Elucidation of manufacturing process of Japanese sword by microstructural characterization using neutron diffraction

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1. Introduction

The metallurgy of historic melee weapons is one of the most interesting topics in archaeometallurgy. In particular, Japanese swords are paid great admiration in the world as the honor of classical technology and of the art. There have been many reports in the past that tried to elucidate this Japanese sword's microstructure and/or manufacturing process scientifically. These reports were mainly done using the microscopy analyses and X-ray diffraction (XRD) on the cross sections of swords after mechanical cutting. In this study, we tried to use neutron diffraction as the non-destructive testing method.

2. Experiment

TOF neutron diffraction experiment was performed at TAKUMI of J-PARC. Diffraction patterns were simultaneously obtained by 1D-detector banks at $2\theta = \pm 90°$. The gauge volume of the sample was limited to $2 \times 2 \times 2$ mm^3 by using radial collimators and an incident beam slit. By moving the sample at intervals of 2 mm, 13-16 points along the sample's center-line, and 6-8 points along the ±1.5 mm shifted from the center-line, were measured. Fig. 1(a) shows one of the four measured samples; Tadahiro, where red dashed-lines represent the measured position. Data sets for the normal and transverse direction (ND and TD), at $\chi = 0°$ as shown in Fig. 1(b), and the normal and radial direction (ND and RD), at $\chi = 90°$ were obtained. All diffraction data were analyzed by the Rietveld refinement program to obtain lattice constants, phase volume fractions, preferred orientation, the crystallite size and the microstrain from the line-broadening.

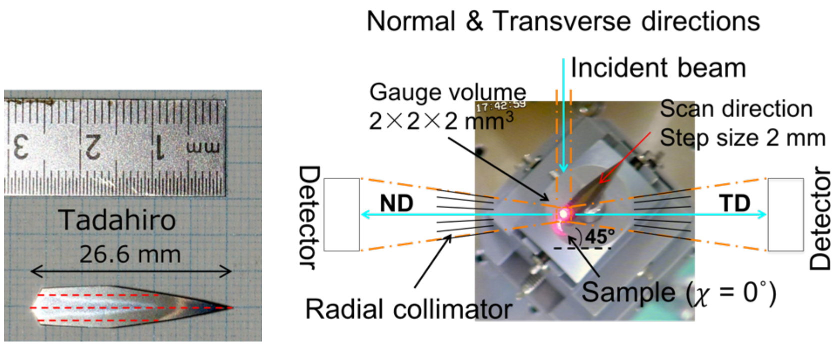

Fig. 1 (a) Picture of a sample Tadahiro. Red dashed-lines represent the measured position. (b) Schematic view of the experimental arrangements.

3. Results

Figures 2(a) and 2(b) show the Rietveld refinement patterns for the back side and the cutting edge of the Tadahiro in the normal direction. Diffraction data between 0.66 and 2.46 Å in d-spacing were analyzed using Z-Rietveld software. Two-phase refinement, ferrite with cementite and martensite with retained austenite, was carried out for data of the back side and the cutting edge, respectively.

Other inclusions, such as Wustite (FeO) or Fayalite (Fe_2SiO_4), were not detected in the present data set. As a starting point, it is roughly summarized as follows.

1) The tooth tip is a martensite phase with retained austenite phase, and the rest are ferrite phase with cementite phase. The cementite may exist as pearlite structure.

2) The averaged lattice constant in three directions (ND, RD, and TD) is about 2.867 Å, which tends to gently increase toward the tooth tip. The difference by a sword is not so large.

3) However, the difference in lattice constant between ND, RD, and TD in a sample is large. It is necessary to reconsider the tendency in each reflection.

4) Martensite phase is reproduced assuming BCC structure with anisotropic line-broadening.

