Development of soft magnetic composites by field-assisted sintering technology (FAST)

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Most studies on soft magnetic composites (SMCs) have focused on traditional compaction. However, this consolidation method leads to low densities and, therefore, poor magnetic properties. This work focuses on developing SMCs of Fe-3 wt.% Si powder coated with iron phosphate ($Fe_3(PO_4)_2$) using field-assisted sintering technology (FAST) and compares this innovative route with traditional compaction. FAST consolidation achieved higher density than compaction, increasing saturation magnetization and permeability. Furthermore, SMCs coercivity was reduced due to the stress relief induced during consolidation. By contrast, cold pressing yielded the highest frequency stability of the permeability and the lowest core loss.

Keywords: SMC; FAST; core loss; permeability; eddy currents

1. Introduction

SMCs are typically produced by cold pressing soft magnetic powders coated with an insulator layer (polymeric, ceramic or a mixture of both). SMCs provide high electrical resistivity and, thereby, low eddy currents. However, the large volume fraction of the non-magnetic phase reduces permeability and saturation magnetization [1]. FAST applies pressure and temperature simultaneously to achieve high density compacts. In addition, the high temperature of the process reduces the residual stresses, which in turn reduces coercivity. Among the ceramic coatings, iron phosphate coating is of interest due to its high adhesion to Fe particles and easily controllable thickness.

There are currently few studies on the fabrication of SMCs by FAST. For this reason, this work focuses on the study of the magnetic properties and core loss of iron phosphate-based SMCs produced by this technology and their comparison with those consolidated by traditional compaction.

2. Results and discussion

Fe-3 wt.% Si powder was produced by gas atomization and sieved to keep the fraction 20-63 µm. To prepare the iron phosphate coating, 50 g of powder were dispersed in a solution of acetone (20 ml) and H_3PO_4 (2 wt.%). The powder was then dried in air at 80 °C. The coated powder was consolidated by cold pressing under 800 MPa (sample CP800) or, alternatively, by FAST at a maximum temperature of 825 °C for 15 min, and at 50 MPa (sample F50) or 60 MPa (sample F60).

The density, electrical resistivity, and static magnetic properties of the SMCs are shown in Table 1. Consolidation by cold pressing resulted in a lower compact density but increased electrical resistivity compared to FAST. On the other hand, the higher density achieved by FAST increased the saturation magnetization in proportion. In addition, FAST resulted in lower coercivity due to lower compaction stress. The higher pressure of sample F60 increased the deformation of the particles, resulting in the highest density and, therefore, magnetization.

Table 1: geometrical density (d), electrical resistivity (ρ), coercivity (H_c), and saturation magnetization (M_s) of the SMCs.

Sample	d (g/cm^3)	ρ (µΩ·cm)	H_c (A/m)	M_s (T)
CP800	6.39	$1.28 \cdot 10^6$	554.6	1.67
F50	6.59	$3.18 \cdot 10^5$	313.4	1.75
F60	6.91	$1.19 \cdot 10^5$	357.8	1.81

The lower density of CP800 reduced the permeability but increased frequency stability compared to those consolidated by FAST (Figure 1a). In addition, the higher electrical resistivity of CP800 reduced core losses by reducing eddy currents (Figure 1b). The high density achieved in sample F60 caused the coating to decompose, forming electrical paths between the magnetic particles and losing its insulating properties. This lack of insulation increased the eddy currents, which produced the dramatic drop in permeability at low frequencies (500 Hz) and the increase of core loss. Sample F50 provided high permeability up to 100 kHz and low core loss, demonstrating the feasibility of producing high-density ceramic-based SMCs using FAST.

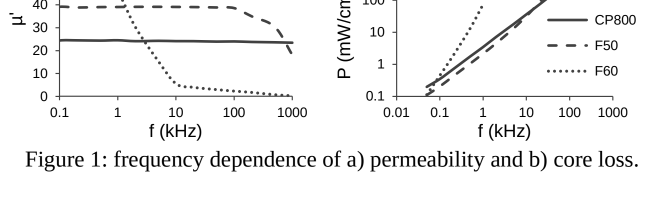

Figure 1: frequency dependence of a) permeability and b) core loss.

References

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