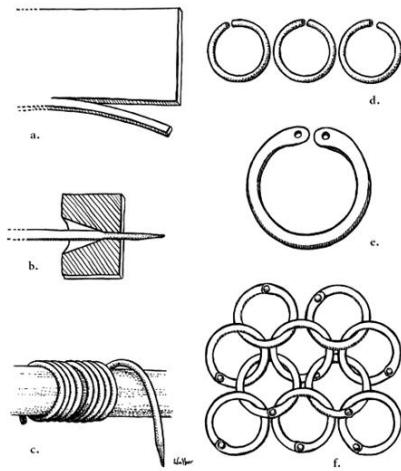


Figure 12. Making of the chain mail.(Newman, 2001)

Knights, who could afford it, would have mail covering made for feet, arms, legs and neck because the mail armor provided a versatile defense and was truly an effective defense. The design of the heavy rings prevented sharp point or edge entering the skin. The mail armor, however, was flexible and therefore could not protect against blunt weapons such as a mace or axe.

IV.1.3. Other Armors

At this time, Knights were fighting in crusades and their main type of defense was the shields, helm, and body armor.

The shield was still a major component of a knight's defense in the 12th century. It helped protect the entire body from any type of melee weapon. The kite and triangular were probably the most used shields for knights. The kite was a large triangular shield that protected almost the entire body of a knight. The top was shaped as an arch and was broad as a man's

shoulder but would become narrow as it stretched downwards. Similarly the triangular shield had the same shape but was straight at the top and not as large as the kite-shield.

The head was probably the most vulnerable spot in battle and therefore the helmet came into great play during the crusades. By the 12th century, almost all helmets were conical in shape. Although other shapes like flat-top and rounded helmets existed, the most preferred one was the conical shape for knights.

The last main component was the body armor. Of course the body armor was made of mail but the mail used in battles was not always consistent. Many hauberks used in battle varied in length. European armies' hauberk covered the body from the chest to the hip and was buckled by a belt, although the crusaders' hauberk tended to be loose and short.

IV.2. The Transition to Plate Armor

Although it was effective against sharp weapons like blades or daggers, the mail armor proved to be ineffective against weapons like the longbow or crossbow. Perhaps, even though it is disputed by historians and scholars, crossbows and longbows were the main reason why plate armor became more popular than mail in the late Medieval Era.

By the mid-12th century, longbows were mainly used by the British. The bow was tall as an archer and the arrows were half that length. Since the bow was so huge, the training required to master the longbow lasted for several years but the effectiveness of the weapon was devastating. The longbow decided many major battles such as "The Battle of Agincourt" where as few as five hundred English men were killed because of the combination of men at arms and long-ranged tactics. Longbows' effectiveness lies in their arrowheads which were

made of chisels or bodkins. They have a much sharper point, compared to broad-head arrow, which could destroy the link of mail armors.

Along with the longbows, the lethal crossbow was another mail-penetrating ranged weapon. The power of the crossbow was so devastating and inhumane that the Pope in 1139 had the weapon banned. Not only was it powerful but it was also easy to use; even an untrained peasant could kill a trained armor solider.

The cross bow and the simple bow were mostly made up of the same material but they differed in their design. There was no need for a person to hold the tension of the crossbow once the bowstring was drawn. Once the string was drawn, the tension in the bowstring was held by metal nut and was released by a trigger. This allows one to aim comfortably without worrying about the tension. The only drawback of this weapon is the slow fire-rate and short-range. In spite of these drawbacks, the crossbow remained a popular weapon in warfare outside of the British army because of its relative ease of use.

The introduction of plate armor was the solution against the piecing ranged weapons throughout the 1250s to 1400s before the dominance of full plate armor emerged. Plates of steel were used to reinforce chain-mail to protect the wearer from shocks or trauma when struck by a blunt object. These plates were attached to areas such as the knee (poleyns), elbow (couters), shin (jambe), and other joints. Although these plates were originally small reinforced additions, they would later become used on a much larger scale to protect the body.

Figure 13 shows the mixed use of mail and plate armor during the mid-14th century. Here we can see a soldier wearing a basinet helm connected to a camail which is a wide collar

mail. The body armor is a surcoat underneath which there is a surcoat: a chain mail with reinforcing plates for the arms and legs. It is also interesting to note that there is no visible shoulder protection made for this armor. Later as plate armor became more developed, larger overlapping plates were made to cover the shoulder.



Figure 13. Picture of Mixed Armor.(Hewitt)

IV.3. Dominance of Plate Armor (1400s – 1500s)

It was evident at the beginning of the 15th century that full plate armor was the most favorable form of armor for knights. Mail was no longer dominant in the industry because modern weaponry had surpassed the effectiveness of mail armor. Just like the mail armor, plate armor could be fashioned to cover any part of the body. Each of these parts would make up the entire suit of armor and each part would have their own significant uses. The next section will describe the individual parts of armor as well as touch upon two styles that dominated Italy and Germany during the 15th century.

IV.3.1. Process

Suits of plate were done through forging by armorers. To produce plate armors of good quality, armorers had to possess a good practical knowledge of metallurgy, good metal working skills, access to iron ores as well as the necessary tools to work and shape the metals.

Armorers would first hammer the metal into a flat sheet of metal. Hammering could be done at both hot and cold temperatures. Typical armorers would do hot-work to increase the carbon content in iron and thus making it stronger. After the metal is flattened, the armorers would cut the metal into the appropriate size plate and shape the metal through heating. This process is repeated until the desire shape is obtained. It is also very important to control the tempering of the iron piece so that the metal does not cool too rapidly and slowly, which causes the metal to become too brittle or too soft. Once the forging is done, the armor is sent to a millman who polishes the armor. Not much is known on the process of the polishing technique but it is known that millman use water-powered rotating wheel in their trade. Finally, decoration done through etching might be used when the armor piece is done. This gave the armor an artistic and wealthy look.

Armorers wouldn't always use metal when it came to plate armor. Some Italian armorers have experimented with whale bones, or boiled leather. Nevertheless, metal such as iron and steel were the popular choices for plate armor during the medieval ages.

IV.4. Evolution of Knight's Armor (List of Armors)

IV.4.1.1. Great Helm



Figure 14. Picture of Great Helm.(De Sutter, 2002)

The helm is one of the most charismatic points of a knight's armor. It is probably one of the armors you would notice first when you see a full suit of armor. There were a number of helms available to a knight but only a few really stood out. They were the great helm and bassinet.

By the 13th century, much experimentation was done on the conical helm to make it more favorable such as an attachment of a face mask or visor. These attachments allowed better ventilation and vision; giving the wearer more comfort while still providing a good defense to the warriors. The addition of face mask, however, did not protect the ears or neck. Thus, in addition to the face mask, a neck guard, ear flap and extension of the helmet to cover the entire head were introduced. This, perhaps, was the original blue print for the great helm. It was a large cylindrical helmet with a flat top which covers the entire head.

Later, the common great helm would be made from two plates or bars of iron which were fixed on the front, forming a cross; above the transverse bar, openings called vues or sights were pierced for vision, and holes were drilled lower down for breathing. This was the

typical helm for knight during the 13th century and it was still worn over a mail coif, to reinforce the area between the helmet and the mail shirt.

At the end of the 13th century, the Great Helm lost its flat top shape and the design became more conical. It was also drawn out on the bottom to touch the chest and a moveable visor was attached so that the mask could be open for better vision.

IV.4.1.2. Bascinet Helmet



Figure 15. Picture of Bascinet Helmet.(The Wallace Collection)

Although the great helm was favored over the conical helm, it had the disadvantage of being heavy and uncomfortable. By the 14th century, the bascinet helmet grew in popularity due to its light weight and comfort-ability.

The first bascinet was coined the “pig –faced helmet” for the shape of the movable visor that was attached to the helm. The helm itself was a small globular shape, pointed on the crown, and curve down on each side to cover the ears. The second bascinet was similar to the great helm except for the pivoted visor and triangular shaped nasal guard. Around 1330s, all bascinets became attached to a mail avente, or mail mantle which covered the neck and shoulders, and attached to a visor. The visor was then modified over time to completely cover

the entire face and became reputed for its arched pointed nose. By the mid-15th century, all type of bascinets became more conical and with the domination of plates, mail mantles were replaced by plates instead.

IV.4.1.3. Breastplate



[Figure 16. Picture of Breastplate.\(Online British Museum\)](#)

A breastplate was an independent torso armor which was introduced by 1350s. The breastplate protected only the upper chest area which made it very unique unlike the typical body armor such as the brigandine which only covered the chest and torso.

Around the 1370s, a skirt of hoops, or fault, was attached to the bottom of the breastplate in order to cover the rest of the torso. By the end of the 14th century, the breastplate once again changed in its appearance. A hinged bracket was fastened on to the breastplate to help hold lances. Another change was the attachment of an iron "V" shaped bar riveted to the neck of the breastplate; this prevented weapons like the lance from sliding into the throat.

The Breastplate shapes differed from those in Germany and Italy. German breastplates had a more curved shape; the upper part stretched out while the lower back inclined into the waist. Thus the entire armor was shaped like a rectangular box, but this would change during

the middle 15th century. The breastplate later became thinner, stretched with wave-like borders; this particular style was known as the “High Gothic”. Italian designs were known for their two-part breastplates. The upper breastplate was rounded and ended at the waist and the lower breastplate covered the waist and was fastened onto the upper one by buckles and straps. The Italian also commonly had a back-plate which attached to the breastplate along the shoulder and waist.



Figure 17. Maximilian style breastplate.(Castelnau Museum)

Interestingly, around the 1500s the popular style of German and Italian breastplate merged into a single production of breastplate. The breastplate became globular in shape with attached tassets, which protected the upper legs. These breastplates were known as “Maximilian” breastplates and were known for their decorative yet stiff ridges.

IV.4.1.4. Greave



Figure 18. Picture of Greaves.(Royal Armouries Collections, Online)

A Greave is a piece of armor that protected the lower leg. Plate greaves appeared around the mid-13th century and originally protected only the outside and front of the shin. Later as plate armor developed, the greaves protected the entire leg.

IV.4.1.5. Gauntlets



Figure 19. Picture of Hourglass Gauntlets.(Grandy, 2003)

Gauntlets are armor parts that serve to protect the hands, wrists and forearms. The most common gauntlets used in the early medieval ages were the “mail mittens” but were eventually replaced by plate gauntlets by the 14th century.

The earliest plate gauntlets were made from coat of plates; metal plates riveted together. Eventually, later designs of the gauntlets consisted of one large single piece of plate which covered the back and front of the arms and hands.

While 13th century plate gauntlets were loose cuffs, 14th century plate gauntlets became more “close – fitting” and were known as “hourglass gauntlet”. The reason these gauntlets were known as hourglass was because the plate was wide around the forearm but narrowed toward the wrist and eventually got wider again at the cuff.



Figure 20. Picture of Mitten Gauntlets.(Grandy, 2003)

By the 15th century, hourglass gauntlets were discarded in favor of mitten gauntlets. There is an excerpt written by Claude Blair which describes the 15th century mitten gauntlets. Blair describes the new gauntlets as protecting the back and front of the hand while being made one of one plate. The major change was how the gauntlet protected the fingers. Unlike the hourglass which provided a tight-fit around the fingers, the mitten gauntlets did not enclose the fingers but left the front exposed. One can think of it as a boxing glove but with only the back protection.

