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The Forging of a Japanese *Katana*

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June 14th, 2004

Introduction

In the feudal times of ancient Japan, noble warriors known as the *samurai* were charged with the governorship of the nation and protection of its people. Bound by a strict code of ethics known as *bushido*, these fierce warriors served their masters faithfully in times of both war and peace. The mark of the *samurai* was traditionally a pair of finely crafted swords. Each blade was forged by a skilled swordsmith and often elaborately decorated to reflect the prowess of each individual warrior. A number of myths and legends surrounded the creation of these weapons. Made from the very elements of the earth and given life through fire and water, many swords were believed to possess great power and spirits of their own. Only those who were *samurai* were granted the right to wield these weapons, which they often used with remarkable skill and frightening efficiency. Armed with these elegant swords and other intimidating weapons, the *samurai* defended the nation from the threat of foreign invasion and civil war for over fifteen hundred years. Today, while little remains of the *samurai* way of life, a large number of their weapons now lie in museums and private collections throughout the world. These relics serve as a memorial to the noble warriors who once protected the nation with their lives so many years ago and leave little question in one's mind as to why ancient Japanese swords are now considered official national treasures.

The *katana* long sword is a classic example of *samurai* weaponry. While no longer practical weapons on the modern battlefield, many are still produced today for collectors and connoisseurs of fine swords. The fabrication of one of these weapons is truly a remarkable work of craftsmanship. Years of training and experience are necessary to obtain the skills needed to produce these beautiful, highly prized weapons, but the fact that these ancient traditions and rituals are still performed today is a testament to a culture's devotion its rich heritage. While the aesthetic properties of the sword are certainly impressive, the blade itself happens to be a remarkable accomplishment in the fields of forging and metal forming. The technology behind the creation of the *katana* blade is the result of two thousand years of research and development. Due to the efforts of many generations of dedicated craftsmen, present-day swordsmiths are able to combine a number of unique metallurgical, material and mechanical properties within a single blade. The process by which these weapons are created is particularly interesting from a scientific point of view because it involves a series of complicated forging and heat-treating steps that are quite advanced for such an ancient art form. Such technology warrants further investigation. Therefore, the following paper presents a general outline of the forging of a *katana* blade and a brief historical account of the developments leading up to their introduction into Japanese society.

A Brief History of the Evolution of the Japanese Sword

Japanese swords, like many of the weapons of ancient cultures, changed dramatically over the course of history. While the style of warfare and the improvement of metal forming technology greatly contributed to these changes, a number of cultural and political factors were also responsible for the evolution of these weapons. Japanese swords are often identified by a number of features that are characteristic of the period in which they were created. A chronological table of these periods and the corresponding names of the swords created therein can be seen in Appendix A. Some of the identifying characteristics that help appraisers determine the value of a sword and the period in which it was created are the materials used to fabricate the blade and the overall design of the weapon. Another characteristic of Japanese swords is the name of the swordsmith who forged the blade that is often located inscribed on the tang of the blade just below the cutting edge. All swords forged prior to 1596 are known as *koto* or "early swords." Japanese forging and metal forming, like many other aspects of the Japanese culture, originated in mainland Asia. [1] This is clearly demonstrated by the first Japanese swords that were produced around 200 AD. These thin, straight, double-edged weapons of cast bronze closely resembled those produced in China during the same time period. Single-edged blades of hand-forged, high-carbon steel called *chokuto*, first appeared in Japan around 400 AD. [2] A reproduction of a *chokuto* blade can be seen in Figure 1. While possessing a hardened cutting edge far superior to the earlier bronze weapons, these blades lacked the structure and strength required of weapons of war and were most likely used for ceremonial purposes.

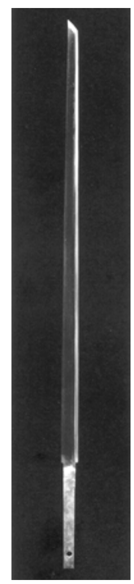


Figure 1: Reproduction of a *Chokuto* Blade. [3]

After 500 AD, Japanese sword forging technologies began to change along with the preferred style of warfare. During this period, rivalries between noble clans often resulted in open hostilities on the battlefield. With the nation in a near constant state of war, the majority of battles were fought by warriors mounted on horseback. These skirmishers who later came to be known as the original *samurai* were usually armed with bow and arrow, but the limitations of such weapons led many to seek alternative arms. The *samurai* required weapons that could be easily used with one hand and possessed a large cutting edge for slashing rather than piercing. Japanese swordsmiths altered the original Chinese sword design resulting in more practical weapons of war. Sword blades grew longer, developed a graceful curve, and finished in a slender tip. These trends culminated during the *Heian* period (794 to 1185 AD) with the development of long, curved swords known as *tachi*. [1] An example of a *tachi* blade can be seen in Figure 2. These were the first blades to possess the basic characteristics of what are now recognized as those of an authentic Japanese sword.

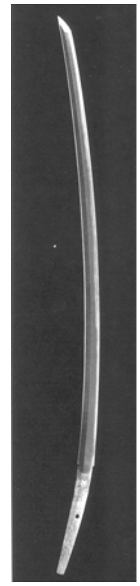


Figure 2: *Tachi* Blade. Note the length and curvature. [3]

The *Kamakura* period (1185 to 1333 AD) marked the beginning of seven hundred years of military rule in Japan. [3] The first *shogun* or supreme military commander was granted absolute power by the emperor in 1185. [1] By command of the newly appointed general, a ruling military council of *samurai* known as the *shogunate* was established to maintain order throughout the nation. A significant change in sword design occurred during this period following two attempted invasions by Mongolian forces in the late 1200's. Numerous encounters with the heavily armed and armored foreign invaders resulted in many irreparably damaged swords. The delicate design of the slender Japanese blades left them prone to chipping and cracking while the extended length of the blades that had once made them such excellent cutting and slashing weapons also rendered them ineffective in close-quarters combat. Such developments quickly demonstrated the need for a new sword design, and many swordsmiths began to explore different methods of forging in an attempt to solve the growing problem. As a result, swords with hardened steel sheaths wrapped around soft ductile cores were developed. These weapons could be easily repaired even when badly chipped or cracked. Under the new sword design, *tachi* became heavy two-handed weapons with broad blades and piercing tips as seen in Figure 3. Sturdy knives known as *tanto* along with longer one-handed swords known as *uchigatana* or *katana* were introduced for use in close-quarters combat. An example of these blades can be seen in Figures 4 and 5. *Samurai* alongwith conscripted foot soldiers known as

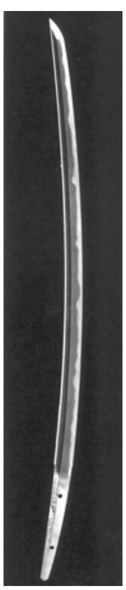


Figure 3: *Kamakura Tachi* Blade. Note the broadness of the blade. [3]

ashiguru armed with these durable blades proved far more effective than mounted cavalry against the Mongolian forces.

Figure 4: *Tanto* Knife Blade.
Length: 8-12” long. [4]

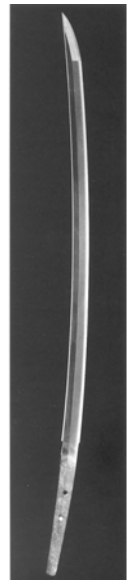


Figure 5: *Katana* Blade.
Length: 24-30” long. [3]

Each attempted invasion by the Mongols forces met with defeat, not as a result of the improved weaponry of the Japanese forces as some might think, but due to violent tropical storms known as *typhoons*. The strong winds and rough waters generated by the storms quickly decimated the Mongol fleet and forced the invaders to retreat to the mainland. Shortly thereafter, civil war erupted again in Japan as the ruling *samurai* lords or *daimyo* began to reclaim land and territory lost in earlier campaigns. These conflicts continued for nearly a century when finally an uneasy peace was established in the middle of the sixteenth century. [1] The years of war and conflict had resulted in the over production of weapons and a significant decline in sword quality, but with the cessation of hostilities between opposing forces, many swordsmiths refocused their efforts toward the perfection of their art. As a result, *shinto* or “new swords” first emerged between 1568 and 1603 (*Aizuchi-Momoyama* period). [2] Without the need for the continuous fighting that had plagued the nation for so long, swords became symbols of power and status. As metal refining and

Figure 6: A *daisho* consisting of a *katana* and a *wakizashi*. [5]

forging technologies improved, swords of bright, highly polished metal, often richly adorned and decorated, became marks of prestigious and influential individuals. The blades of this period were again shorter and broader than those of earlier times, but the quality of these weapons far surpassed that of any previously made. By this time, nearly all the heavy and awkward *tachi* had been replace by the more practical *katana* long sword. This trend was reinforced by a decree from the *shogunate* that required all *samurai* to wear a *daisho* or set of blades as a symbol of their rank and status within Japanese society. The *daisho* seen in Figure 6 consists of a *katana* long sword, the forging of which will be discussed later, and a *wakizashi* short sword. This practice would remain the custom and mark of the *samurai* until the wearing of swords was outlawed in the late nineteenth century.

