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Crystallographic analysis of a Japanese sword by using Bragg edge transmission spectroscopy

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Abstract

Neutron imaging using a pulsed neutron source can give crystallographic information over wide area of a sample by analysing position dependent transmission spectra. With the use of a Bragg edge imaging method we non-destructively obtained crystallographic information of a Japanese sword, signed by Bishu Osafune Norimitsu, in order to know position dependent crystallographic characteristics and to check usefulness of the method for the Japanese sword investigation. Strong texture appeared on the back side. On the other hand in the middle area almost isotropic feature appeared and edge side showed feature between them. Rather isotropic area in the centre area gradually reduced from the grip side to the tip side. The crystallite size was smaller near the edge and became larger towards the back side. The smaller crystallite size will be due to quenching around the edge and this trend disappeared in the grip (nakago) area. The larger crystallite size will be due to strong hammering. Coarse grains were also observed directly as transmission images with the use of a high spatial resolution detector. The spatial distribution of the grains was not uniform but the reason have not been understood. Furthermore, a white area around a tip area was proved to be a void by looking at the Brag edge transmission spectra. This void may be formed during forging process of two kinds of steel.
It is suggested that consideration on differences in the texture and the crystallite size depending on position will give information to clarify the manufacturing process, and Bragg edge analysis will be a profitable tool for research of Japanese sword.

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Keywords: Japanese sword, pulsed neutron imaging, Bragg edge, texture, crystallite size

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1. Introduction

Japanese swords are interesting artefacts due to its sophisticated metallurgical structure as well as artistic value. Detailed manufacturing process was not clear since it was not transferred as a written document. Metallurgical information is useful to speculate the manufacturing process and a region produced. Metallurgical researches have been performed in destructive way (Tanimura 1980) by observing cut planes by a microscope, an EBSD method and so on. However, it is very difficult to apply the destructive method to many of swords and also valuable ones. Therefore, it is highly desired to investigate the Japanese swords in a non-destructive way.

Neutron has strong penetration power and ability to investigate crystallographic information. Several studies have been performed using traditional neutron imaging and diffraction (Salvemini et al. 2012 and Grazzi et al. 2009). Pulsed neutron imaging with the use of spectroscopic analysis of transmission spectra can give spatial dependent crystallographic information such as crystal lattice plane spacing, crystalline orientation, crystallite size and crystalline phase by analysing the Bragg-edges (Kiyanagi et al. 2012). Spectroscopic analysis of the Bragg-edge transmission spectrum through a bulk metal is performed by using the RITS code based on the Rietveld theory (Sato et al. 2011).

The method will be very powerful tool to investigate the Japanese swords non-destructively and it is expected to extend a systematic study. We applied the method to broken Japanese swords. We obtained useful information indicating difference in crystallite size and texture (preferred orientation) depending on age and area of the swords (Kino et al. 2013 and Nagashima et al. 2014). However, the information did not cover whole area of a sword. So far the spectroscopic analysis of the Bragg edge transmission spectra has not been applied to a whole area of a Japanese sword, and it is necessary to see change of the crystallographic characteristics depending on positions of the sword that reflects making process or treatment.

Therefore, neutron transmission measurements of a Japanese sword (Bishu Osafune Norimitsu) were carried out using 2D neutron detectors at BL10/MLF/J-PARC. We obtained texture and crystallite size maps to know position dependent crystallographic characteristics and check usefulness of the method for non-destructive Japanese sword investigation.

2. Experimental

The experiments were performed at NOBORU beamline at J-PARC/MLF in Japan. We used two position sensitive detectors, GEM (Uno et al. 2012) and MCP (Tremsin et al. 2013) detectors. The GEM detector has a 0.8 mm pixel size and $10cm^2$ active area, which was used for large area measurements. The MCP detector has a 0.055 mm pixel size and an active area of 28 mm in diameter, which was used for small area with high spatial resolution measurements.

The sword sample was privately supplied by Dr. Hirota at Nagoya University, which has a sign of 'Bishu Osafune Norimitsu'. A photo of the sword is shown in Fig. 1. The length of a blade area is 45.5, a short type sword. Nominal designations used in this paper are presented in the figure. The sword maker was working around A.D.1430 in Bishu, which corresponds to present Okayama prefecture in Japan. Therefore, the sword was originally made around this age but it was refurbished afterward probably due to a fire. The age of refurbishing was not clear.

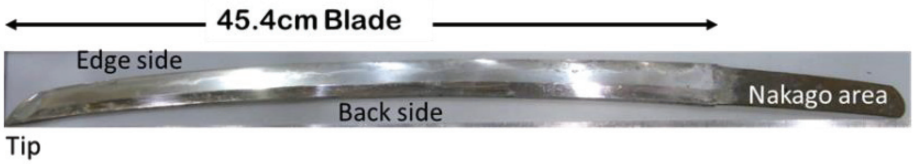

Fig. 1. Photo of a sample Japanese sword signed by 'Bishu Osafune Norimitsu'.