Solidification-Induced Strains in Sintered Nd-Fe-B Magnets and Their Impact on Coercivity

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It is known that in modern sintered Nd-Fe-B magnets, the coercive force constitutes approximately 20% of the theoretical limit of their intrinsic properties. In [1], the influence of strain on the magnetocrystalline anisotropy of Nd-Fe-B was studied, demonstrating that in some cases, the reduction in coercive force can reach 50% or more, depending on the pattern and magnitude of crystal lattice strain. In [2], strains (on the order of 0.1%) were measured in the interface region, which is consistent with our theoretical studies [3]. However, in the region forming the triple pocket junction (TPJ), the strain magnitude ranges up to ±1.2%. We hypothesize that this is due to residual strain caused by changes in the density of the TPJ material during its solidification after annealing. This study focuses on investigating strain arising in the main phase (MP) from the solidification of the intergranular phase (IGP) in TPJs of various shapes and their potential impact on coercive force at the microlevel.

Despite the wide variety of possible microstructural scenarios, the simplest case of a spherical TPJ, significantly smaller than the surrounding grains, was considered. The choice of a sphere is justified by the fact that, on one hand, a near-spherical TPJ shape is frequently observed in sintered magnets, and on the other hand, the spherical surface represents all possible combinations of crystallographic orientations of MP and IGP. Additionally, a spherical inclusion is more amenable to theoretical analysis, offering greater flexibility for further optimization. We examined the interaction of the spherical material with the elastic medium both theoretically and using FEM (OOF2). Calculations showed that with a 4.5% reduction in the density of the intergranular phase (as in Cu) and cooling from 550°C to room temperature, the pressure exerted by the spherical IGP inclusion on the MP is approximately 1.5 GPa in tension. Moreover, at various points on the inner surface of the MP sphere, due to its anisotropy, different strain schemes of the MP’s crystal lattice are observed. For example, at point (A) (see figure), strain patterns include tension along crystallographic axes (a) and (b) and compression along axis (c), while at point (B), tension occurs along axis (a), and compression along axes (b) and (c), with absolute strain magnitudes of about 1.5%. Such deformations lead to changes in magnetocrystalline anisotropy—a reduction of approximately 40% at point (A) and a slight increase at point (B) (according to [2]).

These data were used for micromagnetic simulations in our own code. The coercive field decreases with respect to the unstrained magnet. The reduction in coercivity ranges from-8% to -30% when the diameter of the TPJ increases from 30 nm to 60 nm.

This study demonstrates that accurate calculation of the deformed state in sintered Nd-Fe-B magnets, particularly in TPJ zones caused by IGP solidification processes and thermal deformations, can provide significant corrections in coercive force estimation. Therefore, accounting for mechanical factors is an important component in the comprehensive optimization of magnets, considering real microstructural scenarios, chemical composition, and thermal treatment routes.

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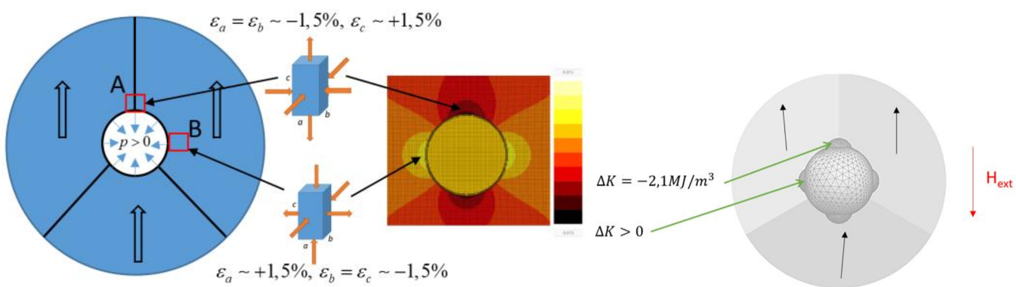

Size of triple junction, nm	Changing of coercivity, ΔHc, %
30	-8.3
45	-21
60	-29

Figure 1. Scheme of a spherical TPJ, deformed state simulation ε_x (OOF2 - https://www.ctcms.nist.gov/) and micromagnetic modelling

References

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