In later years of the Edo period (1603 to 1853), economic hardships brought about numerous social and political changes. [1] The merchant class was quickly gaining power within Japanese society while the influence of the *samurai* was steadily waning. Many of the once noble warriors were forced to become mercenaries or masterless *ronin*. As a result, sword quality quickly declined. Unauthorized blade reproduction was not uncommon. Lesser swordsmiths were known to forge the names of master smiths on mediocre blades and sell them for a profit. Despite the problems of the time, many wealthy and prominent *samurai* were still able to commission rather exquisite blades. Toward the end of the eighteenth century, disgusted with the state of the nation, many *daimyo* began to plot rebellion against the *shogunate*. During the 1780s when civil war and foreign entities once again threatened the nation, many swordsmiths returned to the old methods of forging. The swords of this period are known as *shinshinto* or "new new swords." [3] These weapons ranged in quality and design. Some swords produced during this period resembled *koto* while others appeared to be *shinto*. An example of a *shinshinto katnan* can be seen in Figure 7. Despite the renewed interest in the old ways of metal forming and forging, pressure from powers both foreign and domestic called for the modernization of Japan. Both proved too great for the *shogunate* and the *samurai* to oppose. In 1876 during the Meji Restoration, the *samurai* caste was abolished and the wearing of swords was outlawed. [3] Without the need for the once awe-inspiring weapons, a great number of swordsmiths gave up their trade in favor of other more profitable vocations. While many believe that this period represented

Figure 7: *Shinshinto* Blade [4]

the end of the *samurai* and *bushido*, an appreciation for their weapons continued to grow.

Swords made following the *Meji* Restoration up to 1945 were known as *gendaito* or "modern swords." [2] These blades were usually of extremely poor quality due to the lack of resources and skilled craftsman during the difficult times leading up to the end of World War II. Sword production halted shortly after the Japanese surrendered to the United States in 1945 but began again in 1953, following the reconstruction of the nation in the aftermath of the war. A number of swordsmiths returned to their forges and began to rekindle the ancient tradition. Any swords produced after 1945 to the present day are known as *shinsakuto* or "newly made swords." [4] An example of an excellent *shinsakuto katana* can be seen in Figure 8. While no longer practical weapons of war as demonstrated by the use of the atomic bombs that were dropped on Hiroshima and Nagasaki, Japanese swords became national treasures and symbols of the warrior spirit of the nation and its people. As a result, the Japanese government imposed constraints on the production of bladed weapons to prevent the degradation of the art form. First and foremost, only licensed swordsmiths were allowed to produce authentic Japanese bladed weapons, including but not limited to *tanto*, *wakasashi*, and *katana*. Secondly, to become a licensed swordsmith required a period of training under another licensed swordsmith of no less than five years. Thirdly, a licensed swordsmith was allowed to produce only a limited number of blades per month as a form of quality control. Finally, all swords produced and sold by any swordsmith must be registered with the police. [2] These laws and others represented the beginning of a new era in Japanese sword history.

Figure 8: *Shinsakuto katana* blade forged by Ysoshindo Yoshihara. [2]

In 1960, the *Nihon Bijutsu Token Hozon Kyokai* (NBTHK, Society of the Preservation of the Japanese Art Swords) was founded in Tokyo. [2] This society and others like it have focused on the "study, promotion, and preservation" of highly prized antique Japanese swords and any production of *shinsakuto*. [2] The NBTHK continues its work today, holding contests every year to allow swordsmiths from across the nation to exhibit their works and be judged by a panel of experts and sword connoisseurs. The prizes that go to the winner of this contest are nothing compared to the unimaginable prestige that they have earned. These few chosen swordsmiths are recognized as masters of their craft and the bearers of a long-standing tradition that will, hopefully, continue for many centuries to come.

The Japanese *Katana*

The *katana* long sword and the *wakazashi* short sword were the primary weapons of the *samurai* from the beginning of the *Aizuchi-Momoyama* period to the end of the nineteenth century. [1] Traditionally, only *samurai* were permitted to wear both as a *daisho*, but for practical purposes and due to a number of rules prohibiting the wearing of certain weapons in the presence of higher ranking *samurai*, many chose to keep only the short *wakazashi* or *tanto* within arm's length at all times for self-defense. The use of the *katana* was, therefore, reserved solely for open conflicts between *samurai* and in times of war. The forging of *shinsakuto katana* blades is carried out now in much the same manner as it was in the days of feudal Japan. Each blade possesses a number of unique metallurgical and mechanical properties that are of particular interest from a scientific point of view. These properties are developed in a series of complex forging and heat-treating processes that are described in the following sections as performed by the master swordsmith, Yoshindo Yoshihara.

Before the technical aspects of forging a *shinsakuto katana* can be explained, it is necessary to provide some insight into how the design of the blade allows the sword to be such an effective weapon on the battlefield. A detailed diagram of a Japanese blade can be seen in Appendix B with the names of the individual parts listed in both Japanese and English. The cutting length or *nagasa* of a *katana* ranges between 24 and 30 inches long. [2] Being shorter and lighter than the *tachi*, it can be wielded easily with one hand by both infantry and mounted cavalry. Each sword exhibits a gentle curve known as either *sori* or *zori*, which runs the entire length of the blade. This allows the wielder to draw and strike an opponent in one smooth motion - a distinct advantage when the speed of drawing a sword can greatly influence the outcome of a conflict in close-quarters. The *shinsakuto katana* blade consists of a hard outer sheath of high carbon steel and a soft inner core of low carbon steel. The cross-section of a blade can be seen in Figure 9. Note the clear distinction between the high carbon outer sheath and the low carbon inner core. This combination of features provides a number of beneficial qualities, the forging of which is examined in detail later. The joining of the two metals results in a broad blade that adds a degree of strength and stability many earlier swords lacked. The properties of the different alloys used to

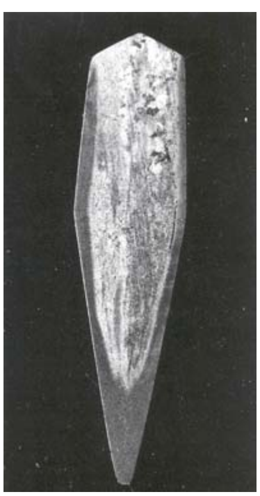


Figure 9: Cross-section of a katana blade. [6]

fabricate the blade allow swordsmiths to repair a weapon damaged in battle. The hard outer sheath can be sharpened many times to the remarkable cutting edge that Japanese blades are known to possess while the soft inner core allows one to deflect strikes from opponents with relative ease. All of these properties are needed to produce a weapon worthy of combat.

The *samurai* always strove to achieve a perfect balance in their lives. While fierce warriors in times of war, in times of peace many practiced arts such as poetry and painting. This ideology was reflected in the quality and beauty of their weapons. A *shinsakuto katana* is not only a weapon of war, but also a work of art. Therefore, a number of aesthetic qualities dramatically influence the value of each blade in addition to its prowess on the battlefield. Some of the more obvious features of a *katana* are the size, shape, and design of the weapon. A properly forged *katana* should give an overall impression of either graceful elegance or overwhelming power, according to the length, width, and degree of curvature of the blade. [2] Other more subtle factors include the quality of the steel used to produce the blade and crystallographic patterns or *hamon* that appear on the surface after polishing. To recognize these requires a great deal of knowledge in the area of ancient weaponry. One must be familiar with all aspects of Japanese swords and the various methods used by swordsmiths throughout the course of history to identify the true value of a *katana* blade. Due to the wide variation in forging methods, only a few are touched upon in the following sections.

