In ancient times, the sword represented the pinnacle of the engineering craft. Today, many of the same technologies are used to produce swords for a variety of purposes.

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Since early times, the search for superior arms and armor has driven the art and the science of metallurgy. European, Middle-Eastern, and Eastern cultures each developed metallurgical and bladesmithing technologies suitable for their swords, for personal defense and military weapons. Swords were symbols as well as weapons, used to show positions in government, social status, and wealth. The sword, arguably more than any other of man's tools, speaks of our innate drive to create items of form as well as function. They were for many eons the pinnacle of the engineering craft. Without scientific knowledge and analytical equipment, ancient smiths were able to convert impure contaminated raw ore into refined metal. From this material they consistently produced the lightest, strongest, most resilient tools suited for a purpose where failure meant death. This was an incredible achievement.

Early swords
The earliest swords were made from cast bronze, and appeared in approximately 1700 BC. Following casting, the edges were carefully cold worked. Bronze swords could be sharper and harder than their iron counterparts, but could fracture where an iron sword would bend rather than break. Early Greek, Chinese, Celtic, and other European cultures developed artful and well crafted bronze swords. Swords of iron probably appeared around 700 BC. The Roman short sword, the gladius, an infantry weapon, normally served along with a shield for defense. The Romans developed effective fighting strategies and tactics based on these weapons and disciplined soldiers, rather than individual warrior combat as practiced by many of their enemies. The Roman cavalry sword was the spatha, a longer, straight two edged sword.

Pattern welding was developing in Europe during this era. Pattern welding was a technique of forge welding different steel or steely irons together to improve the strength and toughness of the material. In this time period, pattern-welded steel was found almost exclusively in the fullers of the blades. The fuller is a ground groove down the center of the blade.

Fig. 1 — Pattern welding was developed in Europe during the Roman era. In this pattern-welded Horsel longsword by Kevin Cashen, pattern-welded steel is in the blade, guard, and pommel of the sword. Image courtesy Matherton Forge, Hubbardston, Michigan.

Fig. 2 — The rapier was not considered a military weapon, but rather served as a personal side arm for self-defense and for settling duels. This rapier is by Kevin Cashen, Matherton Forge.

Fig. 3 — Medieval sword by Randal Graham has a simpler hilt than the rapier. This is an example of an interpretation of a historical sword, not a duplication. Image courtesy Albion Armors.
that reduces the mass, and improves flexibility and balance. Intricate patterns were developed in the blades, and pattern-welding was regarded as the mark of a master smith. Romans were very perceptive, and as the power of Rome spread, they incorporated the skills of those they conquered. Thus, pattern-welded blades from European smiths became integrated into the arsenal of the Roman armies. (Fig. 1)

European development
It is believed that the European long sword developed from the Roman spatha, becoming the primary weapon of the knight throughout the Middle Ages and Renaissance Europe. Other swords developed during this time include the thrust, cut-and-thrust, hand-and-a-half sword, and the two-handed sword.

The rapier and dagger developed as personal side arms, for defense, and of course, for settling matters of honor by dueling. The rapier was not considered suitable for armored combat by sword masters of the time, and was primarily a weapon for the nobility (Fig. 2). In fact, Henry VIII of England passed a law forbidding any but nobility from carrying a rapier; the intent was to be able to distinguish at a glance nobility from commoner.

The Italians developed a two-handed Florentine fighting style with two rapiers. They were designed so that both swords went into one scabbard. This was known as a “case of rapiers.” Until drawn, they appeared to be a single weapon.

As the rapier developed and became lighter, it led to the development of the small sword, a light and deadly weapon, for wear in courts of Europe. Dueling, however, became so widespread that several countries were forced to outlaw it. Nevertheless, this practice continued in secret, long after such laws were enacted. The defensive moves previously the responsibility of the dagger, became incorporated into the technique of the small sword. The change to a single weapon for both offense and defense that developed with the small sword became the foundation of the current sport of modern fencing.

The development of the thrusting sword was caused by the emergence of plate armor in the 1400s. The two-handed sword was a foot soldier's weapon, wielded against both the knight and his horse. Armored combat was left to the Renaissance war sword, with a simpler hilt than the rapier (Fig 3).

Middle East
Notable in the development of Middle Eastern swords of Islam were the Persian yatagan, the scimitar, and Damascus steel. Damascus was a later European term for the steel made from wootz ingots, probably originating in India, but encountered by Europeans in and around Damascus, Syria. The proper raw ore, long-duration casting, and specialized pottery crucibles were required to produce the wootz ingots. In addition to wootz, swords in the Middle East were at times made from meteoric iron, taking advantage of the dendritic structure and alloy content. (Fig. 4)

Japanese swords
The katana and other Japanese swords were based on iron swords that were straight and double edged, with early influence from China. The long-sword katana (Fig 5) and the short-sword wakizashi paralleled the rapier and dagger from Europe in both form and function.

The Japanese weapons began as iron-based sands that were formed into tamahagane, spongy blooms refined many times by the smith. Subsequently, the smith forged and folded the metal, further refining by squeezing out or breaking up the slag inclusions,
and preparing the material for final forging. The sword was normally assembled from several different prepared segments, including the core, sides, spine, and edge. The entire bladesmithing process became a revered art. The pattern manipulation melded practical metallurgy, heat treatment methods unique to Japan, an artistic approach, and metallographic skill in polishing the sword to bring out the patterns produced in heat treatment.