IV.4.1.6. Pauldron



Figure 21. Picture of Pauldron.(Forgeng, 2008)

Armor for the shoulder, a pauldron typically consists of a single large dome-shaped piece to cover the shoulder (the "cop") with multiple lamés attached to it to defend the arm and upper shoulder.

In the early 15th century, the most common style was a large squared shaped plate on the left shoulder and a smaller version on the right shoulder. Later throughout the years, the pauldron became less square shaped and more spread out in the back. Plates were also added to reinforce the pauldron.

IV.4.1.7. Sabaton

Sabatons were armor parts that covered the feet and consisted of riveted iron plates or over-lapping lame on the boots. Styles ranged from round, curved, or long-pointed toes. During the 14th century, the most popular design for the Sabatons consisted of narrow overlapping plates shaped like a pointy shoe which covered the top of the foot and was attached by the laces to a leather base. Even by the 15th century, when full plates emerged, sabatons style did not change much with the exception of introducing rounded shoes.



Figure 22. Picture of Sabatons.(Royal Armouries Collections, Online)

V. Mongolian Armors

During the medieval ages, the Mongol army under the rule of Genghis Khan was considered superior to other armies due to their great military performances and their invasion of many territories across Asia and Europe. No army in history has conquered as much land and won as many battles as the Mongols. Their superiority is not only attributed to their overwhelming numbers but also to their weapons and armors. Mongol armies consisted of horseback archers, and light and heavy cavalry. The preferred weapon of the Mongols during that time period was the bow and they had a wide variety of arrows. Each arrow had a specific purpose such as armor piercing, blunt stun and instant killing if the arrow was poisoned. The soldiers also had sabers, maces, axes and spears with hooks at the bottom of the blade.

Their armors were usually lamellar and made up of layers of hardened leather and metal plates. It is the reason why only very few Mongol armors from the Medieval Era were recovered, leather decay over time and the metal plates were usually collected after battles. The armor was usually worn over their daily attire which consisted of a heavy coat fastened by a leather belt at the waist.

Leather was a convenient material for them to use as it was light, easy to wear and long lasting. Mongol warriors were generally horse riders and leather also gave them more mobility and flexibility of movement. The leather was usually softened by boiling it and then molding it or pressing it into lames in order to make the lamellar armor. On drying, the leather would harden and retain the shape given to it. The hardness of the leather was determined by the drying temperature, wet leather usually becomes tougher if moderate heat to dry the leather is used.(Royal Armouries Collections, Online) The leather was then covered with a lacquer. The lacquer was to protect the leather from humidity and the fish glue was a natural weather resistant material that protected the leather from humidity. The metal plates usually made of iron were added to the leather in order to protect the warrior from arrows and sables. The metal plates were assembled in an overlapping pattern and they were usually sown into the leather. The leather was pierced and holes were made for sowing the iron lames. Silk and metallic threads were used for sowing. Mongolian armors are different from other usual armors in that they focus more on flexibility and less on endurance. They were composite armors and were not as stiff and heavy as other armors.



[Figure 23. Lames in an Old Mongolian armor.](#)(University of Washington, Online)

Due to the very cold weather in that part of Asia, the Mongol warriors wore fur or sheepskin caps with long earflaps to protect their ears from the cold. The helmets had

ornaments like feather, horsehair tufts, horns and other elements which were used for intimidation purposes. They were supposed to protect the warriors from the evil spells.

A helmet was a must in the military equipment of professional Mongol warriors. It protected their head from blows and was a symbol of the authority of the warrior wearing it. A warrior wearing a helmet was named "duulgat". The helmet design and its material composition differed depending on the rank of the warrior and his social status. In the late Medieval Era, helmets were usually conical in shape and the upper part was made up of iron and steel plates or hardened leather. The neck was covered with layers of leather and hardened leather pieces for protection.



[Figure 24. Picture of Mongol Helmet.\(Hermitage Museum, 2011\)](#)

The headpiece in Figure 24 can be traced to the 13th or early 14th century. It is said to have belonged to the Golden Horde which refers to the Western part of the Mongol empire in Eastern Europe: Ukraine, Moldova and Kazakhstan. During the mid-13th to the end of the 14th century, the Golden Horde was a prominent part of the Mongol empire. The Golden Horde consisted of the Turks and the Mongols; the Mongols being considered the aristocrats.

Like the helmets in Eastern Europe, the helmet in Figure 24 has a low, sphero-conical crown with a visor with openings for the eyes which were used to protect the upper part of the face as well as the nose. The helmet is also characterized by ridges on its upper part which is a distinguishable feature of the Golden Horde. The helmet is made of iron which is then covered with a thick layer of gild. Under the gilding, there is a layer of silver sheet which helps the gild to shine more brilliantly. On the side of the helmets, there are small holes which were used to attach a chain mail.

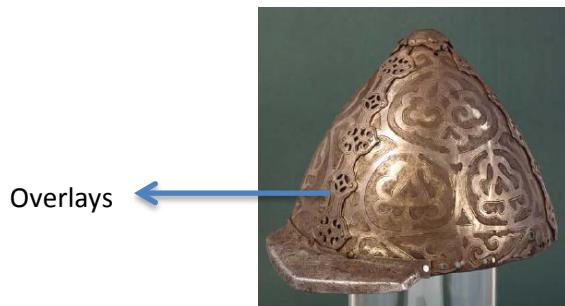


Figure 25. Mongol ceremonial sphero-conical helmet.(Bobrov & Hudiakov, 2005)

The helmet shown in Figure 25 is another sphero-conical helmet which can be dated to the 15th to 17th centuries. The high precision of artistic detail indicates that it must have been made especially for highly ranked individuals. Even during the late Medieval Era, it had a great value.

It has a combination of a sphero-conical dome and a forehead plate with a “box-shaped” visor that is traceable to the late Medieval Era. It is made of iron and belongs to a class of riveted crown. The helmets in this class are made up of plates that are assembled with overlays and rivets. Its dome is made up of three triangular plates which are assembled together at the top. The joints are camouflaged by narrow overlays which have five gaps in the form of slotted circles and double-ended curls with a rhombic opening at the center.(Bobrov &

Hudiakov, 2005) Unlike the previous helmet, this headpiece shows is decorated with silver printing. The lower edge of the cone contains a floral arrangement pattern and the visor has a kind of vine sprout pattern. At the base lower edge of the cone; there are six holes which were most likely used to hold the Barmitsa. The Barmitsa was a chain mail attached to the helmet to hang down over the shoulders and its role was to protect vital areas of the body such as the neck and part of the face.

It is also interesting to know that beneath the armor, Mongol warriors wore a silk fabric undergarment. It might not be considered military equipment but in fact, silk is a very tough and resistant material. Arrows that were shot from a long distance could not easily pierce the silk. The silk fibers act as a cushion for arrows that have been slowed by the armors but have pierced the skin. The arrow would usually end in the wound with silk wrapped around it. Silk made it easier and less painful to remove the arrow; the arrow was taken out of the warrior's body just by slightly opening and stretching the silk. It did not hurt as much as when the barbed head of an arrow is removed and tears the flesh of the injured warrior. Silk also prevented the poison sometimes contained in arrows from spreading inside the human body.

From the 1300s to the 1500s, as the Mongol Empire was growing and amassing riches, the military army invested mostly into the production of warfare equipment. There were many workshops all over the Mongol territory, which were making many weapons and armors. They melted their own metal to produce armors.

VI. Japanese Armors

The late Medieval Era was known as the Ashikaga era or most commonly as the Muromachi period. This part of Japanese history runs approximately from 1336 to 1573. Muromachi comes from the district in Kyoto where the Ashikaga family was residing. The Ashikaga family had the political over Japan during this time period. It was during this time period that the Japanese was able to resist two major Mongol invasions and given the military power of the Mongols during that time period, it was considered a triumph for the Japanese.

War was a central theme during the Muromachi Period where there was a feudal system. Political power was associated not with political ties but with military strength. The daimyos ruled during this time period and they invested their resources in making weapons, armors and the Bushido. It was then that the Samurai gained popularity. They were experts at fighting on the ground and on horseback.

Early Samurais used bows and arrows to fight; in fact they were often referred as “men of the bow”. The daikyu or the longbow was the favorite weapon of the samurais since it could shoot arrows over long distances. It was usually more than 6.6 meters long and made from wood, bamboo and reinforced with palm stems. The bow string was often made of very strong and tough plant fibers like hemp or ramie. They also used the short bow or the hanyu for battles as they were easier to carry and handle. The arrows were usually made from reeds and a variety of different sizes were usually made. The sizes of the arrows depended on their use and, in battles samurais would use arrows with steel heads which was strong enough to cause concussions.

However, after the Mongol invasion in the late thirteen centuries, Japanese warriors started to make greater use of the sword and spears. Their swords were made up of iron and carbon. Fire, water, anvil and hammer were used to produce the sharp and tough swords that the samurai wanted.

In general, Japanese armors were lighter and more flexible than the chain mail and the plate armor used in Europe. They were also among the most colorful armors in the world. The armor producers in Japan used a combination of malleable materials like wrought iron, silk, leather, lacquer, dyed textiles along with metal plates. The leather used was usually cowhide and the preferred hide was usually the cow's back. The leather in this part was thicker. The Japanese armors were also easily transported and stored since they could be folded or collapsed. The material used, the color of the lacing as well as the lacing pattern of the armor were used to identify clans, highly ranked warriors and officials. There were certain armor designs specially reserved for them.



Figure 26. Different lacing style.(Bottomley & Hopson, 1988)

Japanese armors had a defensive advantage compared to other types of armors that existed during the Medieval Era. They were better at absorbing shocks from blows received. This is because the energy from the blows were actually diffused and propagated through the

layers of overlapping scales and lacings of the Japanese armors. One of the other favorable aspects of the Japanese armors was their ease of repair. The damage done to the armors could be repaired by the warriors on the field. The individual scales or zanes were also recycled so that they could be used into new armors though a process called shigaeshi.

VI.1. Main Parts of Japanese Armors

The armor worn by the samurais evolved with time but their armor was basically the same with a few minor changes. The full armor suit was usually made up of 23 or more elements but it was basically made up of

- 1. A Kabuto** - It was the helmet which protected the head. It is made up of two main parts: hachi the bowl and shikoro which is the neck part.
- 2. A Do** - It is the cuirass which is worn over the torso and is the biggest part of the samurai armor.
- 3. A pair of Sode** - Its purpose was to protect the shoulders. It covered the arms from the elbow to the shoulders and was usually rectangular in shape.
- 4. A Kusazuri** - It was an armoured skirt or apron and it was used to guard the upper thighs. It was held by the suspending cords to the lower end of the cuirass.
- 5. A pair of Suneate** - It was used to protect the shins
- 6. Haidate** - It was used to protect the thighs but it was rarely worn on the battlefield.

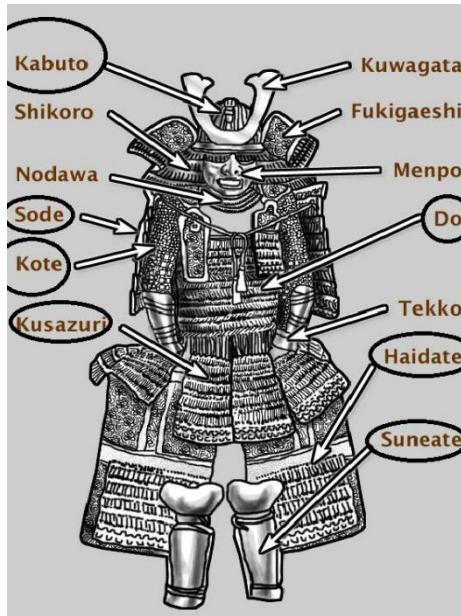


Figure 27. Parts of a Japanese armor.(Boris, 2003)

The pieces of the Japanese armors were made up of Kozane which was a small set of scales made from iron or rawhide laced together by a leather cord or silk braids. The hide came from both cattle and horses. They were prepared by soaking them in water which loosened the hair and fatty tissues as a result of bacterial fermentation. They were then cleaned, stretched and dried to give a tough and translucent material.

