

Traditional Process Produces Lath Martensite Effectively

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Abstract

The traditional Japanese sword is a highly regarded metal craft in the world from very early times. Its exceptionally sharp cutting edge, wavy banding pattern (called *hamon* in Japanese) toughness and durability are well appreciated. It is said that the Japanese sword cannot be produced by ordinary steel as some traditional methods and techniques are employed in its preparation process. Microstructural studies of the specimens taken from different stage of preparation show that initially the materials of the Japanese sword include ferrite bands in a pearlite matrix. It has been observed that the structural morphologies change with the turns of successive forge-fold operations gradually. In a complete sword the structural configuration is quite different; it shows martensite at the sharp edge and a combination of pearlite and ferrite in other regions. It has been realized that repeated forge-fold operations as well as thermal quenching are attributed to the formation of structural morphology. In the present article the preparation procedure, microstructural and a few mechanical properties of a traditional Japanese sword will be discussed.

Background

A great deal of interest has been found in the recent years to study the micro-structural characteristics of traditional wootz steel especially used in the fabrication of swords. In different parts of the world different types of swords were used as weapons in the medieval age [1]. The extraordinary mechanical properties, exceptionally sharp cutting edge and wavy banding pattern of those swords are of special interest to the researchers. On the basis of archeological research and documentation at least three methods of production of ancient steel-swords are recognized [2,3]. i) Japanese technique for the production of traditional swords, ii) 'Eastern Damascus' techniques diffused in the Indian-Persian regions and iii) 'Western Damascus' or 'Welded Damascus' which has encountered a significant success in the regions around the Mediterranean Sea.

Japanese swordsmiths have had their own recipe to prepare the swords. Many excellent Japanese swords were found in the period of 11th-16th century in Japan but most of them are extinguished now. In the recent years the new generations of old swordsmiths are trying to produce the sword of same quality as those of the old sword. The swords made in Japan today are not, of course, intended for actual use but its quality, design and durability have conferred the dignity of an aesthetic object to it in Japanese society. Swords of different size and shape of different ages are found in NBTHK (*Nihon Bijutsu Token Hozon Kyokai*-The society for preservation of Japanese Swords) in Tokyo, which works for preservation, improvisation and study of the antique swords [4].

Preparation Process of Japanese sword

The swords in Japan are made from a special kind of steel called *tamahagane*. The origin of this *tamahagane* comes from fine black iron sand called *satetsu*. The iron in this form is actually a mixture of iron oxides such as- Fe_2O_3 , Fe_3O_4 , $FeTiO_3$ etc. In order to produce steel from *satetsu*, oxygen is removed and carbon is added. In Japan this is done in a traditional smelter called *tatara*, using charcoal both as the fuel and as the source of carbon. When the smelter temperature is sufficiently high, the oxygen introduced by the bellows reacts with the carbon present in the charcoal to form carbon monoxide. The iron oxide in the ore then reacts with carbon monoxide to form pure iron and carbon dioxide, which escapes as gas. In *tatara* process the steel produced is an inhomogeneous mass of steel- called *tamahagane* that can then be sorted out according to its carbon level. The block of *tamahagane* is flattened into thin sheet by hammering and then cut into small pieces called *heshi* chips. The *heshi* chips containing high carbon (brittle) and low carbon (ductile) are segregated and then forge and fold several times separately to produce refined steels of expected level. Fig. 1 shows a schematic flow chart of preparation of materials of Japanese sword by cyclic forge-fold operations.