Materials and Preparation

The first step in producing a Japanese *katana* is the selection of the high-quality materials used to fabricate the blade. The steels that current Japanese swordsmiths use to produce most bladed weapons consist of 99.99% pure electrolytic iron (*denkai-tetsu*), sponge/oxygen free iron (*kangan-tetsu*), or the more popular *tamahagane* steel. [2] The *tamahagane* seen in Figure 10 is the traditional form of steel used in the fabrication of swords. This form of steel is produced in a simple smelter or *tatara* from charcoal and *satetsu*, the elemental iron found in streambeds. A diagram of a *tatara* can be seen in Figure 12. The charcoal and the *satetsu* are heated in the *tatara* to a temperature between 1200 and

Figure 10: *Tamahagane* Steel. [2]

1500°C over a period of three days. [2] This process acts as a rudimentary refining process when the impurities within the base elements are removed in the form of slag. When cool, the *tamahagane* steel is then broken into usable pieces and sorted by quality and carbon content. The carbon content of the *tamahagane* produced in this smelting process can range from 0.6 to 1.5%. [2] High quality *tamahagane* is clearly distinguished from metal of poor quality. High quality *tamahagane* is quite dense with a “bright, silvery color” and fine crystalline structure. The metal should possess 1.0 to 1.2% carbon. [2]

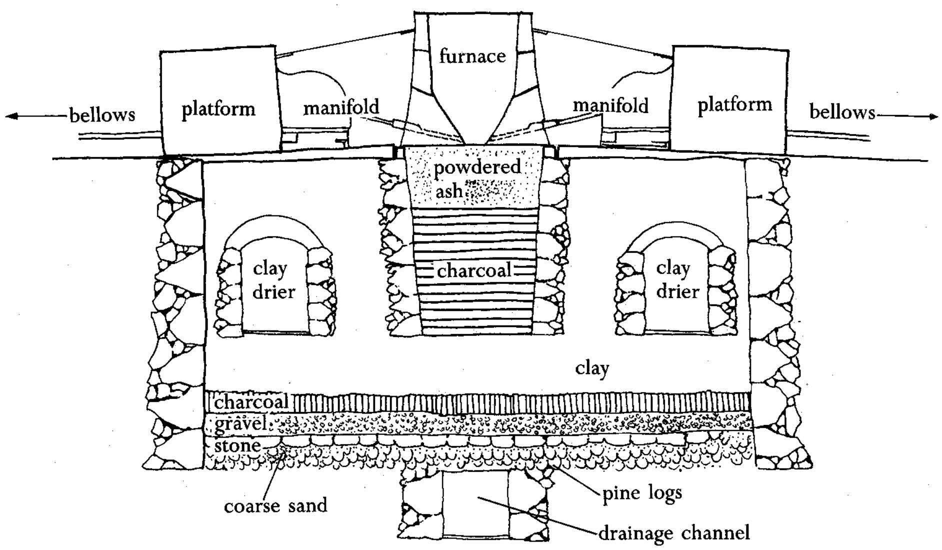


Figure 11: *Tatara* smelter diagram. [2]

Swordsmiths carefully examine each shipment of *tamahagane* and select only pieces with the proper carbon content for each part of the Japanese blade - the hard *kawagane* or “jacket steel” and the soft *shingane* or core as seen in the diagram in Figure 12. [2] Despite the considerable care taken by the smelters in producing the *tamahagane*, most of the steel the smiths receive is not suitable for either part of a blade. If the carbon content is too high, the steel is brittle and does not forge or weld easily. If the carbon content is too low, the steel is too soft and will not hold an edge. Both cases result in the production of a low quality blade. Therefore, further refining or *oroshigane* processes are required to adjust the carbon content of the steel to make it suitable for sword production. For *tamahagane* with high carbon content, the pieces

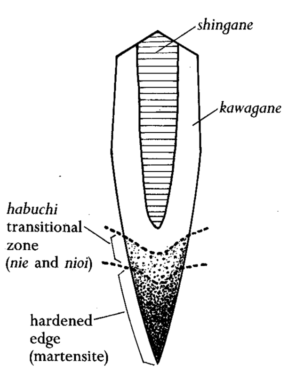


Figure 12: Diagram of *katana cross-section*. Note the position of the *kawagan* and *shingane*. [2]

of steel are heated in the *tatara* while air from the bellows is forced up through the metal. The volumetric airflow and high temperatures of the *tatara* remove excess carbon from the metal in the form of carbon dioxide. For *tamahagane* with low carbon content, the pieces of steel are simply remelted in a similar fashion to the initial smelting of the metal in the presence of excess charcoal. Diagrams of the *tatara* during this process can be seen in Figure 13a and 13b.

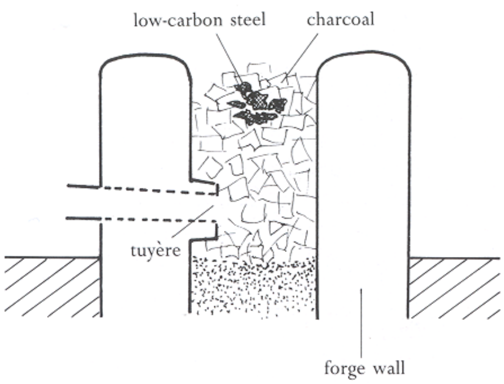


Figure 13a: Diagram of *tatara* during *oroshigan* process when the carbon content of the *tamahagane* is too high. [2]

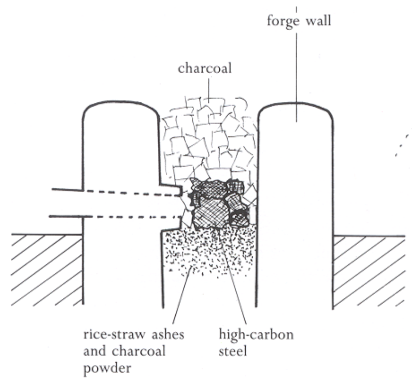


Figure 13b: Diagram of *tatara* during *oroshigane* process when the carbon conten of the *tamahagane* is too low. [2]

When the pieces of steel possess the proper amounts of carbon, the forging process can begin. Graphical diagrams of each step of the forging process can be seen in Appendix C. The *tamahagane* is reheated and hammered into roughly one-quarter inch plates. The plates are again broken and the pieces used to create the *kawagane* and the *shingane* are selected. The chosen pieces are stacked to form a 3” x 5” block weighing roughly four to five pounds on a steel plate of similar composition that has been welded to a long handle. The block is wrapped in rice paper and coated in insulating clay slurry, as seen below in Figures 14 and 15, to maintain its form during heating and then placed into the forge where it is heated to 1300°C (glowing yellow or white). [2]

Figure 14: A stack of *tamahagane* steel being wrapped in rice paper to maintain its form during heating. [2]

Figure 15: Clay slurry is applied to a heated stack of *tamahagane* to provide insulation during heating. [2]

When the metal has reached the proper temperature, the block is removed from the forge and hammered to fuse the plates together into a single bar. Subsequent hammering and heating steps are required following the initial fusing of the metal to draw the bar out to nearly twice its original length.

Forging or "*Kitae*" of the *Kawagane*

The *shita-gitae* or "founding forging" is performed when an elongated steel bar of the proper carbon content is deemed ready to be forged into the hard *kawagane*. The process consists of folding the bar back upon itself to form the distinct layers of steel that are unique to each blade. It begins with the heating of the elongated bar to the appropriate forging temperature. The heated bar is struck with a chisel in the middle of its length until it is almost divided into two equal halves. In Figure 16, one half of the nearly bisected bar is held against the edge of the anvil while a series of hammer strikes forces the other half of the bar to bend at the notch made by the chisel. When the two halves form a ninety-degree angle, the bar is then completely folded back upon itself and fused together in another series of hammer strikes as seen in Figure 17. When the two halves are fully fused, the metal is once again drawn out to twice the length of the original bar. A single fold requires about thirty minutes of precision forging and the number of times the bar is folded depends greatly on the style of the individual swordsmith.

Figure 16: Bar of *kawagane* steel being folded. The metal is being bent to a 90 degree angle. [2]

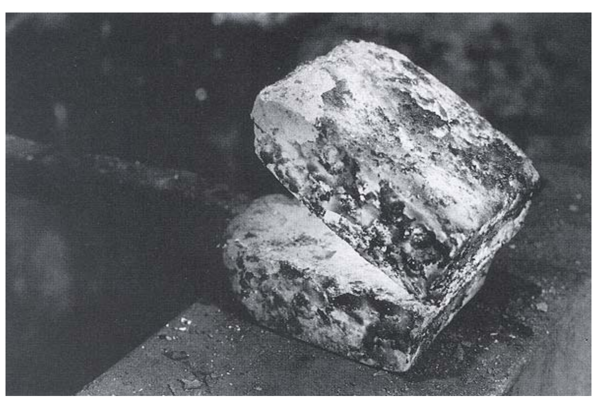


Figure 17: Folded bar of *kawagane* steel. The two halves are ready to be fused together. [2]

As the heated metal is worked, it cools quickly and becomes increasingly difficult to forge. When the bar becomes a dull red, it is placed back in the forge and reheated to the appropriate temperature. Each fold requires two to three "heats." During the heating process, the high temperatures of the forge and oxygen rich air provided by the bellows can quickly remove carbon from the metal, thereby reducing the carefully prepared steel to pure iron and rendering the metal useless for sword fabrication. To prevent this, the swordsmith will occasionally remove the bar from the forge, roll it in rice straw ash as seen in Figure 18, and recoat it in clay slurry. This step dramatically reduces the oxidation and decarburization of the metal during heating, but nearly half of the original *tamahagane* is consumed in the *shita-gitae*, despite precautions to prevent material loss.