Iron scales were used in areas where greater protection was needed to cover the body vital areas. Over the years, the size of the Kozane changed to become smaller; it became shorter and narrower. The scales that the Japanese were using also grew curvier; the kozane became more of an “s” or “c” shape. The curves made the armors more flexible and firm. Different sizes of kozane were used depending on the armor part. The kusazuri, the sode and the other armor parts all had sizes of Kozane. The scales were usually pierced with holes so

that they could be laced together. There are two primary types of Japanese armor scales: hon kozane and iyo zane.

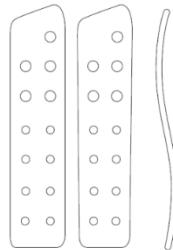


Figure 28. Kozane.(Bryant, 2003)

VI.1.1. Hon Kozane

Hon Kozane's English translation means true small scales. It is the earlier form of scale and the scale has a trapezoidal shape. The hon kozane scales overlapped each other by about half or two third of their width. To make a Japanese armor, thousands of hon kozane scales were usually needed.

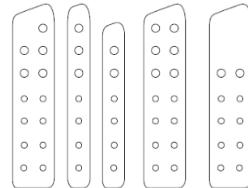


Figure 29. Main types of Hon Kozane.(Bryant, 2003)

VI.1.2. Iyo Zane

Iyo Zane scales were usually characterized by the cut in their upper ends. The cuts had different shapes and the rows of holes in the iyo zane were more spaced than they were in the hon kozane. The iyo zane only overlapped at their ends and therefore, fewer scales were needed to make armor. Armors made from Iyo Zane scales were hence faster to produce since

fewer scales were used. Armors made from Iyo Zane were lighter since they had less scales and did not offer a good protection to the warriors.



Figure 30. Iyo Zane.(Bryant, 2003)

VI.1.3. Odoshi

The kozanes were assembled together by a process called Odoshi. It was considered to be an art because lacing with different colors produced different patterns from which the clan of a warrior could be determined. Some of the patterns are shown in Figure 26. Tight, elaborate lacing of the armors was for higher ranking warriors whereas looser and wider lacing was for the lower ranks of soldiers. The materials used for lacing were usually leather and silk braids. Silk was preferred since it was available in a wider range of colors and they were available in longer strips than leather. The threads were braided together using a loom or a frame in which the workers knelt. Once the threads were braided, they were used as lacing for the armors. There are several types of lacing, but for this IQP, we will focus on two main ones: Kebiki Odoshi and Sugake Odoshi.

VI.1.3.1. Kebiki Odoshi (Close Lacing)

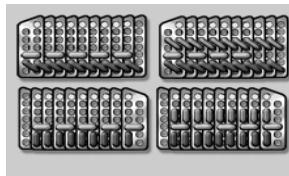


Figure 31. Scales with Odoshi lacing.(Boris, 2003)

Kebiki Odoshi means close lacing and it is one type of Japanese lacing. The lace used was usually rich and thick as there were usually no apparent gaps between the scales. This type of lacing starts by assembling the scales in rows forming broad plates. It was used to hold one board to the next as the lacing went back and forth between two boards. The lacing ran either up and down or diagonally through the plates. The lacing starts from left plates to right ones; the diagonal lacing goes from south west to north east.

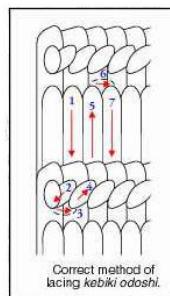


Figure 32. Steps for an Odoshi Lacing.(Bryant, 2003)

VI.1.3.2. Sugake Odoshi (Loose Lacing)

It is a later type of lacing that was used to save money and time at the end of the 15th century. It is much simpler to make than the kebiki odoshi since it has less holes, less lacing to do and is therefore not as time consuming. Unlike the kebiki odoshi, it runs through more than two pairs of lames and it can be easily recognized through an "X" that appears on pairs of

braids. The lacing cord usually runs from the top to the bottom of a whole piece and the lacing is also usually at the back of the lames. Sugake odoshi makes use of bigger and thicker threads and when properly done, there is no space between the pairs of lacing cords. The lacing was also done at a wider interval to save labor and material.

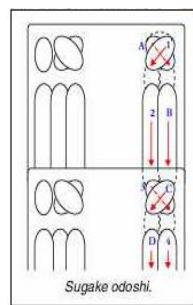


Figure 33. Steps for a Sugake Odoshi.(Bryant, 2003)



Figure 34. Sugake Odoshi in a Do-maru.(Royal Armouries Collections, Online)

VI.1.4. Lacquering

The plates and leather parts of the armor were often lacquered to prevent them from damp which causes the iron plates to rust and the leather to soften. The lacquer used was a non-resinous substance which is like the sap of trees. It is obtained from trees just like latex is tapped from rubber trees. The lacquer comes from a tree whose botanical name is "*Rhus Verniciflua*" and originates from East Asia. After each layer of lacquer has been applied, it is allowed to dry and harden before another layer is applied. The lacquer behaves as a natural polymer which adheres to the surface of the object applied. The lacquer will prevent the metal

from being exposed to moisture, insects and mild acids for some years. It also improved the strength and the durability of metal without increasing the weight of the armor. Furthermore, it makes the metal plates less shiny and hence less conspicuous from the enemies during the day and at night. In Asia, natural dyes were also added to the lacquer for design and decorative purposes. Beautiful colored dyes were obtained from blossoms, stems, vegetables and roots of various plants. Blue lacing, for instance was obtained from indigo and pink lacing from plum or cherry blossoms. The lacquering of armors was usually done by a lacquer specialist who would do the lacquering and the artistic part of the work. Each armor workshop had a lacquer specialist.

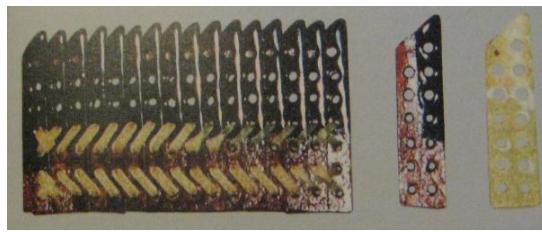


Figure 35. Lacquered Zanes.(Ogawa, Harada Kazutoshi;Ikeda,Hiroshi)

VI.1.5. Kusari

Kusari stands for mail, it also means chain in Japanese and when it is used with another word, it means that the object is made of mail. Mail was introduced during the Nambokuchō period in Japan which spans 1336 to 1392 before the Muromachi period. Unlike Europe, mail was not used as a mean of defense but rather to fill gaps between plates and minor parts of the armor. It is based on a system of circular links which lay in the section of the mail and oval links at right angles to it.(Bottomley & Hopson, 1988) Each link was made by coiling the wire on a mandrel with the shape and geometry needed then cutting the wire on the side with a chisel. The individual links were squeezed to keep them closed unlike in Europe, where the mail was

riveted. Each circular link was then connected to four others with oval links leading to a rectangular arrangement known as gusari.

In places where more strength was required, the mail links were made from 2 or 3 turns of wire which led to double or triple mail known as seiro gusari. In places where a greater flexibility or lighter protection was needed, such as near the elbow, rectangular spaces were left between the oval links in the mail. This type of mail was known as so gusari.

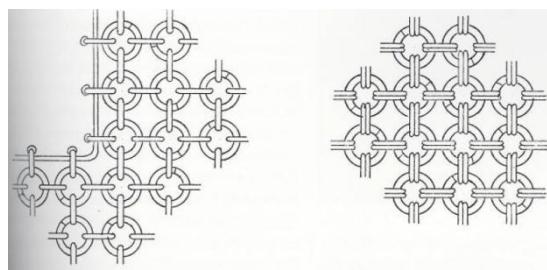


Figure 36. So Gusari (Left) and Seiro Gusari (Right). (Bottomley & Hopson, 1988)

Mail was usually used in the armor in combination with other material but never by itself. It was sewn onto some sort of fabric or leather backing or sometimes it was placed between layers of fabric. Just like the zanes, mail was lacquered as well to prevent rusting. A black lacquer was most often used.

VI.2. O-Yoroi

The O-Yoroi was the armor that was worn by highly ranked samurais as well as upper-class Japanese officials. It was used by the samurais between the 10th to the early 14th century in the Gempei wars and against the invasion of the Mongols in 1274 and 1281. Furthermore the O-Yoroi was a beautiful and heavy armor with intricate design. It was made up of both lamellar and plate elements. It has a multi-colored lacing pattern that was used to identify the

clan to which the warrior belonged. It was suitable for mounted warriors on horseback like cavalrymen and archers.

The O-Yoroi had a box-like appearance with a large square sode and a large kusazuri. It was also characterized by its cross section, which was similar to the Latin letter "C". Its cuirass was made up of three lamellar boards which protected the back, left and front part of the body. The boards were made up of konzane which were laced together with silk cords. The right part of the body, where the "C" part was opened, was protected by a fourth lamellar board: the waidate. It is where the warrior would enter and exit the armor. The waidate was attached to the body by two silk cords, one at the waist level and the other one across the chest over the left shoulder.

The front part of the cuirass plate was covered by the tsurubashiri which was a leather panel. Its main purpose was to protect the warrior's bowstring from being blocked and damaged by the scales. The tsurubashiri was usually decorated with designs, patterns and pictures of Japanese deities. The O-Yoroi shown in Figure 37 has an image of Fudo Myo-o who was a Buddhist deity revered by the samurais for the attributes like calmness and inner strength. The colored lacings around the edges of the skirt represented the rainbow which was a symbol of good fortune and fleeting beauty.



Figure 37. An O-Yoroi dated from the mid-14th century.(Tokyo National Museum)

The helmet was often shaped as a hemispherical bowl with a slight conical tendency which is known as Hachi and it was made from trapezoidal iron strips riveted together. The rivets were usually large and dome headed and they were placed along the rear edges. The heads of the rivets were made hollow in order to reduce their weight as well as that of the helmet. Attached to the base of the Hachi was a neck guard which protected the neck.

Sendan no ita and kyubi no ita are two asymmetrical plates which protected both the armpit areas in front of the cuirass and the shoulder straps. They were movable sections which were tied to the shoulder straps. Sendan no ita was usually made up of three thick plates or rows of scales lined with leather. It was square in shape and was worn over the right armpit. Kyubi no ita was more rectangular in shape and longer than the sendan no ita. Both sendan no ita and kyubi no ita were usually made of steel plates and rarely made of lacquered leather.

The shoulders and the upper arms were covered with a pair of sode. The sodes, the shoulder guards, consisted of six or seven rows of scales, and the top part of each sode had a

long plate of steel tied to it. They were usually large and flat; their area was more than one square foot. The shoulder guards were attached to the cuirass via the shoulder straps or watagami. They were attached with a complex system of leather strips and silk cords tied to the rings on the shoulder guards. The sodes offered good protection to early samurais who were mostly horse archers.