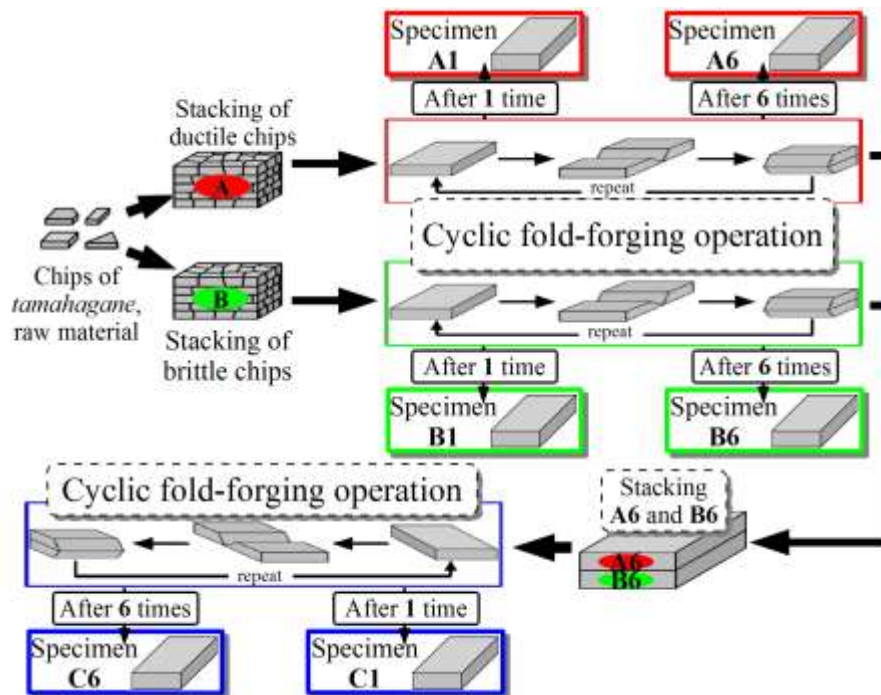


Figure1. Illustration of preparation of the materials of Japanese sword by cyclic forge-fold operations (schematic).

Formation Microstructural Morphology under Forge-Fold Process

The materials of Japanese sword in its different stages of preparation contain different types of microstructures. In Figure 1 the A and B-type materials, initially contains a few ferrite bands in the pearlite matrix which become narrower and thinner gradually with the recurrence of forge-fold operations. The C-type material (mixture of A and B) shows the different microstructure combined with pearlite and plate-like ferrite. Microstructure becomes little finer with increasing the turns of forge-fold

operations but no major change are observed between C1 and C6 [5]. Formation of micro structures in different stages of preparation observed by optical microscopy is shown in Figure 2.

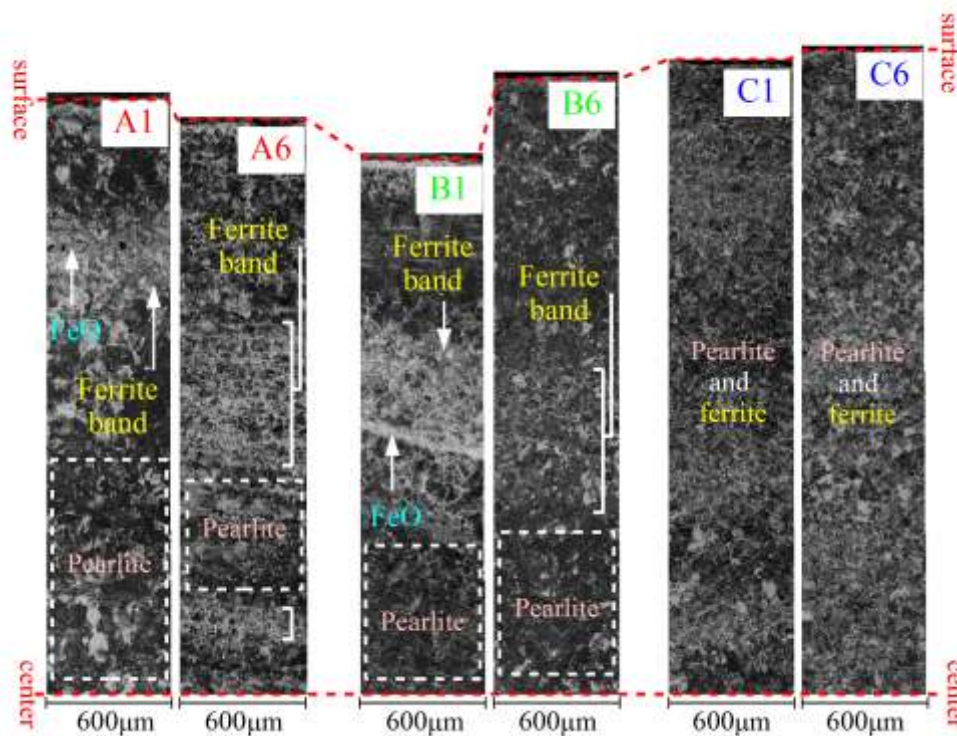


Figure 2. Microstructure observed in different stage of preparation.

However, in a complete sword as shown in Figure 3 the microstructure is different as some more treatments are performed after assembling the A and B-type materials together. Consequently, lath martensite morphology appears in the sharp edge which produces the glazy wavy banding pattern as observed in Figure 4 and fine or coarse pearlite in the other regions [6, 7]. The lath martensite is a typical and unique morphology in Japanese sword which is rare in other swords [1, 2 & 3].

Final Processing of Producing Sword

There are many ways of producing Japanese sword depending on the swordsmiths. Most typical way is that two types of C6 materials (ductile and brittle) are prepared depending upon their carbon level and then ductile one is wrapped by brittle one to fabricate a sword. After having the shape of a sword it is coated by a layer of clay mixed with charcoal (called *Tsuchioki* in Japanese). The clay coating is thinner near the blade, so that after heating up to 800°- 850°C and the following plunging in the water, the blade can undergo a quenching process in order to produce the lath martensite, whose microstructure is different from Damascus steel. Only the blade zone undergoes the phase transformation which causes the lath martensite in the fast cooled region and the related thermal expansion causes the particular bended shape of the typical Japanese swords [4].