Figure 18: Heated bar of *kawagane* steel coated in rice straw ash. [2]

The folded steel bar produced from the *shita-gitae* is usually 10" x ¾" x 1 ½" and weighs two and a quarter to three and a half pounds. [2] There is usually a nonhomogenous distribution of carbon within the metal bar even with all the precautions taken by the swordsmith up to this point. Such a condition is unacceptable when attempting to produce a *kawagane* of superior quality. To correct this, the swordsmith cuts the bar into three equal pieces, stacks them upon each other, and returns them to the forge. For a *katana*, four pieces of steels are required to produce the long blade of the sword. The pieces are again fused into a single bar and a second folding process known as the *age-gitae* or "finish forging" is performed. The metal is folded an additional number of times and results in a two to three and a half pound steel bar containing about 0.7% carbon uniformly distributed throughout its length. [2]

Two particular characteristics of the *kawagane* result from the quality of the steel and the manner in which it was folded in the *shita-gitae*. The *jitetsu* (steel quality) and *jihada* (surface pattern) are terms used to describe the arrangement of the folded layers in the steel and the design that will show on the blade's surface when the final polish has been performed. [4] Many factors can influence both the *jitetsu* and the *jihada*, including the direction of the folds, the strength of the hammer strike, and the combining of metals plates from different bars. Depending on the swordsmith's particular method of forging, one can obtain the aesthetically pleasing patterns seen in Figure 19 that often greatly add to the value and character of the finished sword. Diagrams of some of the grain structures created from different folding methods can be seen in Figure 20.

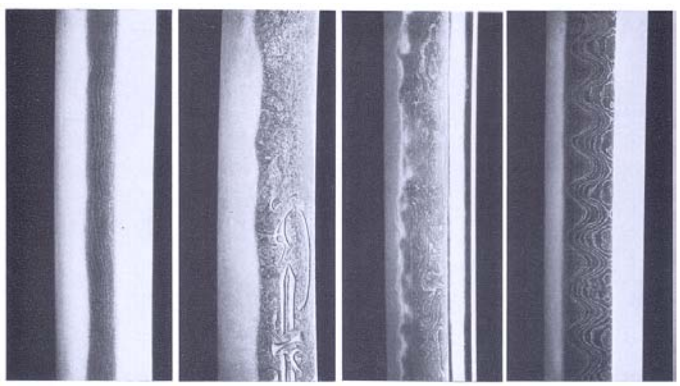


Figure 19: Examples of *jihada* patterns on the surfaces of Japanese blades. [4]

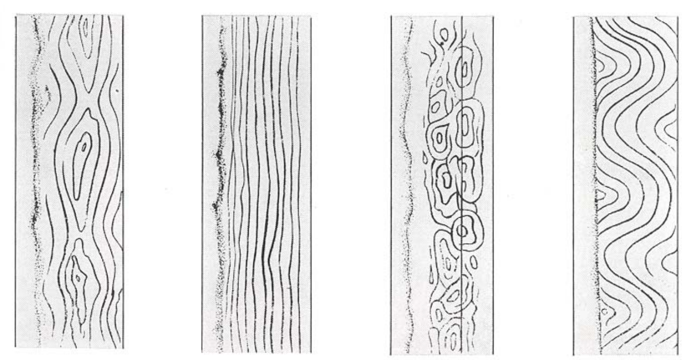


Figure 20: Diagrams of some of the grain structures seen in the surfaces of Japanese blades. [5]

Forging of the *Shingane*

While many of the shorter bladed weapons, such as *tanto* and *wakizashi*, are made entirely from the hard *kawagane* "jacket steel," long blades such as the *katana* possess a soft, low-carbon, steel core or *shingane* that enables the sword to be both flexible and durable, even when damaged. The production of the *shingane* is very similar to the *kawagane* in that the pieces of *tamahagane* that contain the proper amount of carbon are heated, hammered, and folded into a single bar. The swordsmith usually begins with a two-pound stack of *tamahagane* that contains roughly 0.5% carbon. [2] The stack is heated and hammered into a flat bar in a similar fashion to the metal bar of the *kawagane*. The *shingane* bar is then folded ten times in the same manner mentioned earlier. Additional folding of the *shingane* is required due to the fact that the metal usually contains high amounts of impurities. These impurities must be removed to ensure the two pieces of the blade, the *kawagane* and the *shingane*, will fuse together properly and to prevent the presence of blemishes and flaws in the surface of the finished sword. Again, due to the harsh conditions of the forge and depending on the initial carbon content of the metal, some of the original material is lost in the process and the final *shingane* weighs about a half a pound with a carbon content of 0.2 to 0.3%. [2]

Forming the Steel Stock (*Tsukurikomi*)

There are two joining methods or *tsukurikomi* that are currently used to properly fuse the *kawagane* and the *shingane* into a composite that possesses the desired qualities of a Japanese *katana*. In the simple jacket-and-core-steel forging or *kobuse-gitae* method that is depicted in Figure 21, the swordsmith heats and hammers a two and a half pound bar of *kawagane* into a 15" long flat plate. [2] The plate is then bent into a U-shape and a heated one-pound bar of *shingane* is inserted into its base. The *shingane* bar does not run through the entire *kawagane* length as that the piercing point of the finished blade is made from only the best of the hardened "jacket steel" bar. The two bars of semi-joined metal are then reinserted into the forge and heated above 1300°C. [2] When the proper temperature is reached, the bars are removed from the forge and hammered so that the *kawagane* completely enshrouds the *shingane*, forming the steel composite. A finished bar of steel forged in *kobuse-gitae* style can be seen in Figure 22. A cross-section of a *katana* blade forged in a similar manner can be seen in Figure 23. This process is extremely delicate and vital for the successful forging of a Japanese sword. If the two parts of the blade are not welded perfectly and voids or gaps exist, the final work is considered worthless. If the *shingane* is not completely covered by the *kawagane*, the final work will possess weak points and is considered equally worthless. In both cases, the blades are destroyed and the metal recovered for future use.

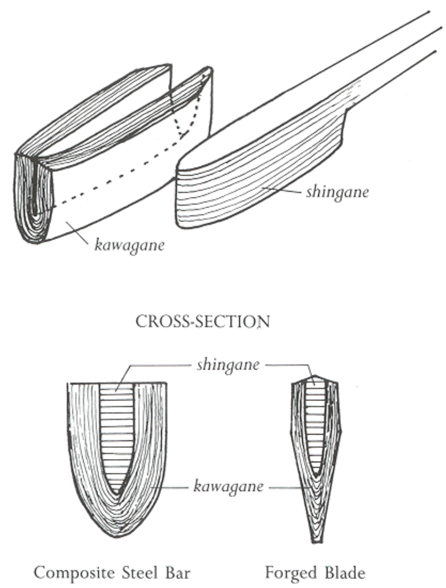


Figure 21: Diagram of *tsukurikomi* design. *Kobuse-gitae* style. [2]

Figure 22: Welded bar of steel from *tsukurikomi* process. *Kobuse-gitae* style. Note how the *shingane* core rests in a jacket of *kawagane.* [2]

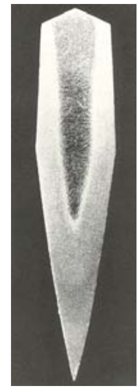


Figure 23: Cross-section of *katana* blade. *Kobuse-gitae* style *tsukurikomi*. [2]

The second method of *tsukurikomi* is a far more complicated method of joining the *kawagane* and the *shingane*. This process is known as the *hon-sanmai-gitae*. The *hon-sanmai-gitae* style of *tsukurikomi* depicted in Figure 24 utilizes anywhere from two (two sides) to four (two sides, a back and an edge) pieces of hard, high-carbon steel to form the steel jacket around the soft, low-carbon, steel core. A cross-section of a *katana* blade forged in the *hon-sanmai-gitae*

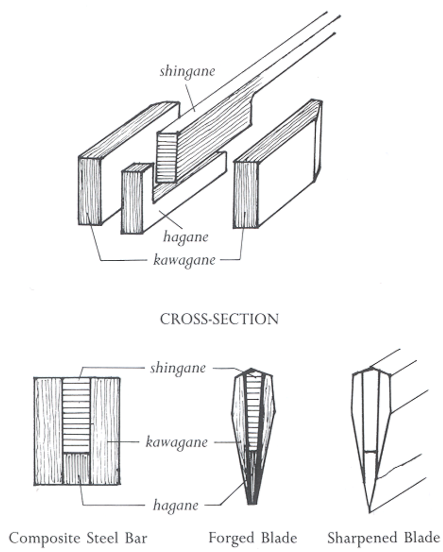


Figure 24: Diagram of *tsukurikomi* design. *Hon-sanmai-gitae* style. Note the number of pieces of hard *kawagane* steel needed in this process. [2]

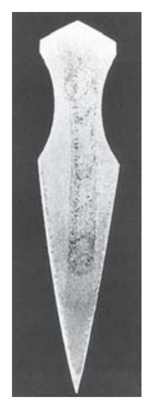


Figure 25: Cross-section of a *katana* blade. *Kobuse-gitae* style *tsukurikomi*. Note the difference between the soft, dark core and the hard, bright sections of metal. [2]

style can be seen in Figure 25. Each piece must be skillfully attached in separate welding processes that may include a layering operation of steels with different carbon contents. This process of producing a complicated steel composite undoubtedly changes the physical properties of the finished sword, but the variations have not been critically studied. Regardless of how the *tsukurikomi* is performed, the differences between the various joining methods represent a clear indication of the different forging styles that developed over the course of Japanese history.

