Journal of Magnetics 16(3), 318-321 (2011) http://dx.doi.org/10.4283/JMAG.2011.16.3.318

Fabrication and Magnetic Properties of A New Fe-based Amorphous Compound Powder Cores

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(Received 2 August 2011, Received in final form 7 September 2011, Accepted 9 September 2011)

A new Fe-based amorphous compound powder was prepared from Fe-Si-B amorphous powder by crushing amorphous ribbons as the first magnetic component and Fe-Cr-Mo metallic glassy powder by water atomization as the second magnetic component. Subsequently by adding organic and inorganic binders to the compound powder and cold pressing, the new Fe-based amorphous compound powder cores were fabricated. This new Fe-based amorphous compound powder cores combine the superior DC-Bias properties and the excellent core loss. The core loss of 500 kW/m^3 at B_m = 0.1T and f = 100 kHz was obtained When the mass ratio of FeSiB/FeCrMo equals 3:2, and meanwhile the DC-bias properties of the new Fe-based amorphous compound powder cores just decreased by 10% compared with that of the FeSiB powder cores. In addition, with the increasing of the content of the FeCrMo metallic glassy powder, the core loss tends to decrease.

Keywords : amorphous compound powder cores, DC-bias properties, low core loss

1. Introduction

Recently, the soft magnetic materials of powder cores with high B_s and low core loss attract more and more attention to be capable of dealing satisfactorily with the high-current supply and to improve the power loss characteristic [1,2]. Because of good soft magnetic properties, a large number of studies on the amorphous alloys in Fe-based system were reported [3-7]. Especially, Fe-Si-B amorphous powder cores [8] exhibit an excellent direct-current overlapping characteristic at a flow of large current with a "percent permeability" of about 70% at H = 100 Oe (μ = 60) which is comparing to "High Flux" powder cores. While Fe-Cr-Mo metallic glassy powder cores [9] exhibit ultra low core loss of 329 kW/m^3 at B_m = 0.1T and f = 100 kHz which is the lowest compared to any other metallic powder cores, so compounding these alloy powder is a hopeful concept for powder cores to achieve both superior DC-Bias properties and the ultra-low core loss.

2. Experimental Details

Fe-Si-B amorphous powder was prepared by crushing $Fe_{78}Si_9B_{13}$ amorphous ribbons as the first magnetic powder, and Fe-Cr-Mo metallic glassy powder with a nominal composition of $Fe_{74}Cr_2Mo_2Sn_2P_{10}Si_4B_4C_2$ [9] was fabricated by high pressure water atomization as the second magnetic powder. The sieved FeSiB amorphous powders with particle sizes 50-150 μm and FeCrMo metallic glassy powders with particle sizes 30-45 μm were used to prepare the compound powder cores.

The amorphous compound powders were uniformly mixed with 0.5 wt.% of organic binders (methyl silicone), 2 wt.% inorganic binders (a glass with low-melting point) and 0.5 wt.% of zinc stearate. The mixture was dried with the help of xylene as a co-solvent. By cold pressing at 2 GPa, and then being annealed at 693 K for 30 min in vacuum, the FeSiB amorphous powder cores, FeCrMo metallic glassy powder cores and the new Fe-based amorphous compound powder cores were fabricated. The core size was 22.9ϕ × 14.1ϕ × 6.5 mm.

The phase structures, crystallization behavior and magnetic properties of the powders were examined by XRD and VSM, respectively. Examination of morphology was carried out using SEM. Initial permeability was calculated from core inductance measured by Agilent 4294A Impedance Analyser, the DC bias field performance was measured by Agilent 4980 A and the magnetic core loss was measured by IWATSU SY-8232 B-H analyzer.

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3. Results and Discussion

Fig. 1 and Fig. 2 show morphology of the FeSiB crushed amorphous powders and FeCrMo water-atomized metallic glassy powders observed by SEM. High pressure water-atomized powders exhibit a clean and smooth surface and spherical shape. In contrast, crushed powders have irregular shapes and rougher surface morphologies. The particle sizes of FeSiB crushed amorphous powders and FeCrMo water-atomized metallic glassy powders were 50-150 μm and 30-45 mm respectively, which was suitable for forming consolidated powder cores with high density. The amorphous state of FeCrMo powders and most of FeSiB powders was confirmed by X-ray diffraction patterns from Fig. 3.

The further magnetic properties of powders used in pressing were shown in Table 1. Both of the FeSiB and FeCrMo powders all have relative high flux density of 1.5T [8] and 1.06T [9], respectively.

