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Analysis of crystallographic structure of a Japanese sword by the pulsed neutron transmission method

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Abstract

We measured two-dimensional transmission spectra of pulsed neutron beams for a Japanese sword sample. Atom density, crystalline size, and preferred orientation of crystals were obtained using the RITS code. The position dependence of the atomic density is consistent with the shape of the sample. The crystalline size is very small and shows position dependence, which is understood by the unique structure of Japanese swords. The preferred orientation has strong position dependence. Our study shows the usefulness of the pulsed neutron transmission method for cultural metal artifacts.

Keywords: pulsed neutron; transmission; crystallographic structure; Japanese sword

1. Introduction

Japanese swords have been recognized as very high quality iron products because of their properties: they do not break, not bend, and are very sharp. Sword manufactory has a long history in Japan, and the unique manufacturing process that lead to these properties have been developed as early as 700 years ago.

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[1,2] The studies of Japanese swords from metallurgical point of view are focused on their crystallographic structure and the perfect combination of the different phases of carbon steel. Scanning electron microscopy (SEM) and the electron backscattering pattern (EBSP) have been applied to analyzing the metallurgy of the object. However, these methods are confined in scope to near the sample surface because of the limited penetration of the electron beams. Therefore, Japanese swords have to be destructively sampled to obtain internal crystallographic information, and this is often not acceptable, especially for the highest quality objects. In this case, neutron beam is a better probe because of its high penetration into materials with a high atomic number. The most popular technique using a neutron beam is the diffraction, which has been applied for the average characterization of Japanese sword fragments [3]. However, diffraction requires surveying over a wide area of a sample to get position dependence of the crystallographic structure. Recently, a method for analyzing the position dependent crystallographic structure has been developed, which uses the pulsed neutron-transmission method combined with a data analysis code RITS (Rietveld Imaging of Transmission Spectra) [4-6]. The RITS code provides quantitative data of the crystallographic structure by fitting the theoretical calculation on the Bragg edge structures seen on the wavelength spectra of transmitted neutrons. Spatially averaged crystallographic structure of the external and internal parts of the samples can be obtained without destructoying them. Therefore, we applied this new method on a Japanese sword fragment already analysed through neutron diffraction [see ref. 3].

2. Experiment and Analysis

We performed a neutron transmission measurement at the ISIS facility at the Rutherford Appleton Laboratory, UK. The N2 beam line (ROTAX) was used. The moderator is the 95 K methane. The proton beam was about 140 μA. A GEM (Gaseous Electron Multiplier) type two-dimensional neutron detector was set at 16.0 m from the moderator. This detector mainly consists of an aluminum cathode plate coated with 2μm thick boron-10, two GEM plates of 50 μm thick, and readout strips. The sensitive area is 100×100 mm^2 and the position resolution is 0.76 mm at FWHM. The neutron detection efficiency is about 6% for neutrons with a 0.18 nm wavelength. Figure 1 is a picture of the detector and sample setup. The Japanese sword sample was set just in front of the detector. The sample, which was provided by one of the collaborators (F. Grazzi), was made in the middle of 16th century in Okayama prefecture, Japan. The available beam spot size was about 43 mm × 27 mm. The number of pixels in this area is 1836 (54×34). Therefore, the area inside the dashed light blue line in Fig. 1 was analysed.

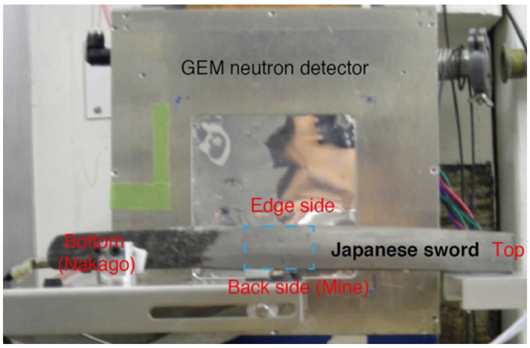

Fig. 1. Experimental setup. The area in the dashed light blue line was analyzed.