Forming the Blank (*Sunobe*)

When the *kawagane* and the *shingane* are properly joined in the *tsukurikomi*, the swordsmith reheats the metal and begins to form the initial shape of the sword. This sword "blank" or *sunobe* is formed as the swordsmith draws out the steel composite in another series of heating and hammering steps that result in what closely resembles the shape of the finished *katana* in Figure 26. The *sunobe* is roughly 90% of the *katana's* final length and width, but much

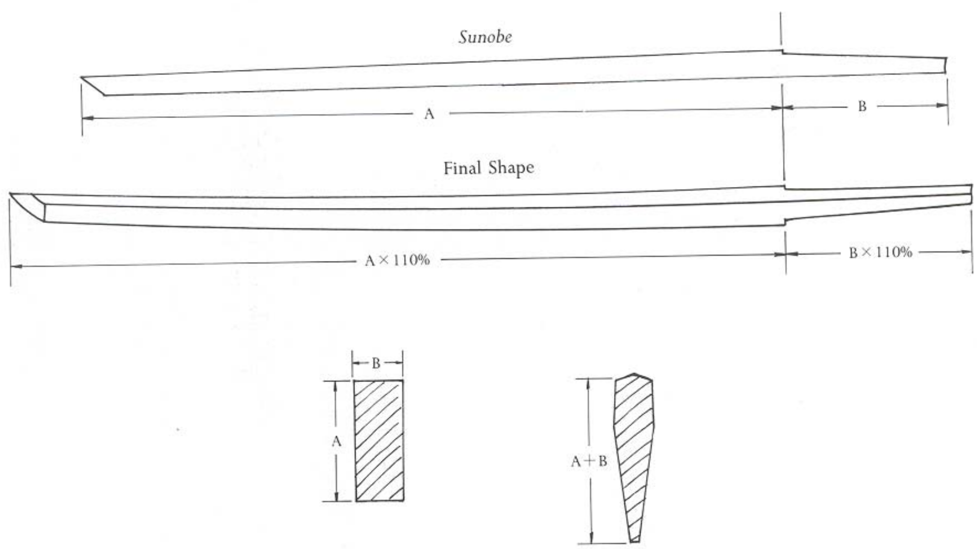


Figure 26: Dimensional comparison between a *sunobe* and a finished *katana* blade. [2]

thicker than finished blade with no curve or edge definitions. [2] At this point, the swordsmith also defines the tang (section of the sword know as the *nakago* that is secured in the hilt), indicated by a notched section of the s*unobe*, and the piercing tip or *kissaki*, indicated by a rounded edge. To complete this process, the swordsmith then uses a hammer to make the s*unobe* uniform in thickness from the front of the blade to the back and from the tang to the tip.

Shaping the Blade (*Hisukuri*)

The shaping of the *katana* blade begins with the drawing out of the cutting edge or *ha-saki*. The swordsmith flattens the edge of the s*unobe* perpendicular to its length by heating a 6" section of the blank to 1100°C. [2] The section is steadily hammered into its final form, Figure 25, until the metal is too cool to work, at which point the section of the *sunobe* is reheated and the process continued. Heating is closely controlled during this process and only a 6" section is worked at a time due to the delicate nature of the material. [2] If the metal is overheated, a firm hammer strike could easily cause the separation of the *kawagane*-*shingane* composite, ruining days of careful work. If the section is too cool, the surface of the s*unobe* could be damaged and the blank could simply fracture.

Figure 25: A 6" section of a *sunobe*. The cutting edge is being drawn out. Note that only a 6" section is worked at a time. [2]

The piercing *kissaki*, ridgeline (*shinogi*), and back of the sword (*mune*) seen in Figure 26 also emerge during the *hisukuri*. The swordsmith continually moves the s*unobe* on the surface of the anvil and works quickly to avoid the cooling of the metal during the forming of the long, straight blade. If done properly, the blade will appear to elongate as the metal along the cutting edge is tapered and stretched more than the metal of the back. Novice smiths often produce blades that begin to twist and turn due to uncontrolled hammer strikes. Master smiths, on the other hand, who have trained for many years are capable of quickly working the top, sides, back, and edge of a blade by knowing how to vary the strength of each hammer strike to produce the desired effect. Precision forging at this point greatly reduces any filing or grinding required to finish the blade, but while the shaped *sunobe* may look like a sword, the *ha-saki* is still quite dull and about a tenth of an inch thick.

Figure 26: A fully formed *kissaki*, *shinogi*, and *mune* from a *sunobe sword blank.* [2]

Rough Grinding and Filing (*Shiage*)

When the forging of the blade is completed, the swordsmith must then prepare the *sunobe* for the process that will give the finished weapon its hardened cutting edge. This begins with the rough grinding and filing of the metal or *shiage*. First, the swordsmith uses the drawknife seen in Figure 27, known as a *sen* or a metal planer, to shave off any irregularities or unevenness from the surface of the metal. Next, a file is used on the back and edge of the *sunobe*. Finally, a rough grinding is performed with a carborundum stone over the entire blade surface. When the *shiage* is completed, the shape of the *katana* is well defined with all the necessary lines and surfaces of a finished sword, but the ground surface of the cutting edge is kept very rough in preparation for the next step of the hardening process.

Figure 27: The removal of irregularities from the surface of the metal. Note the drawknife or *sen.* [2]

Creating the ***Hamon*** (***Tsuchioki***)

There are many forms of steel, each with its own specific physical and chemical properties. As mentioned previously, these properties are determined by a number of factors, the most significant of which when referring to Japanese bladed weapons are the carbon content and the thermal history of the metal. A diagram of the various forms of steel based on carbon content and temperature of the metal can be seen in Figure 28. The cutting edge of a Japanese *katana* or *yakiba* is an extremely hard form of steel known as martensite. [2] Martensite can easily be sharpened and will effectively hold a lethal cutting edge but it is often too rigid and brittle to provide the flexibility and durability needed to absorb and deflect blows without sustaining permanent damage to the blade. These qualities are better suited for the softer forms of steel known as ferrite and pearlite. After centuries of development, Japanese craftsmen have discovered

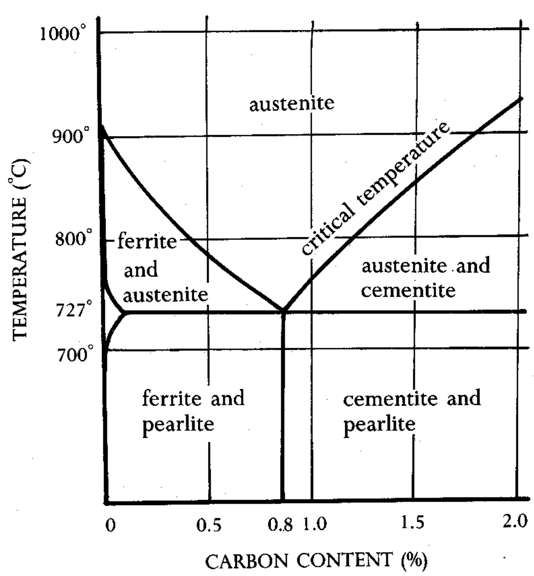


Figure 28: Iron-Carbon phase diagram. Note the different forms of steel. [2]

methods that enable the swordsmith to harden the *ha-saki* of the sword while leaving the body both flexible and durable. The key to this process is the heat treatment that is used to change the metal of the cutting edge from soft pearlite to hardened martensite. The transition zone between these two phases or *habuchi* is clearly visible in a finished sword, so many efforts are taken to produce an aesthetically pleasing crystal pattern. This pattern is known as the *hamon* and considered the most important aesthetic property of the Japanese blade. The design and complexity of the *hamon* directly correlates to the artistic skill and prowess of each swordsmith and greatly influences the value of each individual sword.

To produce the *hamon*, the swordsmith first creates the *tsuchioki* or "*hamon* design." [2] This process begins with a clay mixture known as *tsuchi-dori* that will be applied to the blade prior to heat-treating. The *tsuchi-dori* usually consists of roughly equal parts of riverbed clay for insulation, charcoal powder for heating control, pulverized sandstone to prevent cracking, and other elements that are specific to each swordsmith. [2] Water is added to the mixture and worked until it is viscous enough to stick to the previously roughened metal surface. The *tsuchi-dori* acts as an insulator by slowing the cooling of the metal and causing the formation of ferrite and pearlite. The swordsmith applies the mixture to the blade surface with a spatula in varying thicknesses as seen in Figure 29, depending on the desired properties of each part. The thinner the insulating layer, the more martensite there will be in the microstructure. Therefore, a very thin layer of *tsuchi-dori* is used for the cutting edge while a thicker layer is used for the upper portion and back of the blade. The distribution and thickness of the mixture will ultimately determine the final pattern of the *hamon*.