Figure 38. Sode 1352.(Bottomley & Hopson, 1988)

The lower part of the body and the upper thighs were protected by the Kusazuri which is the skirt part of the armor which is laced to the bottom of cuirass by suspending cords. The kusazuri was made up of four trapezoidal scale constructions which would just fold outwards like an umbrella from the body when the samurais would mount the horses. Therefore the kusazuri facilitated horse-riding for the warriors.



Figure 39. Open O-Yoroi.(Bottomley & Hopson, 1988)

The legs and knees were protected by greaves: the suneate, which were usually made from steel and leather. The suneates were for the most part made of several longitudinal plates hinged or sewn together to padded leggings. On the inner side of the greaves, there was often a leather guard which offered protection from stirrups or saddle fiction.

The kotes which are the armored sleeves consist of individual metal covers for the hands, lower arm, upper arm and elbows which are assembled together by a flexible iron mesh and sewn onto textile sleeves. They were considered less important than the body armor and the helmets and were therefore not worn as much.



[Figure 40. Kotes.\(Ogawa, Harada Kazutoshi;Ikeda,Hiroshi\)](#)

Usually the kote: the armored sleeves and the suneate would contain the same design and fabric even though they had different forms. The cuisses called haidate were invented around the 13th century and it was the last piece of armor to be created and added to the armor. They look like apron; the lower part consisted of kozanes of iron, leather and sometimes whalebones. They were however rarely worn on the battlefield because they tended to obstruct movements of the Japanese warriors.

VI.2.1. Disappearance of the O-Yoroi

In the 14th century, the O-Yoroi started to disappear because they were gradually becoming impractical for the battles. During that time, more and more battles were being fought on foot instead of horses and the war campaigns were also becoming longer. O-Yoroi was too heavy for the battles and did not provide enough flexibility and freedom of movement for the hand-to-hand combat during that time period. As a result, the samurais opted for the Do-maru, which is the armor worn by the foot soldiers. It was lighter and easier to fight in. The O-yoroi remained within the highly ranked samurai families and ancient armories as symbol of their status and family pride. It was used for official ceremonies or parades

VI.3. Do-maru

The do-maru is another type of Japanese armor which appeared in Japan in the 11th century and was usually worn by foot soldiers. It was much simpler in design and structure than the o-yoroi and also allowed greater freedom of movement. It surrounds the soldiers' body around the front and both sides from the chest. Do-maru actually means around the body in Japanese.

Do-maru has a lamellar construction and does not have any hinges. Because the armor was to be as light as possible, iron in the armor was used only to cover the vital parts of the body. Leather was used to protect the rest of the body. Overall the do-maru was more comfortable to wear than the O-Yoroi since it was less bulky and lighter to wear. It was also more form fitting than the O-Yoroi; the armor was tied together under the right arm which made it possible for foot to put on their armors without extra help.

Unlike the O-Yoroi, the do-maru lacked the sodes or the shoulder guards which were deemed cumbersome and impeded movement of the Japanese warriors. In its place, they had very thin leaf-like plates: the gyoyo which was laced to the watagami or the shoulder straps. The cuirass or the do was secured using two cords: one at the level of the waist and another one at the level of the chest.

The kusazuri, the skirt part of the do-maru, was divided in more sections than in the O-Yoroi, usually seven to eight sections to allow more movement. The freedom of movement was necessary for the warriors who usually ran or walked mostly near the houses of the daimyos. It was also smaller and was gently curved downwards so that it did not protrude outwards as much as the skirt of the O-Yoroi. As a result, the kusazuri fitted the legs better giving the region below the waist a bell shape structure. The armor also had a tighter fit around the waist; this was done by tapering (thinning) the lower end of the lames above the waist region thinner. This slight change caused some of weight from the shoulder to shift to the hips.



Figure 41. Do-maru from Muromachi Period.(Ogawa, Harada Kazutoshi;Ikeda,Hiroshi)

The Do-maru in Figure 41 is from the late Muromachi period; the body length is about 33.9 cm and the kuzazuri is about 28.8 cm. Its main parts were made from small iron scales and black lacquered leather plates using the Keibiki-odoshi method just like the O-Yoroi.



Figure 42. Keibiki-odoshi lacing in a do-maru.(Tokyo National Museum)

The helmet shown in Figure 43 is 10.8 cm in length and it can be traced to the 14th century. It was made from fifty two narrow strips of iron assembled together with small star-shaped rivets. After the assembly, the helmet was then covered with a layer of lacquer. The particular helmet has a gilt holder called kuwagata joined to the visor. The kuwagata is engraved with a design of chrysanthemums on a fish-egg pattern. Another horn like gilt is supported by the kuwagata holder together with the maedatemono: the main helmet ornament with the Chinese bell flowers made with black lacquer and gilt.



Figure 43. Helmet of a Do-maru.(Tokyo National Museum)

VI.4. Armorers in Japan

Due to the use of different materials like silk, iron, lacquer and copper in the making of the armors, a number of different specialists were needed for their different skills. There were craftsmen who were specifically made the sane: the small scales and they were called saneuchi. There were artisans who made fashioned and dyed the leather, others who made the braids, applied the lacquer and forged the metal fittings and mail. During the late Medieval Era, most of the armors were produced in Nara and Kyoto which at that time were famous for armor making. There were also some local production facilities which supplied the military needs of powerful daimyos. During that time, there were many schools of armorers where armor makers were trained. Handa, Haruta, Iwai, Sakonji and Wakito were well known century school of armorers during the fifteenth and sixteenth centuries. Each of the school has an area of specialty. For instance helmets signed by Haruta armorers suggest that the school was more specialized in iron work while the Iwai of Nara were more focused on assembly and lacing of the Japanese armors.

VI.5. Japanese Battle Casualties

The results of battle analyses carried out by Shakado Mitsuhiro (Friday, 2007) show that seventy percent of wounds mentioned in the casualty reports occurred in the legs and arms. These parts of the body were not covered by armors like the O-Yoroi. The majority of the wounds to the chests and the head were from the regions not protected by the helmets and the cuirasses. The face, the lower neck and underarms usually were the parts of the body which experienced the most injuries among the elite warriors. The foot soldiers faced more wounds on their arms because they did not wear kotes on both arms to protect themselves.

Thigh and calve wounds were the most frequent; they consist of forty one percent of the casualties because the lower part of the body were not usually covered by armor pieces.

VII. Ottoman Empire

The style of armor indicative to the medieval Near East was unique in design compared to those in Western Europe. At the Empire's largest size, the boundaries extended from just outside Venice in the West, Hungary in the North, Egypt in the South and Iran in the East. In 1453, the Ottoman Turks took Constantinople, the capital of the Byzantine Empire and a major trading post between Europe and Asia, and made it their own capital, Istanbul. Being at the center of so many different cultures and having so many widespread conquests led to a style of armor heavily influenced by the empire's constituents and trade partners. One example of this is the conical, or turban, helmet.

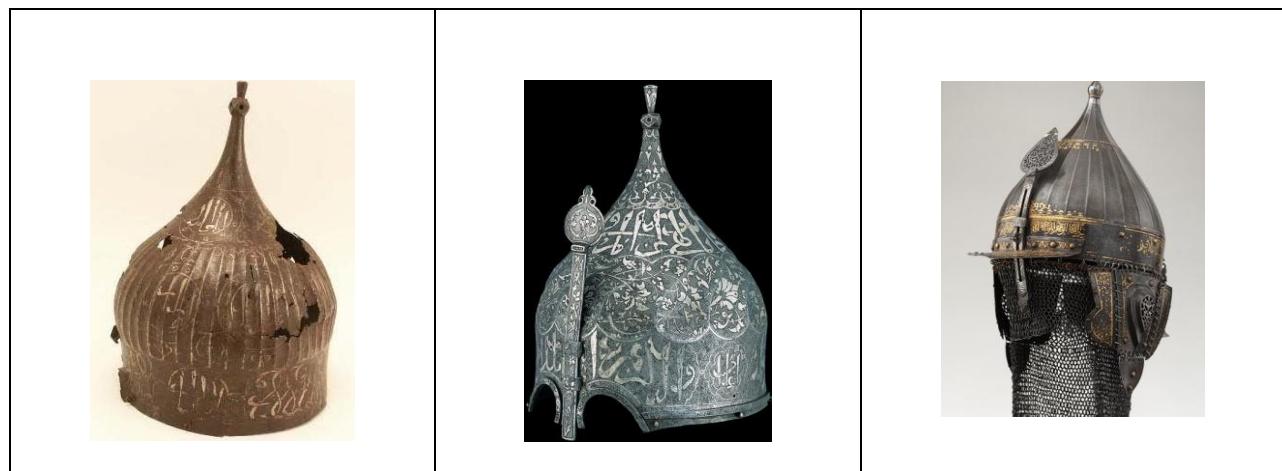
A turban helmet is characterized by its pointed cap, sometimes topped with a pendent. Its larger diameter allowed it to be worn over a turban and without padding, hence its name. Common to many, turban helmet was a small strip of metal that extended from the brim of the helmet over the nose, called a nasal. The two main influences for the design of this helmet were the Persians, of present day Iran, and the Malmuks, of present day Egypt. Despite these cultures being separate geographically, they were linked by trade with the nomadic tribes that moved through the area. For this reason the variations of the turban helmet were found in both regions. Persian helmets tended to have two semi-circular cuts in its brim for the wearers' eyes. Aside from the helmet itself, no extra protection was afforded for the face or neck. Malmuk helmets were often found without the holes for the eyes but they did have an aventail,

a section of mail attached to the helmet to provide protection for the face, neck, and shoulders.

The helm used by the Ottomans by the 15th century was a combination of these two designs.

The featureless brim of the Malmuk turban helmet was kept, but the aventail was eschewed as

well. Many of these “Turkish” style helmets were damascened.



[Figure 44. Ottoman Helmets.\(Higgins Armory, 2011\), \(The Metropolitan Museum of Art\)](#)

Damascening was a metal working technique used for armor, swords, and jewelry in the Ottoman Empire, and it was used heavily and to great effect. First, the surface of the metal is chiseled and the interior of the cut is roughened. Then, a precious metal, gold or silver, is laid in the groove and hammered into place. Damascening was not created by the Turks, but the Near East has a strong affinity for richly decorated arms.

The hot climate and highly mobile battle style required a different style of armor than the heavy plate armor of Western European knights. The infantry of the Ottoman Empire wore plate mail: armor made from small oval or rectangular plates that were attached to each other, although not overlapping like in chain mail or lamellar armor. These plates covered the chest, abdomen, and back. The rest of the body was covered in chain mail. The plates offered

additional protection to the vital areas of the body while still maintaining the lightweight and flexible nature of chain mail. The total weight was only approximately 25 pounds. Two kinds of designs were used prominently in the Ottoman Empire: Bakhterets and dyawshan, both originating from Persia. The difference lies in the size of the rectangular plates used in the armor. Bakhterets uses many smaller plates while the dyawshan style uses 100 larger plates. From there it migrated to Mongolia, Russia, and then Turkey.(Nalley) Another design common later in the Ottoman Empire (16th-17th centuries) is the “pot-lid” plate mail. This design featured a large disc of metal in the center of the torso and back and was surrounded by mail and augmented with the small steel plates found in Bakhterets and dyawshan.



