Development of High B_s Fe-Ni Based Metal Amorphous Nanocomposite by Optimization of Glass Forming Ability

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A growing interest in electric vehicles challenges soft magnetic materials to improve efficiency and power density. Metal amorphous nanocomposites (MANCs) have lower coercivities and eddy current losses, allowing for greater efficiency and higher switching frequency. The later allows for high motor speeds and improved power density. However, commercially available and laboratory demonstrated MANCs have shortcomings. Fe-based MANCs, such as FINEMET have excellent magnetic properties, but mechanical properties limit their application in high speed electric motors (HSMs). Fe-Co based MANCs, such as HITPERM, have high saturation inductions and good mechanical properties, but elevated magnetostrictive losses. Co-based MANCs and more recent Fe-Ni based MANCs have low losses and good mechanical properties, but lower saturation inductions (1-1.2 T), that limit power density in HSMs.

Recently, much work has explored improving saturation induction in MANCs by increasing the content of magnetic elements, which comes at the cost of glass-forming ability (GFA). These efforts where generally limited to trial and error testing. Additionally, all work to date has focused on Fe-based alloys. In this work, a method of using Thermocalc simulation to locate near-eutectic compositions has been applied to Fe-Ni based alloys. Minima in liquidus temperature and solidification range were found for a ternary composition range and used to identify compositions that retain good GFA as the percentage of magnetic elements is increased.

The $(Fe_{70}\ Ni_{30})_x(B\text{-}Si\text{-}Nb)_{100\text{-}x}$ alloy system for x=82% and x=85% was explored by Thermocalc simulations. This is an increase in magnetic element content compared to previously developed x=80% alloys. 3 compositions in the x=82% system, and 1 alloy in the x=85% system where identified and successfully cast as amorphous ribbon. The amorphous nature of the ribbon was confirmed by a bend test and XRD. Magnetic testing was performed by PPMS to measure saturation induction and Curie temperature of the amorphous material. The Curie temperatures increased to 407-438 °C for the x=82% alloys, and 462 °C for the x=85% alloy. Saturation induction increased to 1.28-1.36 T for the x=82% alloy and 1.48 T for the x=85% alloy, which is a significant improvement over the ~370 °C Curie temperature and 1.2 T saturation of previous Fe-Ni alloy.

Crystallization behavior was studied by XRD for the x=85% alloy, showing that crystallization process follows a 2-step process of **Amorphous → BCC+FCC+Amorphous → BCC+FCC+Fe_3B+$Fe_{23}B_6$.** Post annealing magnetic properties were studied by strip testing, and saturation induction as high as 1.48 T was seen after optimal annealing. TEM was used to study structure of as cast and annealed material. 2 alloys with x=82% compositions were identified with an optimal crystalline size of 10-20 nm, while the x=85% alloy had this structure in the as cast state. This opens the possibility of using the alloy in the as cast state, without requiring annealing. In conclusion, alloys with good GFA and improved magnetic properties were identified by Thermocalc simulation.

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