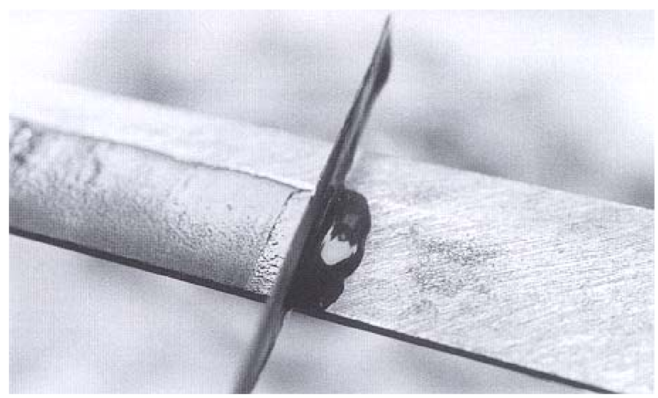


Figure 29: *Tsuchi-dori* is applied to the surface of a blade in the *tsuchioki*. The layer on the back of the blade is relatively this when compared to the layer applied to the cutting edge. [2]

It was mentioned earlier that while martensite is a very hard form of steel, it is also very brittle. [2] This means that if struck properly, the *ha-saki* of a *katana* could potentially crack and lead to further damage of the blade. This is clearly an undesirable trait that must be prevented at all costs. Therefore, the swordsmith applies a large number thin strips of the *tsuchi-dori* across the surface of the blade, perpendicular to the cutting edge as seen in Figure 30. This action will cause veins of pearlite or *ashi* to form behind the hardened edge of the blade. When the *ha-saki* cracks or is chipped in battle, the crack will propagate through the brittle martensite until it is arrested by the soft pearlite, thereby preventing the catastrophic failure of the sword during combat. *Ashi* is an intrinsic part of the *hamon* design and is often seen in many different designs and styles.

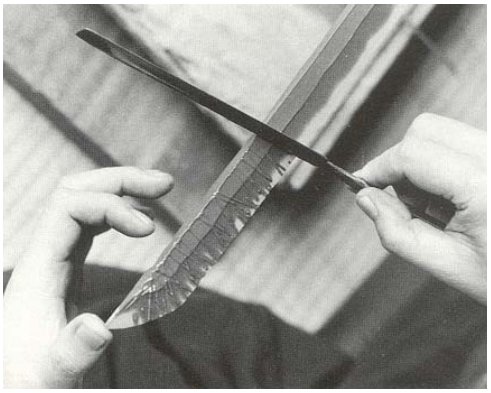


Figure 30: *Tsuchi-dori* is applied in thin strips. These will create regions of pearlite known as *ashi*. The *ashi* will preven the blade from breaking by arresting cracks that originate in the hard martensitic edge. [2]

Hardening the Edge (*Yaki-ire*)

The actual process of hardening the *yakiba* of a Japanese blade is known as *yaki-ire.* When the *tsuchi-dori* fully dries, the sword is heated to a glowing red or orange and then quickly quenched in water. While this process may bring to mind images of glowing red metal, deep pools of water, and billowing clouds of steam, the process is in actuality very delicate with every aspect meticulously controlled. The *yaki-ire* is usually performed at night to enable the swordsmith to better see the true color of the metal and gauge the temperature by observing its glow. Such a discriminating eye is a product of many years of practice and experience. Swordsmiths must also be highly in tune with the materials they are working with as every sword is unique and will react differently during the process.

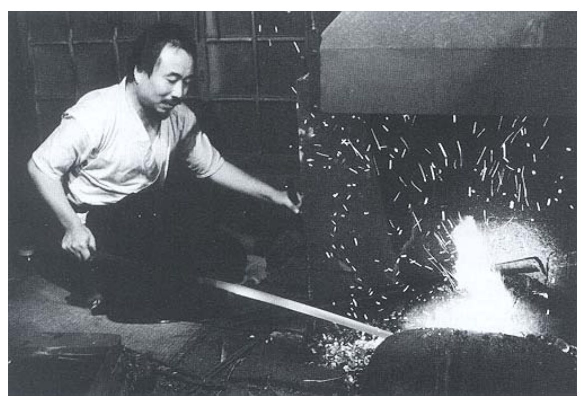


Figure 31: The sword smith draws the blade through the forge to homogenize the temperature of the metal. [2]

The first step of the *yaki-ire* is the stoking of a forge to produce an even temperature throughout the heated area. When the forge is prepared, the swordsmith inserts the tang of the blade into a notch in another steel bar and binds the two with a leather strap. The blade is then drawn through the forge several times with its edge facing up and several more times with its edge facing down. An image of this can be seen in Figure 31. This is simply to homogenize the temperature of the metal. After a quick inspection of the color of the blade which should be bright red or orange (above 700°C), the swordsmith then quenches the sword in a trough of water as seen in Figure 32 to rapidly cool the metal to its hardened state. [2] There are many forms and styles of *yaki-ire*, each with different methods that influence the qualities of the blade. Some smiths use steels with different chemical compositions while others use higher or lower temperatures to heat-treat the steel. Such variations produce a number of aesthetically pleasing effects that are often attributed to the skill of the swordsmith and the quality of the materials used to make the blade. In any case, these factors ensure that each blade will be as distinct and unique as each swordsmith and characteristic of a specific technique.

Figure 32: Quenching of the heated blade. This process will cause the formation of hard martensite in the cutting edge. [2]

Following the *yaki-ire*, the swordsmith removes the blade from the trough and again draws it through a low-temperature forge. The blade is uniformly heated to about 160°C and quenched as part of a tempering process or *yaki-modoshi*. [2] This process relieves some of the residual stresses produced in the initial quench and is often repeated several times. The swordsmith must be extremely cautious during the *yaki-modoshi* because that while the tempering process can result in a more complex *hamon*, it can just as easily cause the *hamon* to fade or disappear from the surface of the blade. Following the final quench of the *yaki-modoshi*, the dry clay is removed from the blade's surface and the metal is examined for flaws. If the blade is acceptable, the smith applies a 2% nitric acid and ethanol solution to the metal's surface to bring out the fine definition and design of the *hamon*. [2] At this point, the swordsmith examines the blade to determine the effectiveness of the *yaki-ire*. If the metal was too hot when the blade was quenched, stress cracks may have developed or the loss of the *hamon* may have occurred. If the metal was too cool, the cutting edge may not have hardened or the *hamon* might be poorly defined. In either case, the smith can simply reheat the metal to 700 or 800°C and allow it to cool slowly to return the microstructure to its pearlitic and ferritic state. [2] The *yaki-ire* process can then be repeated in hopes of producing a better blade.

Adjusting the Curvature (*Sorinaoshi*)

During the *yaki-ire* process, the difference between the cooling rates of the cutting edge and back of the blade causes it to curve slightly. The slower cooling rate of the back of the blade causes a continued contraction of the metal that persists long after the cutting edge has fully solidified. The effect of this phenomenon is an increase in the curvature of the blade up to a half an inch. To account for this, swordsmiths often forge a blade with only a slight degree of curvature, usually less than that desired in the final blade. Even with careful preparation and planning, some curvature adjustment is necessary. This process is known as *sorinaoshi*. If the blade possesses too much curve, the swordsmith can simply strike that back of the blade with a hammer, thereby expanding the metal and reducing the curvature of the blade. If the blade possesses too little curve, the swordsmith holds the back of the blade in the areas that require more curvature to a heated copper ingot. The process seen in Figure 33 causes the steel in the back of the blade to expand and a quick quench causes a rapid contraction, inducing a localized increase in the *zori*. [2]

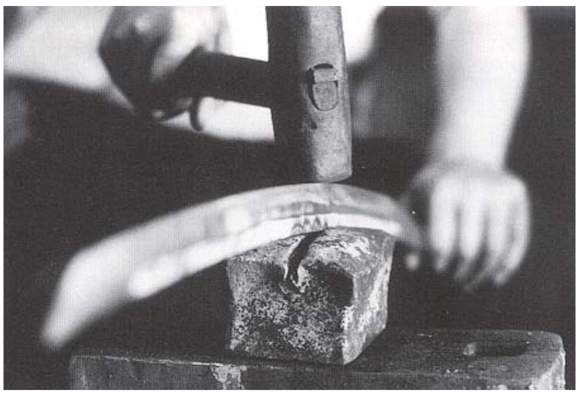


Figure 33: Correction of the curvature of a *katana* blade through the *sorinaoshi*. Causing the metal to expand with a heated copper ingot increases the curvature. [2]

Just the Beginning…

The forging and shaping of the *katana* is only the first of many steps involved in the creation of a Japanese sword. Following the forging process, the smith then roughly polishes the blade and adds decorative grooves (*hi*) and carvings (*hirimono*). The tang of the blade is then finished and the smith’s signature or *mei* is inscribed. The blade then passes through the hands of a number of highly skilled craftsmen. First, the

Figure 34: Polishing of the *katana* blade. [2]

blade is delivered to a polisher who sharpens and cleans the blade, revealing the fine details, color, and texture of the metal, giving life to the swordsmith's creation. This process can be seen in Figure 34. Only after many days of delicate work does a master blade polisher produce the renowned razor-sharp, cutting edge of the *katana* with a well-defined *jihada* and *jitetsu*. The blade is then delivered to metalsmiths who fit it with both a copper collar, Figure 35, called a *habaki* to protect the blade from scratches during storage and a decorated blade guard, Figure 36, or *tsuba* made of iron or precious metals.