**Sword metallurgy and technologies**

By the twentieth century, swords were used little for civilian personal defense; military service also became more limited. But swordsmithing, the art and craft of making swords, did not die out. Today, bladesmiths take advantage of current-day metallurgical knowledge, and combine it with traditional and current technologies to supply swords for the film industry, live theatre, historical re-enactors, martial artists, and private collectors.

Swords begin as flat or round bar stock, heated in coal, coke, or propane-fired forges. Because of the easily controlled reducing atmosphere, propane forges have become more popular with bladesmiths. Blades are initially forged in hydraulic presses, air powered or mechanical hammers, or by hand, with traditional hammer and anvil. Final forging is completed by hand.

Following forging, the blade blank is ground to final contour. An alternative process preferred by some bladesmiths is blade grinding from blank to finished product.

Following forging and rough grinding, distal and profile tapers are ground into the blade. This geometry provides the shape of the sword, across the width of the blade, and in the cross-section, as shown in Fig. 6. The distal and profile tapers play an important role in flexibility of the blade.

Following final grinding, the blade is heat treated. Bladesmiths and metallurgists found that sword metallurgy, whether ancient or modern, differs in several respects from that of knife metallurgy. The primary requirement for a knife is edge-holding capability. Therefore, heat treatments for knives are typically designed to achieve high hardness throughout the blade. The usual microstructure in carbon steel knives is tempered martensite. Rockwell hardness of HRC 62 or higher is typical.

However, swords require more toughness, flexibility, and impact strength than knives. Rockwell hardness typically ranges from 50 to 60 HRC. The microstructure in swords is also usually more complex than that of knives. One effective sword microstructure is tempered martensite in the edge, surrounding a bainitic core. This provides the requisite edge holding capability, while the bainitic core provides needed toughness and flexibility.

**Heat treatment**

Heat treatment is designed to achieve this microstructure gradient. Sword blades are usually individually heat treated. One preferred heat-treatment process consists of austenitizing, followed by mar-quenching (martempering), and any necessary straightening.

The mar-quench process allows the bladesmith several minutes to perform the straightening operation before martensitic transformations make this inadvisable. A final temper follows the mar-quench and straightening operations.

Following heat treatment, the sword is given a final polish. To ensure that the sword is a quality product, it is proof tested. The bladesmith carries out bend tests by hand, to ensure that the blade is
Selected bladesmiths

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<td>Jody Samson, Jason Dingledine</td>
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<td>Matherton Forge</td>
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Swordmaking information resources

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Pattern-welded steels provide the swordsman a form of creative expression that goes far beyond the simple steels. Pattern-welded steel is forge-welded from stacks of steels. Layers of steel with higher carbon content and more carbide formers are alternated with layers of steel having a lower carbon content that has fewer carbide-formers. In common usage these materials have also become known as Damascus steels, though they are distinct from the materials originating from the Middle East in previous centuries.

**Damascus steels**

Modern day Damascus steels, as well as historic Damascus steels, contain vanadium, chromium, molybdenum, or other carbide formers that help to develop striking patterns in the final product. These patterns are brought out by etching the blade. Pattern-welded steels may display simple, random patterns, or complex, repeated forms requiring high levels of expertise to produce.

Historical, recent, and ongoing collaborations between academia and bladesmiths have improved the knowledge of appropriate chemistry, microstructure, and thermo-mechanical treatments to achieve modern pattern-welded steels comparable to that of historical Damascus steels. The table on the previous page lists some of the many techniques and technologies used by bladesmiths to achieve the high level of artistry seen in their swords.

**Swords in the present day**

Modern swords are used in the film industry, for the making of historical, and fantasy films (Fig. 7), in live theatre, historical re-enactments, and by martial artists of both European and Eastern training. The film, theatre, and re-enactment swordsmen perform fight scenes choreographed to convey an actual battle, or duel, while maintaining personal safety.

Martial artists drawing on Eastern or Western fighting traditions may use actual swords, normally with dull or “rabbeted” blades in forms exercises. Another skill is test-cutting, in which woven straw targets are struck with sharpened, fully functional swords.

Collectors of quality swords comprise an important market for the bladesmith today. The bladesmith creates from the raw materials a one-of-a-kind custom piece of art, or limited production custom pieces. Prices for such works range from several hundred to several thousand dollars. (Fig. 8)

**The future of bladesmithing**

Better understanding of the pattern-welded Damascus steels has been provided through the efforts of Dr. John Verhoven, professor of metallurgy, Iowa State University, and bladesmiths Al Pendray and Howard Clark. Their collaboration developed a modern Damascus steel that duplicated historical Damascus steels in both chemistry and microstructure.

Dr. Oleg Sherby and Dr. Jeffrey Wadsworth in the 1980's at Stanford investigated ultrahigh carbon steels and the wootz Damascus process.

Dr. Kyle Metzloff, University of Wisconsin, Platteville, and bladesmith Rick Furrer, have current efforts in developing a cast wootz process.

Pattern-welded, Damascus, and wootz steel will be strong influences on the future of bladesmithing. Because of the beautiful patterns that can be developed, these materials will remain in the mainstream of swordmaking. Practical development by bladesmiths, and collaborations with metallurgists for formal studies of alloys and microstructure will produce valuable techniques and customized steels. We can look forward to breakthroughs that improve historical accuracy of blade materials, as well as developments in new directions.

Bladesmiths with a passion for bringing history to life through steel will continue to make swords that appeal to the eye, and inform us about the past.

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