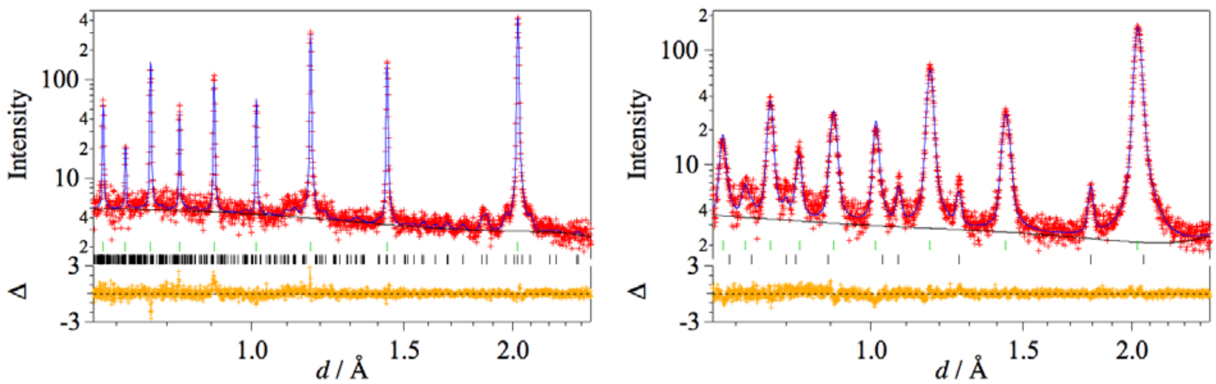

Fig. 2 Rietveld refinement patterns of (a) the back side and (b) the cutting edge of the Tadahiro. Red: observed data y_{obs}; blue: calculated data y_{cal}; black: estimated background; orange: Δ, where $\Delta = (y_{obs} - y_{cal}) / \sqrt{y_{cal}}$. The vertical marks indicate the positions of possible Bragg peaks for each phase.

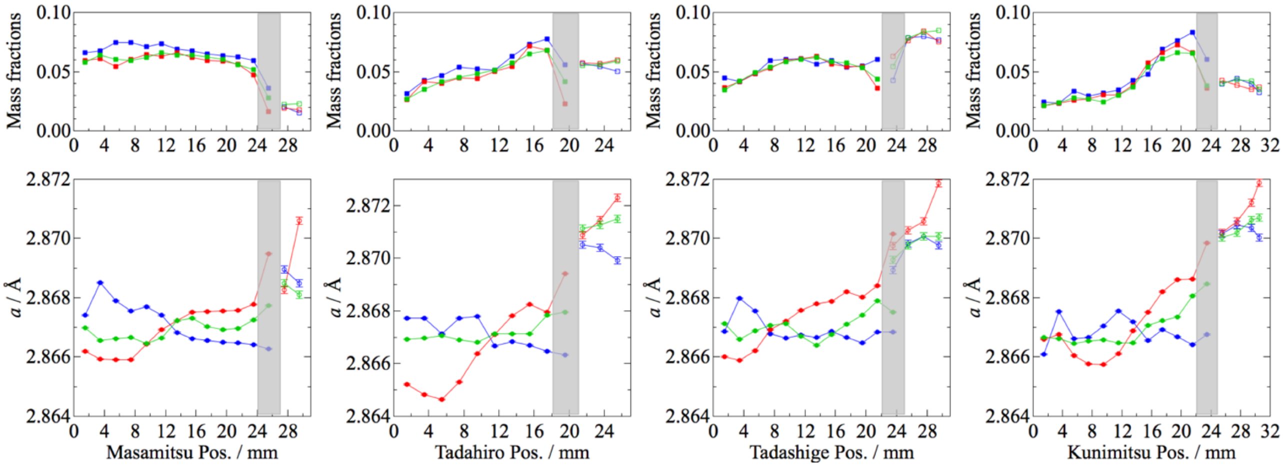

Fig. 3 Mass fractions of cementite/retained austenite and lattice constant of ferrite/martensite of each sample. Position x = 0 is back side, and x ~ 30 is cutting edge of the sample. Blue: normal direction; red: transverse direction; green: radial direction. Grayed out band represents the transition region from the ferrite to the martensite phase.

4. Conclusion

Data analysis are ongoing, and we will compare our results with the results from microscopy analyses using SEM and EBSD and the results from the prior austenite reconstruction method.