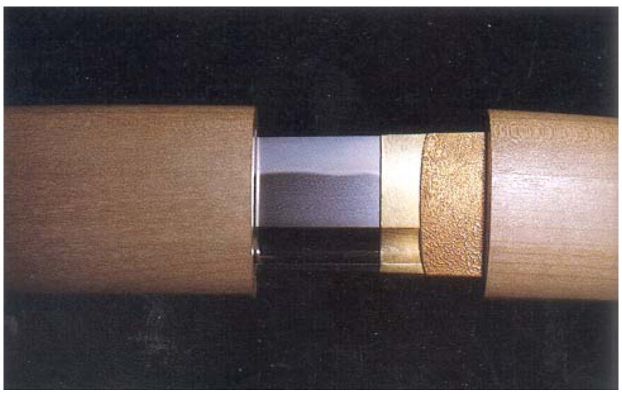


Figure 35: *Habaki* blade guard. These are often made from soft precious metals such as copper, silver, and gold alloys. [2]

Figure 36: *Tsuba* or hilt of a *katana* blade. Often made from iron. In some cases gold was used. [1]

Next, the blade is delivered to woodworkers and carpenters who create a scabbard of plain, unfinished wood known as *shira-zaya* to hold the blade and protect if from the elements. Artisans then elaborately decorate the hilt and the scabbard with everything from gold-flecked lacquer to exotic leathers and stones to produce a finished scabbard or *koshirae* that is a true work of art. An example of a *shira-zaya* and a *koshirae* can be seen in Figure 37. Finally, the finished sword is returned to the swordsmith who carefully examines every aspect of the weapon before presenting it to the client or collector.

Figure 37: A simple wood *shira-zaya* and a *koshirea* elegantly decorated with lacquer and gold flakes. [1]

The purpose of this article is to provide a brief summary of the traditional methods of Japanese sword forging from a scientific and historical point of view. It was written in the hope that others will take interest in this ancient technology and research the matter further. The forging of a *katana* and other Japanese bladed weapons is by no means a simple task nor one taken lightly by the few who continue to practice this ancient art. The creation of these weapons is still a time-honored tradition and performed with the same ceremony and reverence as it was during the days of the *samurai*. Many swordsmiths devote their lives to the perfection their trade and only a select few earn the renown and title of a master. The complex process of welding, folding, and shaping metal into a proper blade requires years of study and experience. The ability to obtain the desired material properties within the blade can only be developed through a lifetime of commitment and devotion. Yet despite the fact that many of these ancient weapons are now simply considered elaborate pieces of art, the beauty of a Japanese sword only belies its lethal nature. Therefore, it is little wonder why such pieces of history are so cherished and revered by collectors throughout the world for few weapons possess the elegance or command the respect of a finely crafted Japanese blade.

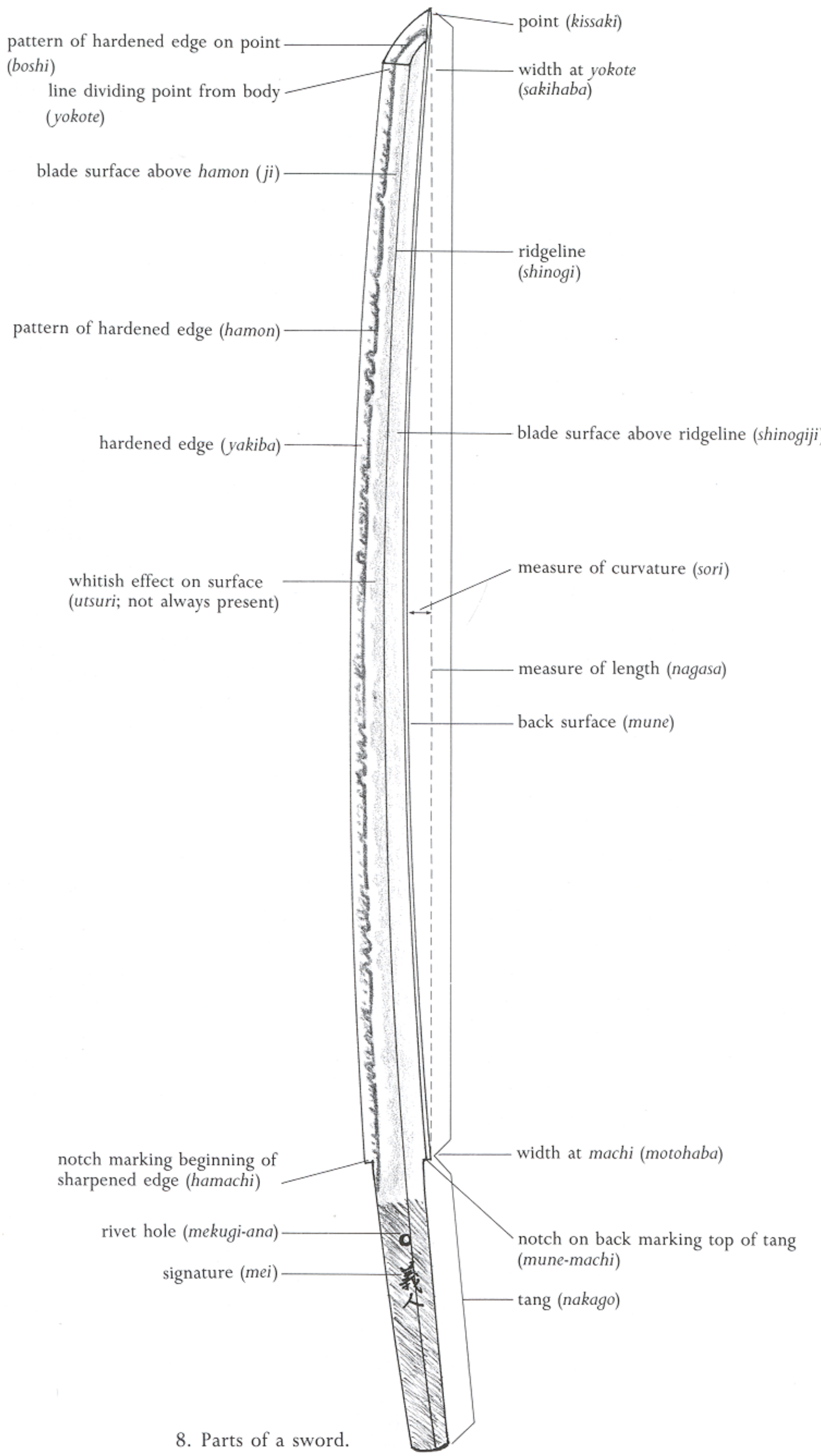
Appendix A: Table of Japanese historical periods and the corresponding names of the swords created therein. [1]

Japanese Historical Periods Related to Sword Production

Nara	710-794	*Chokuto* (ancient straight swords)
Heian	794-1185)	
Kamakura	1185-1333)	
Nambokucho	1333-1396)	*Koto* (old sword period)
Muromachi	1396-1568)	
Aizuchi-Momoyama	1568-1596))	
Edo or Tokugawa	1596-1780	*Shinto* (new swords period)
Bakamatsu (late Edo period)	1780-1877	*Shinshinto* (very new swords) *
Meiji, Taisho, early Showa	1877-1945	*Gendaito* (modern swords)
Later Showa to Heisei	1945 -	*Shinsakuto* (newly made swords)

* Includes first 8 years of the Meiji period.

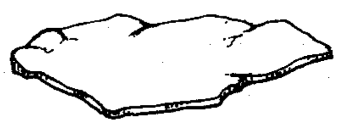
Appendix B: Diagram of a Japanese blade. [2]



8. Parts of a sword.

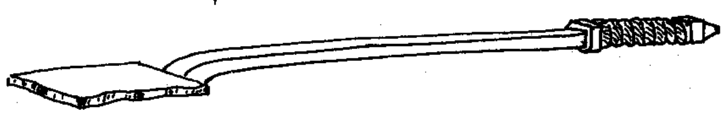
Appendix C: Process of forging a Japanese *Katana*. [2]

Tamahagane steel produced from the *oroshigane* refining process. Ideally, the metal should possess between 1.0 to 1.2% carbon.

