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Microstructure improvement related coercivity enhancement for sintered NdFeB magnets after optimized additional heat treatment

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Abstract:

The microstructure, especially the Nd-rich phase and the grain boundary, in sintered NdFeB magnets plays an important role in magnetic reversal and coercivity mechanism. To better understand the effects of the microstructure on the coercivity, we investigated the microstructure and properties improvements of a commercial sintered NdFeB magnet after optimized additional heat treatment. The coercivity is enhanced from 1399 to 1560 kA/m. This enhancement has been explained in terms of the evolution of the grain boundary structure, and the formation of continuous thin layers of Nd-rich phase is important for high coercivity. The micromagnetic simulation together with the numerical analysis based on the nucleation model suggest that the reversed magnetic domains nucleate mainly at the interface of multi-junctions of $Nd_2Fe_{14}B$ grains with high stray fields during the demagnetization process. Both improved anisotropy fields at grain boundaries and reduced stray fields at multi-junction Nd-rich phases contribute to the coercivity enhancement. This work has importance in understanding the crucial microstructure parameters and enhancing the obtainable properties for sintered NdFeB magnets.

Key words: Sintered NdFeB magnets; Microstructure; Coercivity; Micromagnetic simulation; heat treatment; rare earths

1. Introduction

Sintered NdFeB magnets have a wide range of applications,particularly in traction motors of hybrid electric vehicles and wind generators due to their excellent magnetic properties. For such applications, an enhanced room temperature coercivity is requiredbecause low coercivity generally leads to low thermal stability.[1, 2]As we know, the coercivity is strongly influenced by the microstructure.An optimized microstructure with refined grains, uniform grain size distribution, and smooth intergranular structure is very important for high coercivity [3, 4]. It has been well established that some important microstructure changes, particularly at the grain boundaries,can occur during the heat treatment, which gives a feasible approach to coercivity optimization of the magnet.Some researchers[5, 6] reported the effects of the heat treatment on the magnetic properties of NdFeB magnets and indicated that a continuous, thin, and smooth grain boundary layer is beneficialto the coercivity. On the other hand, except the local low anisotropy region with defects such as grain boundaries, the presence of bulk Nd-rich phase located at the multi-junction of $Nd_2Fe_{14}B$ grains deserves special attention, as it exerts a strong influence on the effective demagnetizing factor.

Micromagnetic simulations have been employed to understand the influence of the microstructure of NdFeB magnets on magnetic properties.Recently, Sepehri-Amin et al.[7] reported that the increase in coercivity with decreasing grain size is due to the reduction in the stray field arising from neighboring grains. Yuan et al.[8] investigated the influence of the amorphous phase on the magnetization reversal process and magnetic properties and found that the coercivity increases with the reducing saturation magnetization of the amorphous phase. Fukunaga et al.[9] discussed the effects of the Nd-rich phase at multi-junctions of $Nd_2Fe_{14}B$ grains on the coercivity based on simulation, and suggest that the increase in coercivity be attributed to a change in the spatial distribution of the demagnetizing field due to the presence of a non-magnetic phase. Hence, the micromagnetic simulation has become an important tool toinvestigatethe microstructure dependent