Figure 45. Bakhterets (Left) and Dyawshan Designs (Center) from Persia (Hermitage Museum, 2011), Pot-lid armor (Right). (Robinson, 2002)

Another metalworking technique used in armors and weapons of the Ottoman Empire was creating Damascus, or watered steel. Damascus steel is characterized by its alternating light and dark bands that form strata in the piece. This exotic material was first discovered in India and then began to be produced in Syria. To create steel, the carbon content of the iron

being worked must be controlled precisely to around one to three percent. This feat was difficult to accomplish. To create steel, blacksmiths melted iron ore in furnaces that were unable to heat the iron to the high temperatures required to melt and homogenize it. When cooled in a crucible, various layers of different strength steel and cast irons. What these medieval metalworkers were able to do, however, was create bands of steel and a darker, high-carbon iron alloy called cementite by welding the iron and steel layers. This cementite is harder but more brittle than steel, allowing it to keep a sharp edge well but cause it to lack durability. By alternating bands of cementite and more flexible steel, a balance is struck, producing a weapon with excellent qualities.

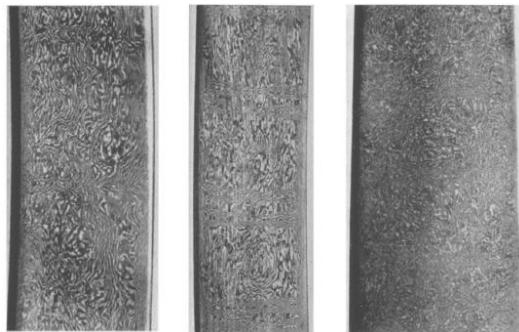


Figure 46. Damascus Steel.(Grancsay, 1958)

VIII. Making Of the Armor

VIII.1. Making Of the Shoulder Piece

Our group tried to make the shoulder guards of a European armor using traditional hand tools like hammers, shears and files. During the Medieval Era, blacksmiths had similar tools but they were probably bigger, heavier and less ergonomic.

VIII.2. Steps for Making of Shoulder Part

1. Before making the armor, we drew the different components of the shoulder guards on paper. The measurements we used were in inches and the drawings are as follows:

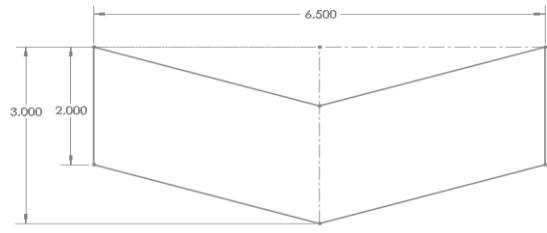
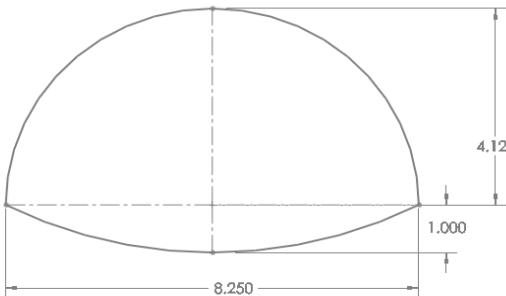
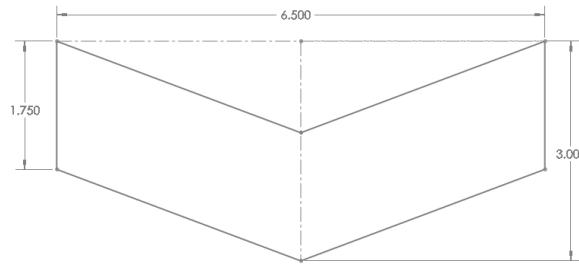
Part	Drawing
A	
B	
C&D	

Figure 47. Drawings of shoulder components.

Using the paper as stencil, we then drew the outline of the paper on a sheet of metal.

The metal sheet that we used was made of steel containing around three to four percent carbon.



Figure 48. Tracing of shoulder components on metal sheet.

2. Once the outlines are drawn on the metals, shears with different cutting angles were used to cut the different pieces of the shoulder guards. When we used the right most shears shown in Figure 49, we had to leave a gap between the pencil line and where we were cutting as the curvature of the cut tends to be more inwards.



Figure 49. Cutting of metal pieces with shears.

3. After cutting, we used a file to smooth the edges and get rid of the dangerous sharp edges. According to Fay Butler, blacksmiths would take a quite thick and hard piece of steel and upset its surface in a consistent pattern using a sharp object like a chisel. After the dents were made at a certain angle, the surface of the metal would become irregular and it would have some small projections or teeth. The piece of metal would then be soaked in horse urine. The effect of the acid in the urine would sharpen the

small projections on the metal surface sharper and give the metal surface an abrasive effect.



Figure 50. Filing of metal pieces.



Figure 51. Picture of cut pieces.

4. After cutting and filing, the next step was to give the different pieces of the shoulder guards a curvature. For this purpose a hammer and a piece of metal block with a smooth surface were used.

To get a smooth surface, Fay butler used an abrasive to polish the surface of the metal block. The left picture shows strips of abrasives with different surface roughness. The strips are tied to a circular rotating wheel and the metal block was pressed against it.



Figure 52. The abrasion process.

The diameter of the hammer head is also important because it will determine the curvature of the metal piece after hammering. Since one of our hammers was a too flat as shown in leftmost picture in Figure 53), Fay Butler adjusted it by using an abrasive to change modify the edges and hence change the diameter of the hammer. In the right picture, sparks are coming out of hammer under abrasion and this is because of the carbon content in the steel of the hammer. Steels with higher carbon content tend to produce more and shorter sparks under abrasion.



Figure 53. Changing of hammer head radius.

Figure 54 shows the filings of the hammer after the abrasion process. The filings from our hammer are very small and dust like because the abrasive material that we used had small and sharp teeth. The bigger filings shown in Figure 54 come from another piece of metal from which a greater layer of metal was taken off and a bigger teeth abrasive material was used.

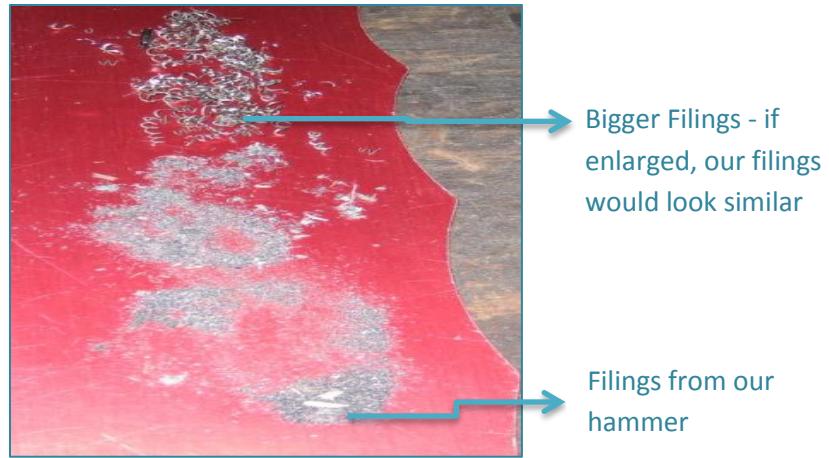


Figure 54. Picture of metal filings.

To get a slightly dome shaped of part A and smooth finish and, we hammered it to bend the metal. This process only involves folding the metal. When hammering, pressure has to be applied in the center of the piece and less pressure on the outer edges like shown Figure 55. This step is then repeated for the other remaining identical parts.

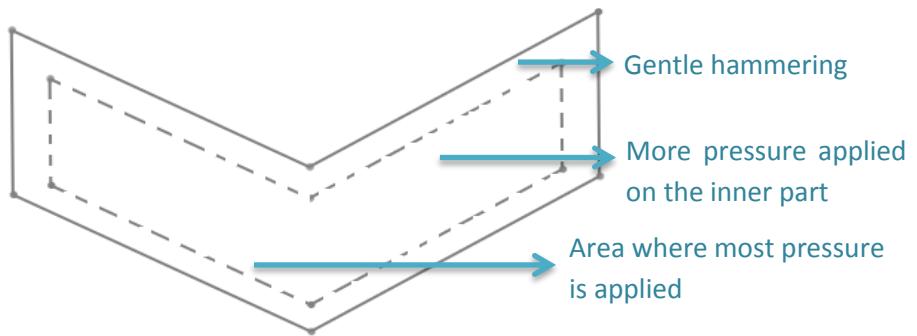


Figure 55. Drawing of hammering areas.



Figure 56. Hammering of metal pieces.

5. The hardest part of the shoulder was to get a dome shape out of Part B which looks like half circle. This process involves shaping and the folding of the metal sheet. The first step was to make a tuck in the metal using the straight peen hammer like shown in Figure 57. The tuck that we made was about one third of the length of the metal piece.

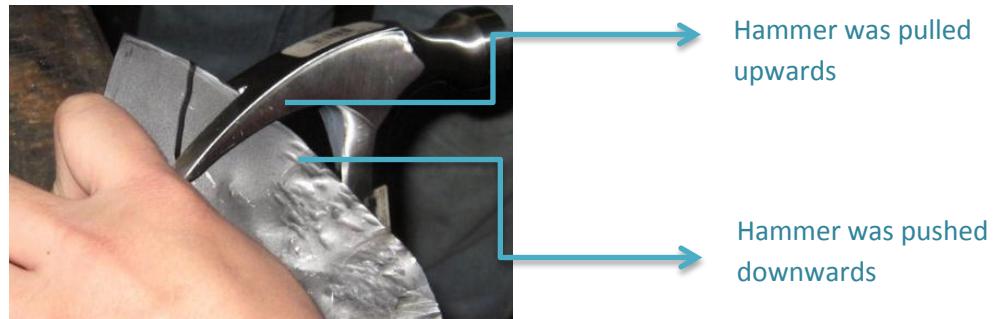


Figure 57. Making of a tuck.

The tuck made looks like the picture in Figure 59.



Figure 58. Steps in making of tucks.

6. After the tuck was made, we used the hammer to flatten it out. This is done in order to crush the metal on itself and shrink it. Metal shaping is generally achieved by changing the thickness of metal which produces a curvature.



Figure 59. Flattening of the tucks.

When hammering, we started inwards and went outwards; we also worked our way up the tuck. The hammer blows on the piece of metal should be very close to each other so that there is an even flattening effect on the tuck. It is also very important when hammering not to allow the tuck to return to its original place. Later on more tucks were made like shown in Figure 60 all around the metal piece and then hammered down like described in Figure 61.

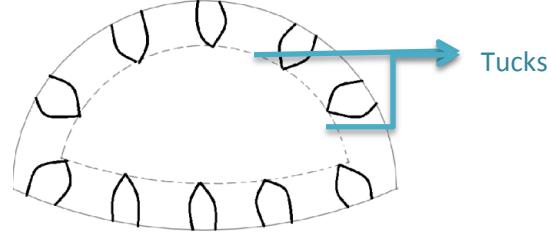


Figure 60. Position of tucks.

After some of the tucks we made were flattened out, the metal piece looks like in the rightmost picture shown in Figure 61.



Figure 61. Tuck making process.

Once all the tucks were flattened out and the outer edges were shrunken, we had to thin out the center of the semi-circular metal piece in order to give it a dome shape. This was done by hammering gently on the outer edges of the metal piece and then applying stronger hammer blows at the center of the metal until we got the dome shape we were looking for.



Figure 62. Hammering middle part of Part B.

