Alloy development and additive manufacturing of Fe-based Co-free amorphous alloys for soft magnetic applications

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The exceptional technological relevance of metallic glasses as soft magnetic materials (SMM) based on Fe and/or Co is known since the discovery of metallic glasses, however their commercialization is limited by technical barriers related to the lack of industrial production routes to obtain magnetic components of large dimensions and of complex geometries. In this talk we will discuss the challenges and steps forward in developing and upscaling a suitable additive manufacturing process chain for amorphous SMM as motor components. This includes the design of novel Fe-based Co-free compositions with enhanced glass forming ability, upscaling of powder production routes, optimization of the LPBF parameters and the design of new electric motor devices tailored ad-hoc to the new SMM properties. The talk highlights the critical link between microstructure engineering and imprinted magnetic properties and offers insights to enhance energy efficiency in electrical applications. *Keywords:* amorphous alloys; soft magnetic properties; additive manufacturing

1. Introduction

We demonstrate in this talk that amorphous rotors and stators can be additive manufactured starting from powders by laser powder bed fusion (LPBF). This technology breakthrough overcomes the technical limitations characteristic of conventional casting processes typical of amorphous alloys.

2. Results and discussion

Using commercially available powders, such as Kuamet- and Finemet-type we were able to produce via LPBF large and complex soft-magnetic motor components, such as the one shown in Fig. 1 [1]. Components made with commercially available alloys exhibit good dimensional accuracy and mechanical stability, however fully amorphicity was not achievable even after extensive parameter optimization because the layer by layer melting processing induces the nucleation of Fe_3Si, Fe_2B and $Fe_{23}B_6$ nanocrystals in the heat affected zones between the layers [2-3]. This compromises the soft-magnetic properties to a certain extent, which we show in this talk that was improved by an extensive alloy design for new Fe-based Co-free metallic glass-forming compositions with enhanced glass forming ability (GFA).

The alloy design went through a reassessment of the eutectic point of the ternary Fe-Si-B system, which was essential for identifying the optimal base composition for further alloy refinement. The GFA of the ternary eutectic composition was enhanced by systematically adding Nb and Ni to above 1 mm in critical casting thickness, enabling the additive manufacturing of fully amorphous components.

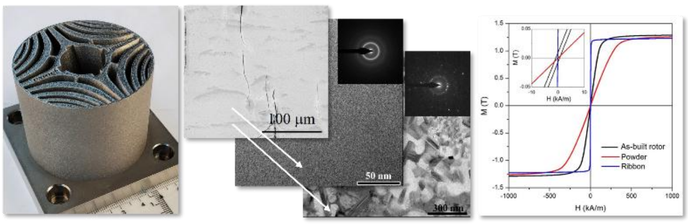

Figure 1: complex shape amorphous electric motor rotor with record dimensions made via LPBF using a Kuamet type powder [1]. The component is circa 70% amorphous having nanocrystalline phases forming between layers, see SEM and TEM images in the middle. The material has H_c=0.51 kA/m, M_s=1.29 T, χ_{Hc}=9.7 and hardness of 877 HV.

For the newly developed multicomponent compositions ultrasonic melting routes were developed and upscaled for the production of amorphous powders. Extensive parameter optimization of the LPBF processing established the fundamental processing- microstructure-property relationships for the processing of fully amorphous SMM. The coercivity of these components is reduced by two orders of magnitudes with respect to the rotor of Fig. 1. It is also observed a dramatic reduction of the power losses at the high frequencies of 1 kHz, which enabled the design of new electromagnetic systems such as synchronous reluctance and axial flux machines.

References

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