Engineering nanocrystalline soft magnets – A novel heat-treatment approach

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Nanocrystalline soft magnetic materials have excellent properties such as high permeability and low losses even at high frequencies. The FAST/SPS process enables heat treatment to crystallize the amorphous ribbons under the influence of pressure. Rectangular loops without magnetic field annealing can be set by applying pressure during the crystallization. In addition, the high heating rate of the process allows the processing of high B alloys such as Nanomet. The highlight is the production of insulated Nanomet tape wound cores with high permeability of 40 000 and low losses such as P_S (1 T, 1 kHz) = 7.5 W/kg.

Keywords: Nanocrystalline soft magnetic; heat-treatment; FAST/SPS; high permeability; low losses

1. Introduction

The field of powder metallurgy is home to a wide range of process technologies for manufacturing and processing highly conductive materials. The FAST/SPS process conventionally uses the sintering of metal and ceramic powder under the influence of pressure. One of the most important advantages of the process compared to normal hot pressing is the high heating rate (100 K/min) during heat treatment [1]. The high heating rate allows producing nanocrystalline tape wound cores from high B alloys. These alloys have overcome the issue of just 1.2 T saturation polarization for the Fe-Si-B-Cu-Nb system by increasing the iron content leading to high saturation polarization of around 1.8 T.

The present work investigates the influence of pressure during heat-treatment on the shape of the hysteresis loop. Additionally, the possibility of the FASTT/SPS process to produce tape wound cores of high B alloys will be examined.

2. Results and discussion

Tape wound cores of the Vitroperm alloy were heat-treated at different pressures and temperatures by FAST/SPS. Depending on the pressure, the hysteresis loop of Vitroperm could be set in rectangular shape due to the local magneto-elastic anisotropy of the Fe-grains as shown in Figure 1 [2].

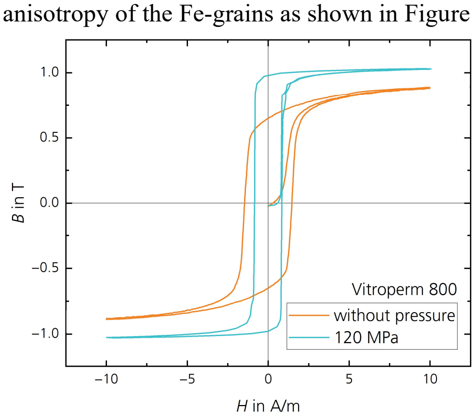

Figure 1: Hysteresis loop of Vitroperm 800 alloy depending on the pressure during crystallization

Next, tape wound cores of the Nanomet alloy were also heat-treated at various pressures. A clear deterioration in the properties with increasing pressure is shown in Table 1. This is due to the compressive stresses applied in combination with the high magnetostriction of the Nanomet alloy (15 ppm).

Table 1: Magnetic properties of uninsulated Nanomet tape wound cores depending on the pressure during crystallization.

p in MPa	J(1 kA/m) in T	H_C in A/m	μ_{max}
10	1.51	7.6	35 800
120	1.55	27.9	13 300

By applying a insulation layer on the Nanomet ribbons, it was also possible to reduce losses leading to P_S(1 T, 1 Hz) = 7.5 W/kg. This value is significantly lower than for other materials with high polarization such as NO-20 (50 W/kg) or Vacodur 49 (42 W/kg).

Finally, the fabricated tape wound cores of the Vitroperm alloy are to be used profitably in power electronics. Due to the high induction and low losses, the Nanomet tape wound cores could be used in medium-frequency transformers or axial flux motors.

References

[1] G. Antou, P. Guyot, N. Pradeilles, M. Vandenhende, and A. Maître, "Identification of densification mechanisms of pressure-assisted sintering: application to hot pressing and spark plasma sintering of alumina," *J Mater Sci*, vol. 50, no. 5, pp. 2327–2336, 2015, doi: 10.1007/s10853-014-8804-0.

[2] G. Herzer, "Creep induced magnetic anisotropy in nanocrystalline Fe-Cu-Nb-Si-B alloys," *IEEE Trans. Magn.*, vol. 30, no. 6, pp. 4800–4802, 1994, doi: 10.1109/20.334226.

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