7. After getting all the shoulder components a curvature, we made some holes in them using a nail puncher and a hammer. We also used a pair of pliers to remove small pieces of metal remaining in the hole.



Figure 63. Hole-making with a nail puncher.

The holes were placed on the shoulder components as shown in Figure 64. We did not use any measurements for the holes; we just approximated a distance from the outer edges of the shoulder parts.

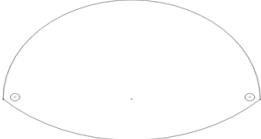
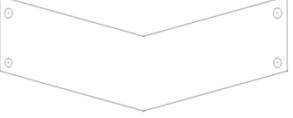
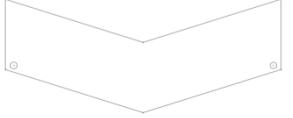
Part	Drawing
A	
B	
C	
D	

Figure 64. Hole positioning in shoulder components.

8. Once the holes were made, we assembled the different parts together using copper rivets as in the pictures shown in Figure 65. To assemble two pieces together, we first inserted a rivet in a hole and then we trimmed a portion of its length because it was too long. Once we got a reasonable length, we added a copper washer and hammered on the trimmed face of the rivet. As we hammered, the diameter of the rivet gradually increased and its longitudinal length decreases until the washer could not move and the

shoulder parts were fastened together. This process was then repeated to make a second shoulder piece.



Figure 65. Assembly of shoulder components with copper rivets.



Figure 66. Before and after assembly process.

VIII.3. Assembly of the Shoulder Parts

The shoulder pieces were then assembled together. To connect them together, our group decided to use a u-shape piece metal plate to cover the upper part of the chest. The metal piece will then be bent like in Figure 67 so that it fits the upper body.

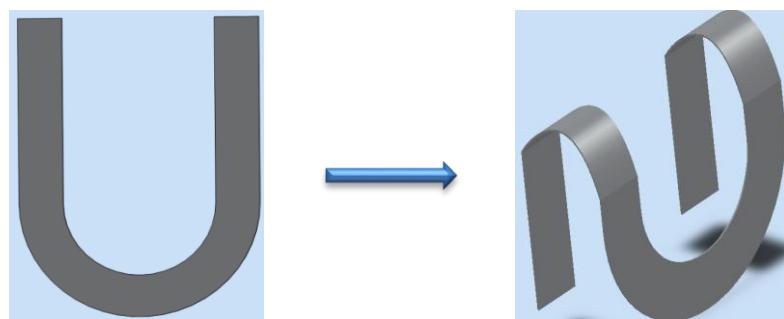


Figure 67. U-shape piece of metal (Left) and U-shape metal after bending (Right).

After tracing and cutting the U-shape piece of metal, it was filed to remove any sharp and rough edges.



Figure 68. Filing of sharp and rough edges of metal piece.

The piece of metal was then hammered like shown in Figure 69 in order to curve the metal in the areas where the metal piece meets the shoulders.

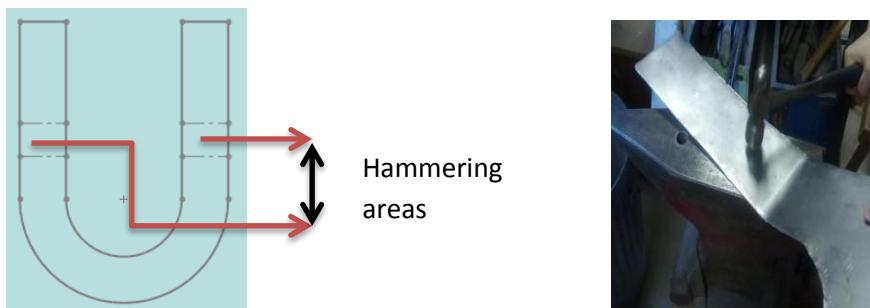


Figure 69. Hammering of U shape metal piece.

The metal piece was then bent in order to adjust it to one of our team member's shoulders.



Figure 70. Sideway view of metal plate.

To attach the shoulder guards to the chest plate, we initially planned to use 3 rings to connect the shoulder guards to the chest plate. Since the ends of the rings did not completely close; we substituted some rings for leather pieces. Leather pieces allow greater mobility of the arms.

We made the rings in a similar way rings were made in the Medieval Era. A long metal wire was coiled around a metal rod like shown in the Figure 71. A rod with a diameter of an inch was chosen since we were looking for rings of about this diameter. A bolt cutter was then used to cut rings out of the metal wire.



Figure 71. Making of rings.

Three holes were made in both the upper part of the shoulder guards and the outermost edges of the chest plate using a nail puncher and a hammer.



Figure 72. Holes made in shoulder guards and the chest plate.

Using a nail puncher and with the help of a screw driver, holes were made in the piece of leather which was then wrapped on the upper part of the chest plate. The leather piece was then closed by lacing it at the back using red leather cords like in Figure 73.

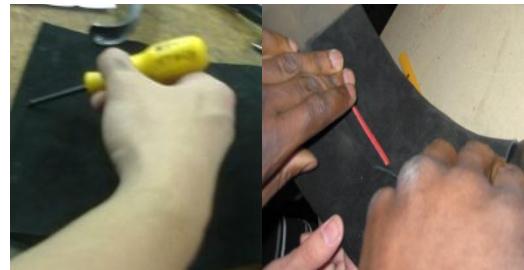


Figure 73. Hole making and lacing of leather.

Once both the upper parts were recovered with leather, the shoulder guards and the chest plate were then assembled using a ring in the middle hole.



Figure 74. Assembly of shoulder guard and chest plate.

Small strips of brown leather of about one by four inches were then cut and two holes were then made.



Figure 75. Cutting and punching of holes in the leather strips.

One of the ends was riveted to the shoulder guard and the other end to the chest plate using copper rivets.



Figure 76. Riveting of the shoulder guards and chest plate.

Two holes were then made on each side of the shoulder guards and leather cords were inserted so that the shoulder guards can be tied around the arms of the person wearing the armor. Using leather cords has the advantage of being adjustable around the wearer's arms.



Figure 77. Hole making of the sides of the shoulder guards.

The final armor is shown in Figure 78. The black leather covering the upper shoulder parts have been decorated with leather rivets which can be easily obtained in any craft store and they just need to be pressed together unlike the copper rivets that needed hammering.



Figure 78. Front view and side view of the armor.

IX. Conclusions

The evolution of armors in the Medieval Era was the product of a host of developments that occurred across the continents of Europe and Asia. The improvement of metalworking techniques resulted in better materials, such as martensitic steel, greatly strengthening armor. The spread of armor design among cultures through trade and conquest created an amalgam of new designs. The evolution of combat and military strategy also lead to changes in armor design.

With the precursors to the blast furnace invented in the late 12th century, access to wrought iron in Europe increased. Though armor for foot soldiers was still prohibitably expensive, weaponry like maces and halberds became more plentiful on the battlefield. To protect against this, knights and other officers wore plate armor, which offered greater protection against the newer heavy weapons. This cycle, of producing better armor to deal with advancements in weaponry, drove the evolution of armor. Because of the greater labor involved in forging, tempering, and carburizing steel, the use of suits of armor stayed with nobility and the military elite. The high price and low demand of armor meant that few blacksmiths learned the art of armor-making, and this art was a closely guarded secret. The techniques of many blacksmiths have been lost to time except in cultures where armor was treated with extreme reverence, like Japan.

While the many countries of the world all had their unique designs for armor, nearby cultures would influence these designs, resulting in different combinations of design features. The countries of Europe, namely Italy, Germany, and France, maintained a very similar style of plate armor, though details such as helmets and breastplate decoration differed. The Ottoman

Empire, borrowing from the great many cultures that it conquered and traded with, utilized chain mail from the Middle East and India, the conical helmet from Persia and Egypt, and steel plates that were popular in Europe and Russia. Further East, Mongolia and Japan relied heavily on lighter suits of lamellar and lacquered leather armors. The exchange of ideas caused armor to change as regions improved their designs to match those of other cultures.

Military strategy also played a key role in the evolution of armor. In the Middle and Far East, the heavy use of cavalry and the vast size of the empires required very light armors, often lamellar armors or chain mails. In Europe, as weapons such as the long bow and the crossbow came into use, this light armor was eschewed in favor of heavy plates. Weight was spared where necessary, and lighter helmets such as the basinet grew into favor in the 1400s. For all these civilizations, there was one military advancement that armor could not adapt to.

With the advent of gunpowder and firearms by the Chinese, the usefulness of armor declined. Firearms spread to Japan and the Ottoman Empire and were used extensively by both. When they reached Europe, the full suits of armor were relegated to ceremonial dress, and their design became more ornamental. Armor did not disappear, as the use of firearms was not widespread in the Medieval Era, but as the gun got more and more powerful, armor could not improve quick enough to withstand it.

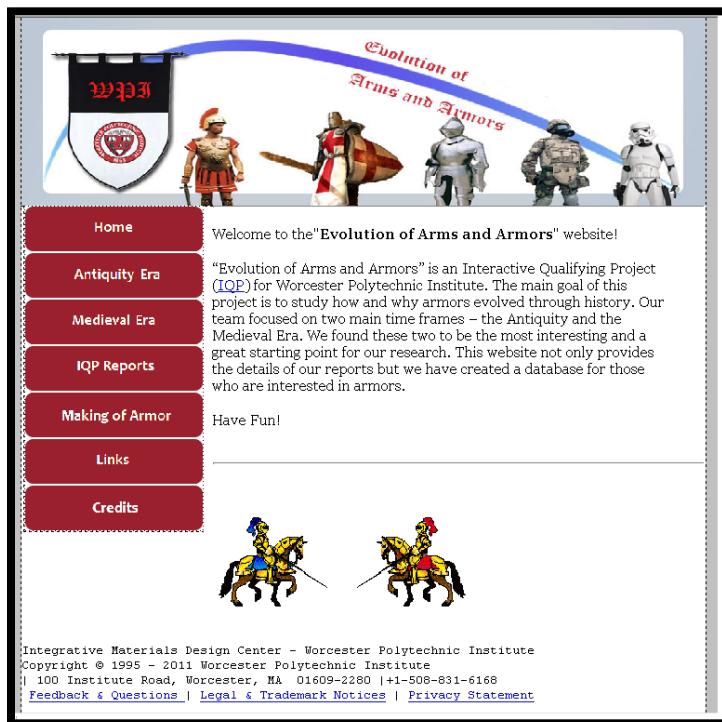
The team also successfully designed a public website which presents a reduced documentation of our website. The main purpose of the website is to allow one to understand visually the main idea of our project. This is done by making tables which chronologically shows the transition of certain armors in a specified time period. For example, Medieval Europe shows a table of helmets. One can then see how the shape, geometry and even the material changed throughout the era.

The highlight of the project is the hand-made creation of the “Spaulders,” or shoulder, and chest-plate. With the guidance of Fay Butler, the owner of Metal Fabrication, the team successfully hammered out a pair of shoulder pieces and a chest-plate. The chest-plate, however, is not to be confused with a breastplate. The chest-plate was made to be simple and protect part of the breast and chest. Given the amount of time and little experience, making a full breast-plate was not practical goal even though it would have been ideal. Even so, the team was satisfied with the overall outcome of the simple armor piece.

Overall, this project is a good starting point for future teams who will continue the study of “Evolution of Material in Arms and Armors”. Future team will learn from this project and expand to more eras and geographical locations. Perhaps, “arms” could be also more developed as the current report covered well little on arms and the relationship between arms and armors. Also, Fay Butler is a wonderful and knowledge man and hopefully future teams will collaborate with him again to work on creating more armors parts.

