Effects of Ni addition on the magnetic and structural properties in Fe-Si-B-Nb alloy produced by different techniques

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The next generation of electrical equipment, such as motors and generators, and power electronics, depend heavily on soft magnetic materials to operate efficiently. In this work, we have investigated the effect of heat treatment and the production methods (melt spinning or laser melting) on the microstructural, magnetic, and power loss properties of Fe-Si-Nb-B alloys with Ni Addition.

Keywords: Amorphous soft magnetic materials, melt-spinning, selective laser melting, glass forming ability, hysteresis loss

1. Introduction

Amorphous soft-magnetic materials play an important role as core constituents in improving the energy transformation efficiency of electrical machines and passive electrical components [1]. Although the melt-spinning process remains one of the main techniques for obtaining amorphous soft-magnetic ribbons, new and efficient production methods based on additive manufacturing have been developed in recent years. These techniques allow to overcome technical limitations characteristic of casting processes and to print complex 3D geometries [2]. It has been reported that the addition of nickel (Ni) to Fe-Si-B-Nb BMGs has shown significant improvements in both their soft magnetic properties and plasticity. Fe-based BMGs that incorporate Ni exhibit a good glass forming ability (GFA), reasonable soft magnetic properties, and improved mechanical performance [3]. This work aims to investigate the interplay between magnetic and structural properties of Ni addition to Fe-Si-B-Nb alloys produced by different techniques, such as melt spinning, suction casting, and selective laser melting (SLM).

2. Results and discussion

Ribbons were obtained by a conventional melt-spinning process, in which the master-alloy was first inductively melted in a quartz tube equipped with a nozzle and then injected under vacuum onto a rotating copper wheel by insufflating high-purity Ar. On the other hand, the 3D printed cubic samples were obtained via SLM using powder of the same alloy as the precursor.

X-ray diffraction (XRD), differential scanning calorimetry (DSC), and differential thermal analysis (DTA) have been used to characterize the structure and thermal behaviour of the samples. Room temperature quasi-static hysteresis loops of ribbons and all printed samples were measured by a vibrating sample magnetometer. AC magnetic characterization has been performed on ribbon samples to appreciate the energy loss behaviour with frequency. Ribbon samples have been annealed in a vacuum furnace below the crystallization temperature to release the quenched-in stress.

The GFA of the plates have been studied by evaluating the critical casting thickness, yet granting amorphous structures according to the XRD data. The GFA of the plates is improved, as testified by an increase in the thickness value, from 800 μm to almost 1000 μm, able to maintain the amorphous structure upon the addition of 2 at. % Ni to Fe-Si-B-Nb alloy.

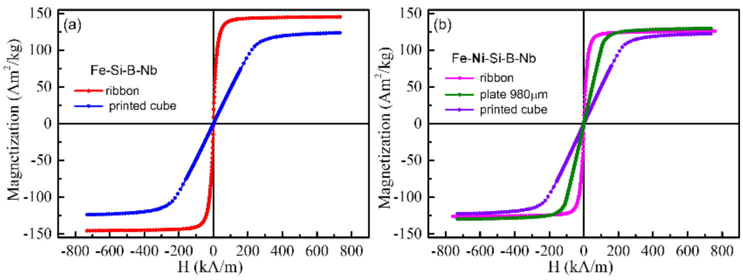

Figure 1: (a) DC hysteresis loops measured by VSM on as-cast Fe-Si-B-Nb amorphous ribbon and printed cube. (b) DC hysteresis loops measured by VSM on as-cast Fe-**Ni**-Si-B-Nb amorphous ribbon, plate, and printed cube.

The notable enhancement in GFA proves the beneficial impact of Ni incorporation on the alloy's compositions. Figure 1 (a) and (b) reports the DC hysteresis loops measured by VSM for alloy Fe-Si-B-Nb and Fe-**Ni**-Si-B-Nb, respectively. The saturation magnetization of the samples seems to depend upon the processing method as different saturation magnetization has been observed for ribbon and laser printed cubes of alloy Fe-Si-B-Nb (see figure 1). A small reduction in saturation magnetization (M_S) and coercive field (H_C) have been observed with the addition of 2 at. % Ni for the as-cast ribbons. Furthermore, the soft magnetic properties improve significantly in the form of reduced coercivity and energy losses after annealing.

References

[1] J. M. Silveyra, E. Ferrara, D. L. Huber, T. C. Monson, Science, 362 (2018), 6413.
[2] L. Thorsson et al., Materials & Design 215 (2022), 1104833.
[3] B. Mohan Mundotiya et al., Futuristic Trends in Chemical Material Sciences & Nano Technology Volume 3 Book 12 3 (2024) 27–45.

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