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Easy axis of magnetization of Fe_3C prepared by an electrolytic extraction method

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ABSTRACT

We have determined the easy axis of magnetization of Fe_3C (cementite) using a powder specimen prepared by an electrolytic extraction method. The easy axis is determined to be the *c*-axis (the shortest axis) of the orthorhombic structure with the space group *Pnma*. The result is different from the one previously reported by neutron diffraction (*b*-axis). The magnetic energy difference between the easy axis and the average of other two axes is approximately 400 kJ/m^3 at 5 K.

1. Introduction

Fe_3C (cementite) is probably the most important precipitate in steels; it has been exploited for centuries to control the mechanical properties of steels regardless of the awareness of its presence. The size, shape, distribution, and fraction of Fe_3C are now intentionally controlled in steel making because they strongly affect mechanical properties of steels. Since Fe_3C is ferromagnetic at room temperature, its magnetic properties should be well understood. Although there are many reports on the Curie temperature [1–3] and the spontaneous magnetization [2,4–6] of Fe_3C, only a few reports have been published for the easy axis of magnetization.

A systematic study on the easy axis of magnetization in Fe_3C was made by Blum and Pauthenet [7]. They determined that the *c*-axis is the easy axis of magnetization through magnetization measurements. However, there are two notations for the space group of Fe_3C; in one notation (*Pnma*) the *c*-axis is the shortest axis [8–11], while in the other notation (*Pbmn*) the *c*-axis is the longest axis [12–17]. Both notations are widely used; most reports on orientation relationship between Fe_3C and α-Fe in steels employ the *Pbmn* notation [18–23] while the Pearson's Crystal Data [24] uses the *Pnma* notation as the standard notation. Blum and Pauthenet failed to specify which of the two notations they employed in their report [7]; therefore, it is not clear from their report whether the easy axis is the longest axis or the shortest axis.

Another study on the easy axis of Fe_3C was made by Fruchart et al. [25]. They reported that the *b*-axis with the *Pnma* notation is the easy axis through experiments by neutron diffraction. The result is possibly different from that by Blum and Pauthenet [7], but they did not mention it. In addition, in a later experiment using neutron diffraction, Wood et al. [11] concluded that determination of the easy axis of Fe_3C by their neutron diffraction was not successful. Thus, until now we are not sure which axis of Fe_3C is the easy axis of magnetization from the literatures published so far.

The present study is motivated to clarify the easy axis of Fe_3C using a powder specimen of Fe_3C, which is prepared by electrolytic extraction and aligned in resign by cure treatment under magnetic field. In the following we use the *Pnma* notation, which is used as the standard notation for the space group of Fe_3C in Pearson's Crystal Data.

2. Materials and methods

Powder samples of Fe_3C were fabricated by electrolytic extraction from an Fe–0.8 mass% C alloy. The ingot of the alloy was prepared by arc melting and was hot-rolled. The rolled sheet was subjected to homogenization heat-treatment at 1273 K, and gradually cooled to 873 K to form the precipitates of Fe_3C. The microstructure of the rolled sheet was composed of Fe matrix and coarse Fe_3C grains and pearlite (very fine Fe and Fe_3C lamellar) structure. Then, only coarse Fe_3C grains were electrolytically