X. Appendix A - Making of the Website

The website was primarily designed in Adobe Dreamweaver, which can help create the HTML and CSS coding of the webpages. A banner and set of buttons were created in photoshop, adorning the main page, the buttons being part of a navigation bar. The knight icons at the bottom of the page are two stock images found on amazing-animations. The maps are also of public domain for educational purposes. The main page also contains copyright information, reports, links, and making of armor pages.



The making of armor page, shown below, contains pictures and videos of the actual making of our armor. These pictures were taken at Fay Butler's workshop and machine shop at Worcester Polytechnic Institute.

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Our group tried to make the shoulder guards of an European armor using traditional hand tools like hammers, shears and files. During the middle ages, blacksmiths had similar tools but they were probably bigger, heavier and less ergonomic.

Steps for armor making

Before making the armor, we drew the different components of the shoulder guards on paper. The measurements we used were in inches and the drawings are as follows:

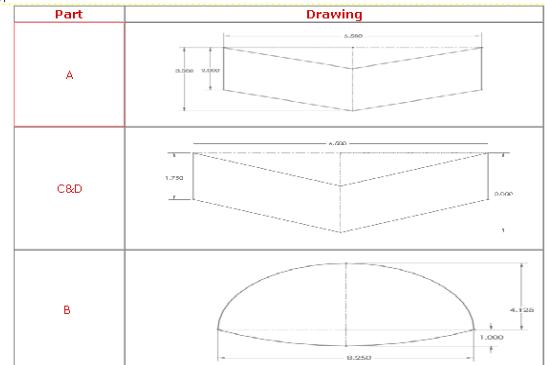


Figure 1-Drawings of shoulder components

After cutting, we used a file to smooth the edges and get rid of the dangerous sharp edges. According to Fay Butler, blacksmiths would take a quite thick and hard piece of steel and upset its surface in a consistent pattern using a sharp object like a chisel. After the dents were made at a certain angle, the surface of the metal would become irregular and it would have some small projections or teeth. The piece of metal would then be soaked in horse urine. The effect of the acid in the urine would sharpen the small projections on the metal surface sharper and give the metal surface an abrasive effect.



Figure 4- Filing of metal pieces



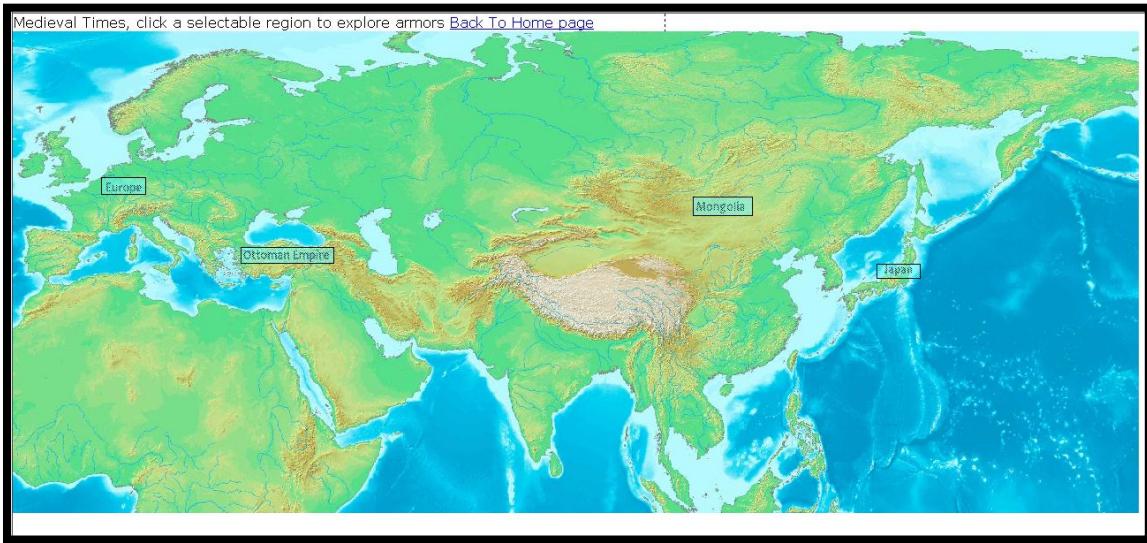
Figure 5- Cut pieces

After cutting and filing, the next step was to give the different pieces of the shoulder guards a curvature. For this purpose a hammer and a piece of metal block with a smooth surface were used.

The videos were all uploaded on youtube because it was easier to take the embedded code from youtube then it is to create one.



The maps are now interactive because the blue “Boxes” on the map are interactive hotspots, which link to the armor pages, and create links indicated on a browser by the cursor turning into a selector, like it would for any other link. Thus the maps become image maps, with multiple clickable links. Below, we can see the medieval era map:



The armor pages themselves contain summaries of the time periods and summaries of the individual pieces of armor, with more information presented in the report. These summaries illustrate how various types of armor evolved over a short period of time in a region. For example, the helmets of Greece from 600-200 BC are shown here:

HELMETS	
 <p>Original image: http://en.wikipedia.org/wiki/ File:Chalcidean_helmet.jpg</p>	Name: Chalcidian helmet. Origin: Greece, late 6th to early 5th century BC. Materials: bronze. Compared to Corinthian helmet, this helmet exposes a majority of the face, and has more space for the eyes and the ears. It is also thinner than its earlier Corinthian counterpart. This helmet consists of just one piece of armor and should be made simply using hammering techniques.
 <p>Original image:</p>	Name: Thracian helmet. Origin: Thrace, Greece, 5th century BC and throughout Hellenistic period. Material: bronze. This design was inspired by the everyday cap worn in Thrace. It has a rising at the top to a forward pointing peak.

For some regions individual pieces of armor that were commonly used are discussed, such as here with the Ottoman Empire:

Armor	Description
 Turban Helmet	<ul style="list-style-type: none"> • Mid-16th Century • Watered steel with gold damascened inlays • Turban helmets derive their name from the fact that they were designed to be worn over a turban. It's easily distinguished by its conical shape. The details of its design can vary from era and origin; this one features a nasal, a strip of metal that goes between the eyes, and an aventail, plates of metal attached to the helmet designed to protect the neck. This design was lighter than the full-faced helmets found on Western European suits of armor, but did not offer the same level of protection.
 Bakhterets	<ul style="list-style-type: none"> • 16th-17th Century • Steel plate mail, steel chain mail • Originally from Persia, this type of plate mail spread to the Ottoman Empire and Russia. Reinforcement to the chain mail shirt comes in the way of small rounded rectangles in overlapping rows covering the front and back of the torso. It is similar in style to the dyawshan. Since mobility was important to the cavalry-heavy armor of the Ottoman Turks, this lightly plated armor was preferred to full plate armor.
 Bakhterets	<ul style="list-style-type: none"> • 16th Century • Steel plate mail with silver inlay, steel chain mail • A plated mail of Persian design, differing from the Bakhterets in the size of the plate "scales." Dyawshan uses about 100 larger plates covering the

Each armor page has a timeline, and for the medieval pages, these timelines appear in separate windows when the link is clicked, while the antiquity map hub has a general history. These timelines document major wars or military advancements in that area in the specific era, for example, here's Mongolia's medieval timeline:

Year	Event
1206-1263	Alliance of Mongol Tribes. Under <u>Ghenghis Khan</u> command, the Mongols started the conquest of other lands to build their empire.
1274-1281	Unsuccessful attempts at invading Japan
1279	Establishment of the Yuan Dynasty in China by Kublai Khan
1368	End of Yuan Dynasty. Mongols return to Mongolia
1409-1449	Renewed Mongol invasions of China
1480-1502	Conquest and Occupation of Russia by Mongols
1571	War ends between the Mongols and the Chinese

The website also has its own report page, which contain the final copy of the medieval and antiquity reports for public access. Also, the links page contains links to works cited, this report, Fay Butler's website, and much more.

XI. Appendix B - Steps in the Project

XI.1. Objectives

- To create a database with concise information of armors, its metallurgy and properties, that can be used as a resource for real life applications such as historical reanimation, or game design.
- To create a resource to increase our own knowledge and that of the public of history through armors.
- To create a resource that can be used to further understand the differences of global regions through history.

XI.2. Methodology

Term A

- Our team split into two groups, each focused on studying the evolution of armors in different time periods. Group one focused on the ancient times of antiquity. Group two researched around the 1000s-1500s A.D., primarily focusing on Europe's High Medieval Era to the fall of the Medieval Era.
- Each group member looked for as much information as possible regarding their respective time frame. We gathered as much information related to armors and technology through different books, online database, and consultation with curator experts such as Jeffery L. Forgeng to get a broad knowledge and scope of the project.
- We came up with objective questions for each type of armor that will be entered in the database.
- The group will come up with a draft of the Proposal by the end of the term.

Term B

- Completion of background and introduction section of proposal.
- In depth research on different types of armor. Focused more on in-depth technical analysis.
- Compiled research in a structured format that can be posted on the site.
- Begun creating the website for our research.
- Visited local Worcester blacksmith for an interview and in depth look at metallurgical processes.

Term C

- Attempted to test and examine the different material properties through the pieces of armors that are provided from Higgins Armory Museum. Material properties that will be analyzed are tensile strength, material composition and hardness, amongst other properties deemed to be important in armor. Equipment that was used to test the armors was provided by WPI and iMdc labs with the guidance of our advisor, Professor Lados.
- Worked on website design
- Completed research of metallurgy
- Begun construction of simple replica on a piece of armor

Term D

- Completed construction of armor piece
- Completed research report and final review of website
- Wrote about website documentation

XII. References

- Agricola, G. (1950). *De re metallica* (H. C. Hoover, L. H. Hoover Trans.). New York, NY: Dover Publications Inc.
- Allen, W. (2011). *Allen antiques*. Retrieved 04/02, 2011, from <http://www.allenantiques.com/Armour-Breastplates-Collection.html>
- Alvesteffer, S. (1999). *The development of medieval full plate armor in europe*. Retrieved April 25, 2011, from <http://stormshock.com/archive/articles/development.html>
- Anton, C.
A short history of the English longbow. Retrieved 11/27, 2010, from
<http://www.archers.org/default.asp?section=History&page=longbow>
- BBC. (2009). *Ottoman empire (1301-1922)*. Retrieved 10/12, 2010, from
http://www.bbc.co.uk/religion/religions/islam/history/ottomanempire_1.shtml
- Bennett, M. (1998). *The hutchinson dictionary of ancient & medieval warfare*. Chicago: Fitzroy Dearborn.
- Bobrov, L. A., & Hudiakov, Y. S. (2005). The metal ages and medieval period., 12/01/2010.
- Boris, B. (2003). *The evolution of Japanese armor*. Retrieved 11/23, 2010, from
http://www.myarmoury.com/feature_jpn_armour.html
- Bottomley, I., & Hopson, A. (1988). *Arms& armor of the samurai: The history of weaponry in ancient Japan*. New York: Crown Publishers, Inc.
- Brass, M. (1999). *The chemical composition of glass in ancient Egypt*. Retrieved April 22, 2011, from
http://www.antiquityofman.com/AE_glass.html
- Bryant, A. (2003). *Online Japanese armor manual*. Retrieved 12/01/2010, 2010, from
<http://www.sengokudaimyo.com/katchu/katchu.html>

Buchwald, V. F., & Wivel, H. (1998). Slag analysis as a method for the characterization and provenancing of ancient iron objects. *Materials Characterization*, 40, 2011-73-96.

