Magnetic Behavior of Amorphous Fe-Si-B Close-Eutectic Ribbons: Compositional Effect

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This study investigates Fe-Si-B ternary alloys through systematic compositional variations of all constituent elements, focusing on elucidating the interplay between glass-forming ability (GFA) and magnetic properties in eutectic and near-eutectic regimes. We aim to identify the compositional windows that synergistically enhance magnetic properties by probing the correlation between alloy stoichiometry and soft magnetic characteristics.

Keywords: Amorphous Magnetic Material; Iron-based; Soft Magnetic Materials, Eutectic Alloy; Glass Forming Ability; Energy Losses; VSM, Flux Metric Measurements.

1. Introduction

Fe-based amorphous alloys exhibit superior magnetic properties compared to conventional soft-magnetic crystalline materials, characterized by reduced saturation magnetic flux density (B_s), reduced coercivity (H_c), enhanced permeability (μ), and significantly diminished core losses. Improving the Fe-Si-B ternary system can play a pivotal role in energy conservation and environmental protection, owing to its widespread application in various electric devices, [1] including the rotors and stators of electric motors, and transformer cores [2].

This study investigates the interplay between alloy stoichiometry and soft magnetic properties in rapidly solidified Fe-Si-B alloys (ribbons) across a composition range spanning silicon-rich to boron-rich regimes, particularly emphasizing the eutectic region.

2. Results and discussion

Ribbons with dimensions of approx. 1–1.5 mm in width and 20–30 μm in thickness were fabricated via the single copper roller melt-spinning technique with high purity elemental composition. The microstructures of the as-prepared ribbons were characterized by X-ray diffraction (XRD) using Cu Kα radiation, confirming their fully amorphous nature. Differential scanning calorimetry (DSC) analyses revealed variations in glass-forming ability (GFA) across compositions, with optimal performance observed near the eutectic point compared to boron- and silicon-rich counterparts.

Thermal and structural analysis

Using DSC measurements, distinct crystallization temperatures (T_x) and Curie temperatures (T_c) . Post-annealing treatments below crystallization temperature reduced coercivity through stress relaxation, confirming the influence of quenched-in stresses from rapid solidification.

Magnetic properties

DC quasi-static measurements of magnetization curves using a vibrating sample magnetometer (VSM) under (H_{max} = 800KA/m) showed consistent saturation magnetization (M_s) values across all nominal compositions, as shown in Figure 1(a). AC hysteresis measurements (f = 5–10KHz , B_s = 0.5 T) demonstrated low energy losses (0.6–2.8 mJ/kg), with a minimum occurring near the eutectic composition, Figure 1(b). Coercivity (H_c) values ranged from 5 to 10 A/m, reflecting compositional variations in magnetic softness and residual stress. In Figure 1(b), samples from R1 to R8 consist of Fe-Si-B alloys near to eutectic point with Si content ranging from 13 to 8 at. % and B content from 11 to 18 at. %. Figure 1(b) demonstrates a correlation between compositions and energy losses with frequencies, exhibiting superior magnetic softness of the eutectic/near-eutectic compositions. Boron/silicon-rich compositions showed increased energy losses at higher frequencies due to enhanced magnetoelastic coupling [3].

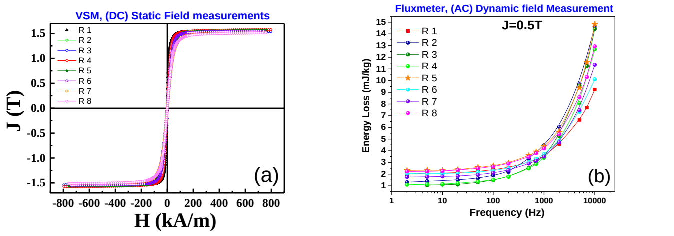

Figure1: (a) DC hysteresis loops measured by VSM on as-cast Fe-Si-B amorphous ribbons. (b) Energy losses (mJ/kg) vs. frequency (Hz) by AC fluxmetric measurements of as-cast ribbons.

This systematic study identifies Fe-Si-B compositions with enhanced soft magnetic properties, highlighting their potential as a basic ternary alloy system to develop the Fe-based soft magnetic BMG compositions for additive manufacturing of motor components. The combination of high GFA near eutectic compositions and stress-relief annealing presents a viable pathway for optimizing energy-efficient magnetic materials.

References

[1] S.Yue, et al, J. Alloys Compd. 776 (2019), 833–838.
[2] McHenry ME, et al, Prog Mater Sci 44(4) (1999) 291–433.
[3] M. Larbi, et al, EPJ Web of Conferences 151, (2017) 07002.

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