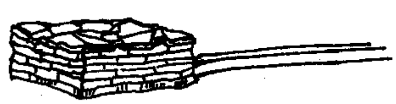


The selected pieces of *tamahagane* are heated to a temperature between 1200 and 1500°C and flattened into ¼” plates.

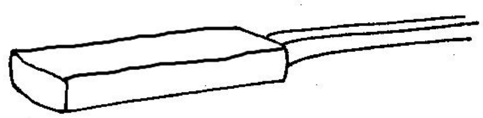
The ¼” plates of *tamahagane* are broken apart and the pieces used to make the *kawagane* and *shingane* are selected according to color and density.



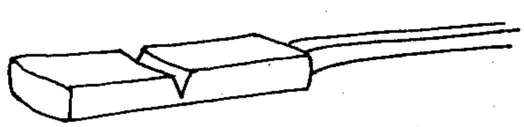
A plate of steel with a similar composition to the *tamahagane* is welded to the end of a long handle.



Four to five pounds of the selected pieces of *tamahagane* are stacked in a 3” x 5” block on the steel plate. The stack is then wrapped in rice paper and heated to 1300°C.

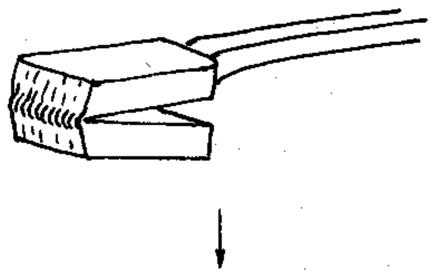


A single bar of steel with the proper carbon content is formed when the heated pieces of *tamahagane* are fused together through a series of hammer strikes. The bar is then drawn out to twice the length of the original stack of *tamahagane* in preparation for the *kitae* or “forging” process.

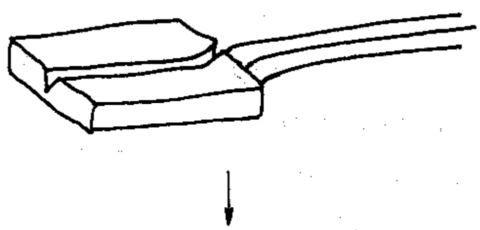


The first step the *kitae* is the *shita-gitae* or “founding forging” which consists of bisecting the steel bar into to two equal parts. This is done by driving a chisel into the heated metal until the bar is nearly cut in half.

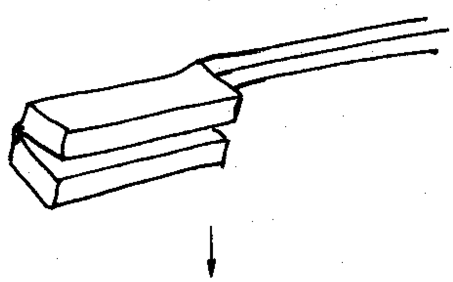
Appendix C: Process of forging a Japanese *Katana*. (Continued) [2]



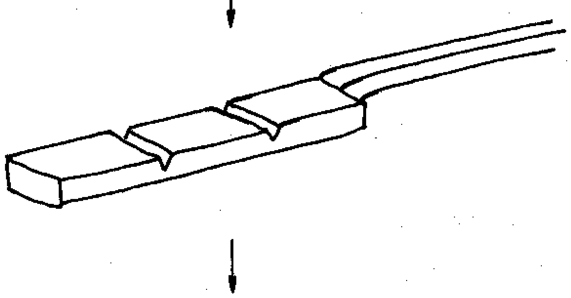
The second step of the *shita-gitae* consists of folding the bisected bar back upon itself. The folded bar is then struck with a hammer until the two halves are fused together. The fused bar is again drawn out to twice the length of the original stack of *tamahagane*.



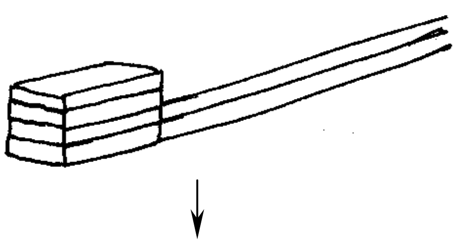
The folding process is repeated a number of times in order to remove any additional impurities from the metal.



The method in which the metal is folded influences the final appearance of the *jihada* and *jitetsu*. These methods vary depending on the swordsmith's style of forging.

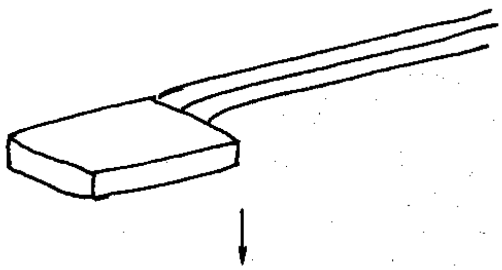


The folded steel bar produced in the *shita-gitae* is roughly 10" x ¾" x 1 ½" with a non-homogeneous distribution of carbon. To correct this, the bar is cut into three equal parts by driving a chisel into the heated metal in the same manner as during the folding process.

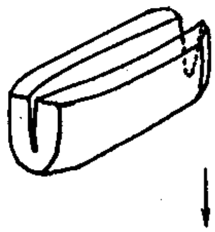


For a *katana*, four pieces of folded steel are stacked upon each other and fused together in a process known as *age-gitae* or "finish forging."

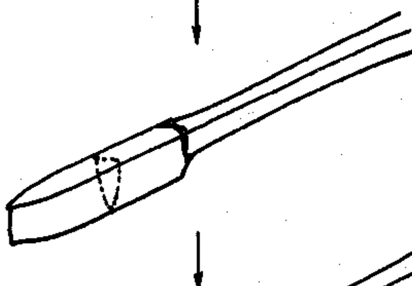
Appendix C: Process of forging a Japanese *Katana*. (Continued) [2]



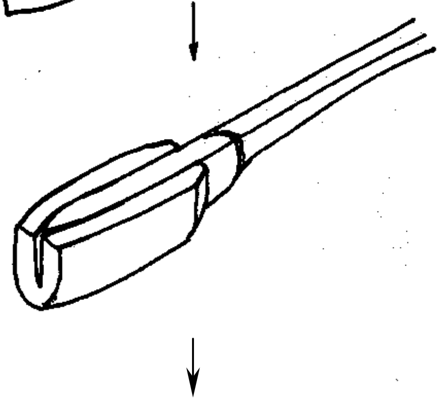
The next step of the forging process consists of fusing the *kawagane* and *shingane* together. This process is known as *tsukurikomi*. The image to the left depicts the first step of the *kobuse-gitae* style *tsukurikomi*. A fused bar of folded *kawagane* steel is flattened into a plate.



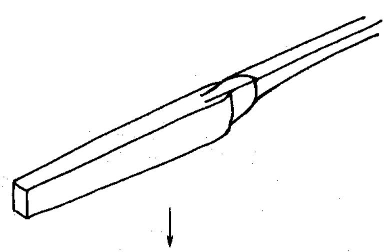
The plate of *kawagane* steel is then bent into a U shape to form the hard jacket of the blade.



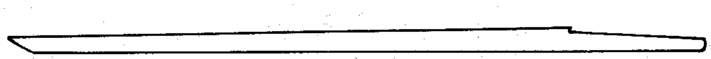
A fused bar of folded *shingane* steel is then shaped to fit the *kawagane* jacket.



The shaped bar of *shingane* is then inserted into the *kawagane* jacket. The two are heated and carefully fused together. If this is not done properly, the finished blade will be useless.



When the *kawagane* and *shingane* are fused together properly, the swordsmith then heats and shapes the metal into a *sunobe* or "sword blank."



The sunobe should closely resemble the shape of a finished *katana* blade.

References

[1] "*Samurai: The weapons and spirit of the Japanese warrior*" by Clive Sinclaire; First Lyons Press; 2001

[2] "*The Craft of the Japanese Sword*" by Leon and Hiroko Kapp and Yshindo Hoshihara; Kodansha America, Inc; 1987

[3] "*The Japanese Sword: The Soul of the Samurai*" by Gregory Irvine; Weather Hill Inc; 2000

[4] "*The Arts of the Japanese Sword*" by Basil W. Robinson; Charles E. Tuttle Company; 1971

[5] "*The Japanese Sword*" by Kanzan Sato and Joe Earle; Kondansha International Ltd. and Shibundo; 1983

[6] "*Arms and Armor of the Samurai: The History of Weaponry in Ancient Japan*" by I. Bottomley and A. P. Hopson; Brompton Books Corp; 1988

Title Page Image: "*Inariyama Ko-Kaji*" or "*The Swordsmith of Mount Inari*" woodblock print by Ogata Gekko. [3]

Final Page Image: *Katana* and *tanto daisho* in matching *koshirea*. Mounted on a *katana-kake* sword rack. Design on sheath is the *Oda* family crest. [1]

NOTE: All Japanese terms, titles, names, and words were drawn from the resource literature.