By The Sword, I. *Medieval swords, medieval clothing, renaissance clothing, leather armour, LARP gear, chainmail, helms*. Retrieved 01/05, 2011, from <http://www.by-the-sword.com/>

Camp, J. M., & Francis, C. B. (1920). *The making, shaping and treating of steel*. Pittsburgh, PA: The Carnegie Steel Company. Retrieved from http://books.google.com/books?id=P9MxAAAAAAJ&printsec=frontcover&source=gb_ge_summary_r&cad=0#v=onepage&q&f=false

Castelnaud Museum. *Maximilian style breastplate*
Retrieved 04/20, 2011, from <http://www.castelnaud.com/images/galerie/zoom/musee11.jpg>

Coke from Poland. *Blast furnace history blast furnace history, part 3 of 6: From China to Europe*.
Retrieved 4/26, 2011, from http://polishcoke.net/Blast_Furnace_Historypart_ofFrom_China_to_Europe,3.html

Das, A. K., Ohbaa, T., Morito, S., Takami, G., Fujikawa, T., Yaso, M. (2009).
Characteristic feature found in typical TATARA product, japanese sword. *ESOMAT*,

De Miranda, A. (2008). *Photo exhibit highlights water wheel history, design*. Retrieved 4/26, 2011, from <http://web.mit.edu/newsoffice/2008/water-wheel-1119.html>

De Sutter, J. (2002). *Great helms*. Retrieved 01/02, 2011, from <http://home.scarlet.be/~klauwaer/helm/>

De, Vries Kelly, and Robert D. Smith. (2007). *Medieval weapons an illustrated history of their impact*. Santa Barbara, California: ABC-CLIO.

DeVries, K. (2003). *Medieval military technology*. Peterborough (Ont): Broadview.

Eggert, G. (2011). *The rise and fall of medieval iron technology*. Pennsylvania State University:

Encyclopædia Britannica. (2011). *Slag*. Retrieved 4/25, 2011, from

<http://www.britannica.com/EBchecked/topic/548015/slag>

Fletcher, A. *Mongols Ghengis to Kublai Khan-the maps*. Retrieved 03/15/2011, 2011, from

<http://www.paradoxplace.com/Perspectives/Maps/Mongol%20Empire.htm>

Forgeng, J. (2008). *Pauldron for the right shoulder from a "stechzeug"(jousting armor)*. Retrieved

03/31, 2011, from <http://users.wpi.edu/~jforgeng/CollectionIQP/artifact.pl?anum=787>

Friday, K. F. (2007). The tools of war. *Samurai, warfare and the state in early medieval Japan* (pp. 89-91, 92,101). New York 10001: Routledge.

Gilbert, A., & Field, J. (1997). *Arms and Armor*. Brookfield,CT: Copper beech.

Grancsay, S. V. (1958). The new galleries of oriental arms and armor. *Metropolitan Museum of Art Bulletin*, 16(9), 246.

Grandy, B. *Lewis Moore 14th century hourglass gauntlets*. Retrieved 11/15, 2010, from

http://www.myarmoury.com/review_lm_gaunthg.html

Hearnshaw, F. J. C., & Barker, E. (2008). *Medieval contributions to modern civilization: A series of lectures* (1922) Kessinger Pub Co.

Hermitage Museum. (2011). *Hauberk half armour, or bakhterets*. Retrieved Feb 2011, 2011, from

http://www.hermitagemuseum.org/html_Eng/03/hm3_4_1c.html

Hewitt, J. In Henry J., Parker J. (Eds.), *Ancient armour and weapons in Europe*

Higgins Armory. (2011). *The Islamic World*. Retrieved 4/27, 2011, from <http://www.higgins.org/arms-around-the-world.php#islam>

Hosler, D. (1995). Sound, color and meaning in the metallurgy of ancient west Mexico. ()

In Encyclopædia Britannica. *Ottoman Empire*. Retrieved 04/03, 2011, from

<http://www.britannica.com/EBchecked/topic/434996/Ottoman-Empire>

Invictus. (Feb 2007). *The Mongol Empire*. Retrieved 11/24/2010, 2010, from

http://www.allempires.com/empires/mongol/mongolempire_map.jpg

Kim, J. (2004). *Japanese swordmaking process*. Retrieved 4/27, 2011, from

http://www.samuraisword.com/REFERENCE/making/japanse_swordmaking_process.htm

Lee Sauder. (99). THE BASICS OF BLOOMERY SMELTING. *The Anvil's Ring*,

Livesey, J., & Wallis, F. (2005). *Medieval science, technology, and medicine: An encyclopedia*. New York: Routledge.

Messiah College Personal Home Pages. *Pictorial armor glossary*. Retrieved 03/04, 2011, from

<http://home.messiah.edu/~gdaub/armor/picgloss.htm>

Mongolia today - online magazine | warriors.(2001, Retrieved from

<http://mongoliatoday.com/issue/7/warriors.html>

Murdoch, J., & Yamagata, I. *A history of Japan during the century of early foreign intercourse(1542-1651)* (http://www.samuraisword.com/nihontodisplay/JUYO/kunimura/kunimura_5.htm ed.)

The Muromachi period. (2000). Retrieved 11/23/2010, 2010, from

<http://library.thinkquest.org/C001119/history/>

Nalley, T. P. *Russian armor in the time of Ivan the terrible*. Retrieved Jan 2011, 2011, from

<http://www.plcommonwealth.org/Russian%20Armor%20in%20the%20Time%20of%20Ivan%20he%20Terrible.pdf>

Nathan Bricault, A. G. *The history of armor*.

Newman, P. (2001). *Daily life in the middle ages*. Jefferson,North Carolina 28640: McFarland & Company,Inc, Publishers.

Nicolle, D. (1998). *Muslims, Mongols and the struggle against the crusades*. . Osprey.

Nikki Veldhuis. (2009,). Medieval village. Message posted to

<http://blog.nikkiveldhuis.nl/tag/medieval-village/>

Noguchi, S. (1993). *Arthurian and other studies: Presented to Shunichi Noguchi*.

O'Donnell. (2006). *Muromachi period*. Retrieved 11/29/2010, 2010, from

<http://www.lakelandschools.us/lh/modonnell/virtualjapan/muromachi.htm>

Ogawa, M. (Harada Kazutoshi;Ikeda, Hiroshi). *Armor of the Samurai:Japanese arms and armor,1156-1868*. Japan: The Metropolitan Museum of Art, New York.

Okun, N. (1999). *Defeating face-hardened armor*. Retrieved April 25, 2011, from

http://navweaps.com/index_tech/tech-033.htm

Oleg D. Sherby, Jeffrey Wadsworth. (2001). Ancient blacksmiths, the iron age, damascus steels, and modern metallurgy. *Journal of Materials Processing Technology*, 117, 347-353.

Oscar Ratti, A. W. (1991). *Secrets of the samurai*. Boston Massachussetts: Tuttle Publishing.

Pirenne, H. (1937). In Clegg I. E. (Ed.), *Economic and social history of Medieval Europe* Houghton Mifflin Harcourt.

Prof. Anne McCants. (2011). *Engineering the medieval achievement*. Retrieved 4/24, 2011, from

<http://web.mit.edu/21h.416/www/>

Prof. Steven A. Walton. (2006). *The system of a blast furnace*. Retrieved 4/23, 2011, from

http://www.engr.psu.edu/mtah/essays/system_blast_furnace.htm

Robinson, R. H. (2002). *Oriental armour*. Mineola, New York: Dover Publications, Inc.

Royal Armouries Collections Online. *Collection database*. Retrieved 03/30, 2011, from

<http://collections.royalarmouries.org/index.php?a=wordsearch&s=gallery&w=japan>

Royal Armouries Collections Online. *Do-maru*. Retrieved
03/30 <http://collections.royalarmouries.org/index.php?a=wordsearch&s=item&key=WYTozOntpOjA7czo2OjJhcm1vdXIiO2k6MTtpOjA7aToyO2I6MDt9&pg=649>

Sherby, O. D., & Wadsworth, J. (1997).
Ultrahigh carbon steels, Damascus steels, and superplasticity (Preprint No. UCRL-JC-127180).
Istanbul, Turkey: Lawrence Livermore National Library.

SIR RALPH PAYNE-GALLWEY. *The crossbow*. Retrieved 12/14, 2010, from
http://www.crossbowbook.com/page_32.html

Smith, K. P. (2004). Ore, fire, hammer, sickle: Iron production in Viking age and early medieval Iceland. *De Re Metallica: The Uses of Metal in the Middle Ages - AVISTA Studies in the History of Medieval Technology, Science and Art*, 4, 183-206. Retrieved from
http://brown.academia.edu/KevinPSmith/Papers/111035/Ore_Fire_Hammer_Sickle_Iron_Production_in_Viking_Age_and_Early_Medieval_Iceland

Solar navigator. *Wealden iron industry*. Retrieved 4/24, 2011, from
South Yorkshire Industrial History Society. (2003). *Glossary of iron working names and term.*, 2011,
from <http://www.topforge.co.uk/Glossary.htm>

Stone, G. C. (1999). *A glossary of the construction, decoration, and use of arms and armor in all countries and in all times: Together with some closely related subjects* Dover Publications, Inc.

The British Museum. *Breastplate*. Retrieved 01/04, 2011, from
http://www.britishmuseum.org/research/search_the_collection_database/search_object_details.aspx?objectid=39378&partid=1

The Metropolitan Museum of Art. *Lacquerware of East Asia | thematic essay | Heilbrunn timeline of art history* ., 2010, from http://www.metmuseum.org/toah/hd/elac/hd_elac.htm

The Metropolitan Museum of Art. (2004). *Islamic arms and armor*. Retrieved Oct 2010, 2010, from
http://www.metmuseum.org/toah/hd/isaa/hd_isaa.htm

The Wallace Collection. *Visored bascinet*. Retrieved 4/21, 2011, from
<http://wallacelive.wallacecollection.org/eMuseumPlus?service=direct/1/ResultDetailView/moduleContentFunctionBar.navigator.back&sp=10&sp=Scollection&sp=SfieldValue&sp=0&sp=0&sp=2&sp=SdetailView&sp=1&sp=Sdetail&sp=0&sp=F&sp=0>

Tokyo National Museum. *Armor of domaru type*.<http://www.tnm.go.jp> Tylecote, R. F. (1976).
A history of metallurgy. Warrendale, PA:

UW Departments Web Server. *The national museum of Mongolian history :The Mongol empire of Chingis Khan and his successors*. Retrieved 04/14, 2011, from
<http://depts.washington.edu/silkroad/museums/ubhist/chingis.html>

Walton, P. S. A. *The system of a blast furnace*. Retrieved April 21, 2011, from
http://www.engr.psu.edu/mtah/essays/system_blast_furnace.htm

Waugh, D. C. (2000). *The Pax Mongolica*. Retrieved 03/15/2011, 2011, from <http://www.silk-road.com/artl/paxmongolica.shtml>

Wilkinson, F. (1972). In Drake (Ed.), *Antique arms and armor*. New York

Woods, T. (2005). *How the catholic church built western civilization*. Washington, D.C.: Regnery Publisher.

Yoroi. Retrieved 11/25, 2010, from <http://www.tsunamidojo.nl/engels/yoroi.htm>