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TRACE ELEMENT ANALYSIS OF SULFUR IN A JAPANESE SWORD

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The Japanese sword or Nihonto is a piece of art, a wonder of metallurgical craftsmanship and – even today – a fascinating object for materials research.

A traditional Japanese sword is made from *tama-hagane* (literally: jewel steel). *Tama-hagane* is steel with a carbon content around 1 % and has the chemical composition best suited for edged steels. Its composition makes it exceedingly malleable. The amount of other chemical impurities present is extremely low. *Tama-hagane* is obtained by a traditional method called *tatara*. *Tatara* iron manufacturing has been developed by the master sword makers for more than 1000 years.

We investigated a sword that was preserved in an old Japanese village headman house. One of the characteristics of a Japanese sword is that is consists of two different steels: a harder outer jacket of steel wrapped around a softer core of steel. A specimen including both steels was produced as cross-section perpendicular to the length of the sword. Stage mappings was performed over a large cross-sectional area of 6 mm x 30 mm with EPMA (JEOL JXA-8230). The outer skin of the blade showed few impurities other than carbon. A striped pattern of Si and Al due to oxide inclusions such as SiO_2 and Al_2O_3 particles was clearly observed. In fact, *tama-hagane* manufacturing with the *tatara* process from iron sand contains, though small, certain amounts of SiO_2 and Al_2O_3 particles. Furthermore, the manufacturing process of the Japanese sword consists of many times of folding, hammering and re-welding of the billet of steel, a process which produces a striped distribution of SiO_2 and Al_2O_3 particles. The observation of the outer skin of the blade agreed very well with those made by traditional sword makers. The inner core of the sword, however, was found to contain lager amounts of Mn and S than those in *tama-hagane*. Quantitative analysis of S with a spot size of 50 μm indicated that the inner core of the sword contained 230 ppm whereas the outer skin of the blade contained 50 ppm. To obtain these trace amount of S, the S-Kα spectrum was measured to confirm that no discernible overlap due to other elements was present in the background. The two standard samples of ICP-MS: JSS003-1 S: 4 ppm and SS001-3 S: 2.2 ppm, were analyzed with a spot size 30 μm. Only 2 ppm difference in these two standard samples could be detected with this EPMA so that the measured value of the outer skin of the blade was considered to be highly reliable. S inner core was found in high magnification mapping as MnS particles with size of few tenths of micrometres. MnS inclusions have never been observed in *tama-hagane*. They are rather a fingerprint of modern iron making, which started at the end of the Edo period in the middle of nineteenth century. This sword was found to be produced relatively recently about100 years old. This was classified as a contemporary work and brief method.

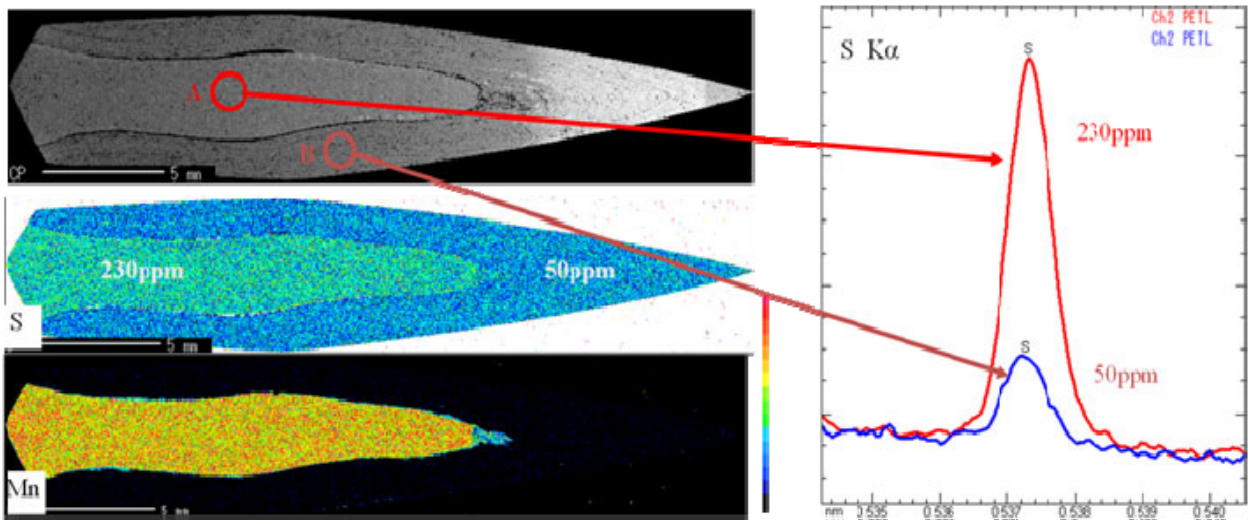

Fig. 1 The X-ray mapping and spectra of Japanese sword at an accelerating of 20 kV. This stage mapping was performed over a large cross-sectional area of 6 mm x 30 mm. It is shown that this Japanese sword consists of two steel as for this data.

Element	A (mass%)	B (mass%)	Detection limit (massppm)	
P	0.0159	0.0171	21	
Ca	-	0.1034	96	
Mn	0.3516	-	60	
Si	0.1365	0.1325	18	
Al	0.0054	0.1090	18	
Mg	-	0.0166	15	
S	0.0232	0.0053	21	
Cu	0.0155	0.0597	60	
Cr	0.0245	-	45	
C	0.3095	0.6054	21	
Fe	99.1179	98.9510		Difference
Total	100.0000	100.0000		

Table.1. The result of the quantitative analysis of a Japanese sword at an accelerating of 20 kV.

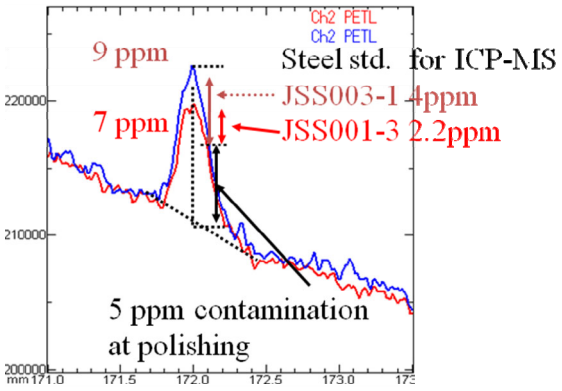

Fig.2. The result of several ppm Sulfur standard samples of ICP-MS. Only 2 ppm difference in these two standard samples could be detected with this EPMA

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