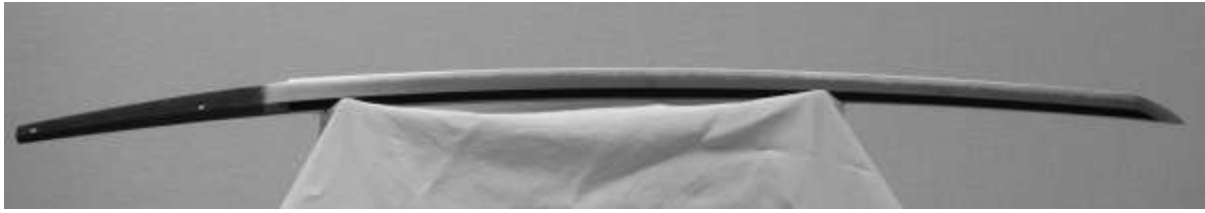


Figure 3. A traditional Japanese sword prepared by Mr. Munehira Koyama in 1837. The length of the sword (blade) is 77.5 cm and curvature is 1.5 cm. The photograph was taken with the consent of Wakoh Museum.

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Figure 4. Top view of the sword (shown in fig.3) showing wavy pattern along the sharp edge.

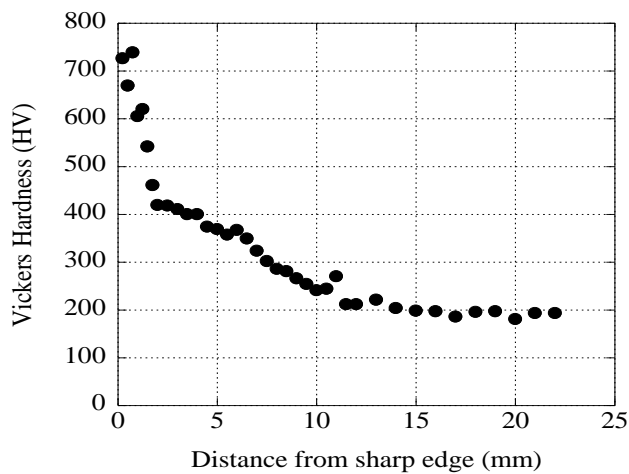


Figure 5 . Hardness profile across the cross section.

Micro hardness

Micro Vickers hardness has been measured to know the trend of hardness across the crosssection along the center line. Figure 5 shows the hardness profile of the sword. The maximum hardness of the sharp edge is 720-730 HV. This hardness level corresponds to the hardness of martensite which contains 0.78 mass% carbon [7]. It has been found that the hardened area is limited to the sharp edge and it decreases drastically beyond the sharp edge. As the structural morphology is pearlite and ferrite outside the sharp edge which is produced for slow quenching effect. The hardness profile shows good agreement with the structural morphology [8].

Summary

Micro structure of a traditional Japanese sword and its preparing materials subjected to successive forge-fold operations were studied metallurgically. Microstructure of the preparing materials consists of a combination of ferrite bands in pearlite matrix at the beginning stage. The ferrite bands become finer with increasing the turns of forge-folding operations and scattered into pearlite matrix gradually. In the complete sword, the sharp edge contains the lath martensite structure where as the other side and the central part show the fine or coarse pearlite structure. The structural configurations resemble

to those of 0.6 mass% C steel [9] even though the concentration of carbon is different. Vickers micro-hardness measurement revealed that the sharp edge is comparatively harder than other sections of the sword. Present study elucidates that the *tatara* iron and its manufacturing procedure give the distinctive features to Japanese swords which is different from ordinary steel. It is also notable that Japanese swordsmiths utilized structurally graded materials without knowing details about it. Recent studies are disclosing the hidden facts behind the old recipe.

Acknowledgements

The present work was financially supported by Tatara project of the Ministry of Education, Science and Culture of Japan Government and the Organization for the Promotion of Project Research in Shimane University. The authors are grateful to Mr. Minagi, Mr. Takaiwa of Wakoh Museum, Mr. Kubota and Mr. Kanaizumi of Hitachi Metals Ltd., Yasugi, Japan for helpful discussion. The authors also acknowledge Mr. Sadanao Mikami, a famous Japanese sword maker for providing the samples employed in present study. The photograph of the Japanese sword was taken under the courtesy of the authority of Wakoh Museum, Yasugi, Japan.

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