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Oxidation study of Nd2Fe14B compound crystal

H. W. Kwon[a*] and J. H. Yu[b]

[a]Pukyong National University, Nam-Gu, Busan 608-739, South Korea

[b]Korea Institute of Materials Science, Changwon 641-831, South Korea

1. Introduction

Since the $Nd_2Fe_{14}B$ compound contains high content of rare earth Nd, which has great affinity with oxygen, Nd-Fe-B magnets and powder are prone greatly to an oxidation. In particular, the Nd-Fe-B powder needs to be kept unexposed to air during the entire manufacturing process. Even the prepared Nd-Fe-B magnets (sintered or die-upset) are still under the risk of oxidation during the service, thus the commercial magnets are coated usually with highly oxidation-resistant metals, such as Ni or Al. The oxidation issue of the Nd-Fe-B magnets has been increasingly raised due to ever higher operating temperature of the magnets for the applications for the motors in the hybrid electric vehicles (HEV) and electric vehicles (EV). A full understanding of the oxidation kinetics of the $Nd_2Fe_{14}B$ compound crystal is essential for improving oxidation resistance. In the present study, the oxidation kinetics of $Nd_2Fe_{14}B$ compound crystalwas investigated using an excessively grown $Nd_2Fe_{14}B$ grains in the annealed Nd-Fe-B alloy ingot.

2. Experimental work

Oxidation of the $Nd_2Fe_{14}B$ compound crystal was investigated using an excessively grown $Nd_2Fe_{14}B$ grains in the annealed $Nd_{15}Fe_{77}B_8$ alloy ingot. The $Nd_{15}Fe_{77}B_8$ alloy buttons prepared by arc-melting were annealed at 1070°C for prolonged period of 4 days under Ar gas for homogenization and full growth of the $Nd_2Fe_{14}B$ grains. After the prolonged annealing, some $Nd_2Fe_{14}B$ grains were grown markedly to size ranging from 50 to 300㎛ in diameter. Cubic specimen with dimension of 8 x 8 x 8 mm was cut from the annealed ingot, and the surface of the cube was polished. The polished sample was exposed to air at the temperature ranging from 623 K to 723 K. The oxidation kinetics the $Nd_2Fe_{14}B$ crystal was examined by measuring the thickness of oxidised layer on the surface of each $Nd_2Fe_{14}B$ grain. The oxide layer was observed by optical microscope (OM) with polarized light, Scanning electron microscope (SEM) was also used to observe the oxide layer. The thickness of the oxide layer was obtained by taking an average value from ten different crystals. Dependence of oxidation rate upon the crystallographic direction in the $Nd_2Fe_{14}B$ crystal was examined. Crystallographic orientation of the $Nd_2Fe_{14}B$ grains was determined by observing the magnetic domain image of the polished flat surface of individual grain using Kerr effect.

3. Results and discussion

Oxidation rate of the $Nd_2Fe_{14}B$ compound crystal showed no dependence on the crystallographic direction (Fig. 1). The oxidation occurred via a disproportionation of the $Nd_2Fe_{14}B$ crystal, which was assisted by the oxygen in the air. The oxidised layer consisted of Nd-oxide, Fe-B phase and α-Fe. The α-Fe existed in a form of dendrite with sub-micron diameter, which is perpendicular to the interface between the oxidized layer and crystal surface (Fig. 2). The oxidized layer barely acted as a diffusion barrier for oxygen movement and the overall oxidation rate of the $Nd_2Fe_{14}B$ compound crystal was controlled by the direct reaction between the oxygen and crystal at the interface. The oxidation reaction was modeled according to simple linear relationship. Activation energy for the oxidation of $Nd_2Fe_{14}B$ compound crystal was calculated and its significance was discussed.

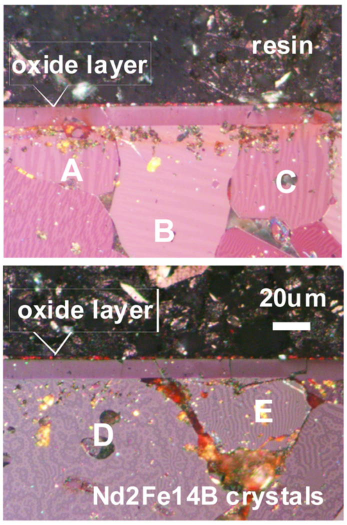

Fig. 1. Oxidised layer and magnetic domain image (showing a crystallographic orientation) of the $Nd_2Fe_{14}B$ crystal grains in the $Nd_{15}Fe_{77}B_8$ alloy oxidised at 673 K for 3 hrs.

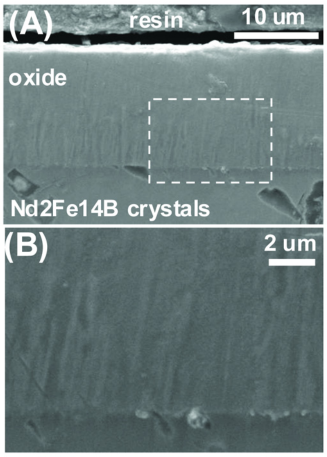

Fig. 2. SEM photos showing the morphology of the oxidised layer on the $Nd_2Fe_{14}B$ crystalgrains in the $Nd_{15}Fe_{77}B_8$ alloy oxidised at 723 K for 3 hrs.