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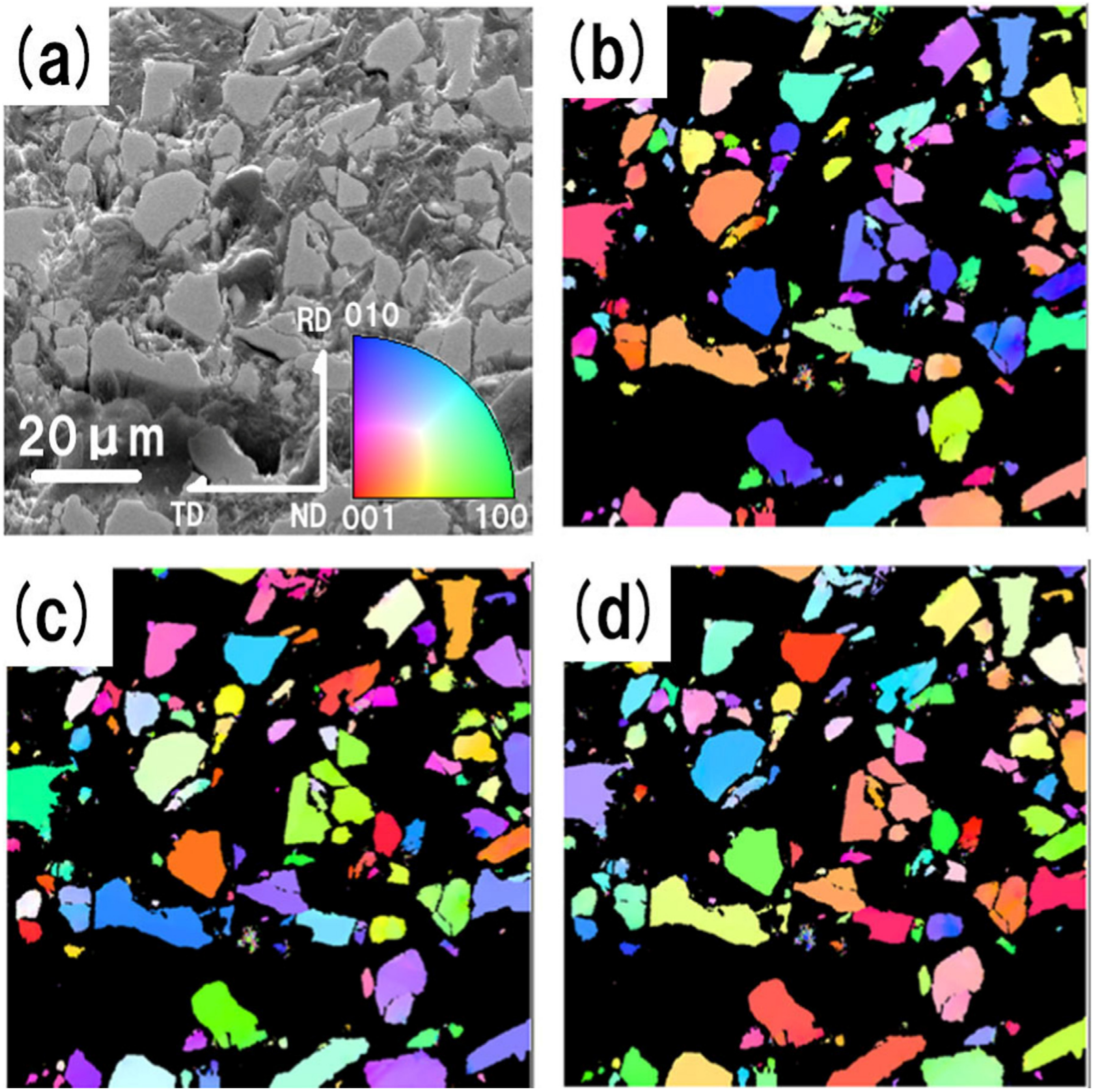

Fig. 1. (a) SEM image of electrolytically extracted particles of cementite. The direction mapping of (b) ND, (c) RD and (d) TD.

extracted using an acetylacetone-based electrolyte. The extracted particles are shown in Fig. 1. The characteristic features of particles are formless and single crystal, and the average size is about 20 μm. These extracted particles were ground using a mortar and pestle. The obtained powder was composed of particles being smaller than 5 μm (average size about 2 μm) in diameter and the particles has no facet and cleavage plane. Therefore, the effect of shape magnetic anisotropy is random on each particle. The crystal

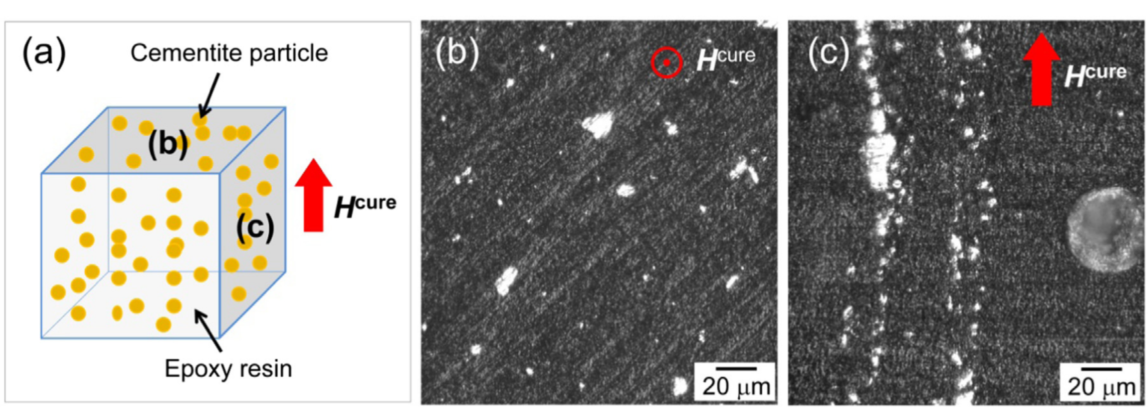

Fig. 2. (a) Schematic illustration of the cure treatment. And OM images observed from (b) the $\boldsymbol{H}^{cure}$ direction and (c) perpendicular to it. Epoxy resin containing cementite powder was cured under a magnetic field (H) of 10 T.