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Improved corrosion resistance and thermal stability of sintered Nd-Fe-B magnets with holmium substitution

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Abstract

The effects of Ho substitution for Nd on the microstructure, corrosion resistance and thermal stability of the Nd-Fe-B magnets were investigated. The (Nd,Ho)-O phase was formed with increasing Ho substitution. The results of potentiodynamic polarization and highly accelerated stress test show improved corrosion resistance with increasing Ho substitution. The optimum mass loss 0.29 mg/cm^{2}is achieved. Moreover, the average temperature coefficients for remanence and coercivity in the range of 25–150 °C are both closer to zero, indicating improved thermal stability. The mechanisms for the improved corrosion resistance and thermal stability are discussed in relation to the microstructure featuring the (Nd,Ho)-O phase.

Key words: Corrosion resistance; Ho substitution; Nd-Fe-B; Thermal stability; Rare earths

1. Introduction

Maintaining the excellent magnetic properties of Nd-Fe-B permanent magnets at high temperatures (HT) has been an interesting but challenging task [1,2]. The poor corrosion resistance and the poor thermal stability are the major handicaps for their HT application. Researches [3–5] have found that the intergranular rare-earth-rich (RE-rich) phases play an important role in the electrode potential difference, on which the corrosion resistance strongly depends. The RE-rich phase with more negative electrode potential comparing with that of the matrix 2:14:1 phase tends to be corroded faster [6,7]. For the corrosion resistance improvement, grain boundary engineering by introducing Dy_2O_3, Nb, Cu [8–10] which raises the electrode potential of the RE-rich phase has been proved to be effective techniques. On the other hand, the magnetic properties decrease rapidly at elevated temperatures due to the strong temperature dependence of the anisotropy of the matrix phase [11]. Sufficiently high coercivity (H_{ci}) at room temperature is considered necessary to offset the losses at HT. Driven by the calling for cost-effective magnets, the enhancement of H_{ci} has captured a lot of recent attention, especially that through the microstructure improvement of low-Dy and Dy-free magnets by means of grain refinement [12–14], grain boundary diffusion [15, 16] and grain boundary modification [17]. However, these techniques inevitably change the chemistry of the RE-rich phase, leading to the complexity of its effect on the corrosion resistance and thermal stability. Heavy rare earth (HRE) substitution is of technical importance for the development of magnet with compensated temperature coefficient of magnetization and the most improved temperature coefficient occurs in $Ho_2Fe_{14}B$ [11]. Research has shown that Ho could be used to substitute Nd for the H_{ci} enhancement [18,19] and thermal stability improvement [20]. The microstructure features account for the H_{ci} enhancement[18]. But the mechanism for the thermal stability improvement concerning the microstructure and the intrinsic magnetic properties [21] is complex and has not yet been clearly understood. Thus, it is of great importance to exploit the mechanism. Meanwhile, the effect of the Ho replacement on the

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