Fig. 4 shows that the dependence of the core loss Pcv of FeSiB powder cores on particle sizes of FeSiB powders at $B_m = 0.1T$, $f = 100$ kHz. It can be seen from the figure that the core loss of FeSiB powder cores increases greatly when the particle sizes of powders below 50 μm. Usually the eddy current loss is proportional to the particle size when the shape of particles is spherical. However, in this article, the FeSiB crushed powders have irregular shapes and rougher surface morphologies, so eddy current loss has not been affected largely by the particle size. The residual stress of deformation processing would be increased largely when crushing the FeSiB ribbons to powders with particle sizes below 50 μm, which results in the increase of hysteresis loss, while the residual stress of powders with particle sizes over 50 μm is small. That may be the main reason why the core loss is inversely proportional to the particle size. It could be explained by the residual deformation processing when crushing the ribbons to powders with particle sizes below 50 μm. That is extremely unfavorable to the use of powder cores, so considering to use FeCrMo water-atomized powders as a substitution of FeSiB powders with particle size below 50 μm would be a solution to this problem.

Fig. 5 shows that the dependence of the core loss P_{cv} on the FeCrMo's percentage in the amorphous compound powders at $B_m = 0.1T$, $f = 100$ kHz. The core loss Pcv tends to decrease with increasing the percentage of FeCrMo metallic glassy powders in the amorphous compound

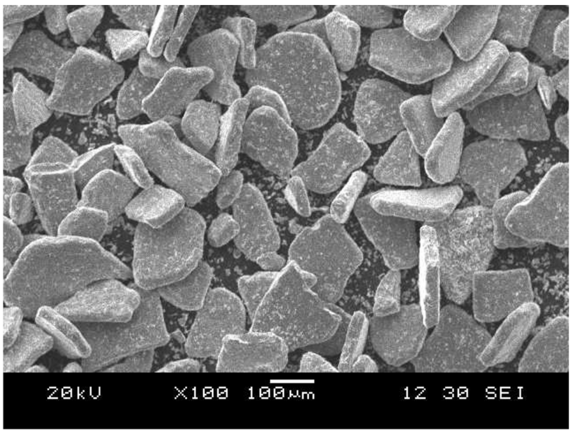

Fig. 1. Morphology of FeSiB crushed amorphous powders.

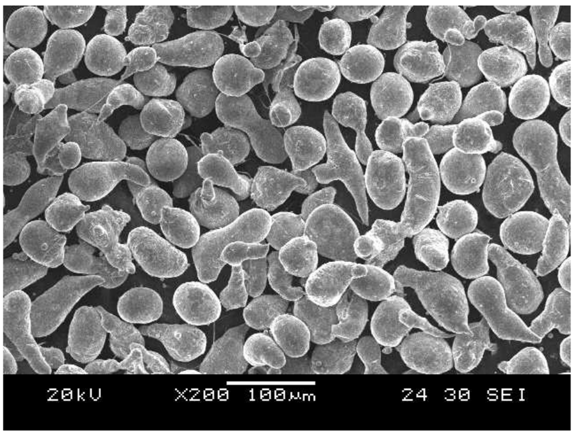

Fig. 2. Morphology of FeCrMo metallic glassy powders by high pressure water atomization.

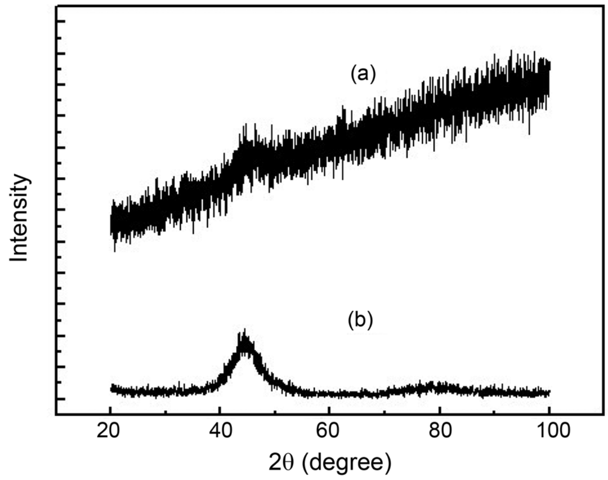

Fig. 3. XRD patterns of FeSiB and FeCrMo powders. (a) FeSiB powders. (b) FeCrMo powders.

Table 1. Saturated flux density of the FeSiB and FeCrMo powders

Composition	Particle size	B_s
FeSiB	50-150 μm	1.5 T
FeCrMo	30-45 μm	1.06 T

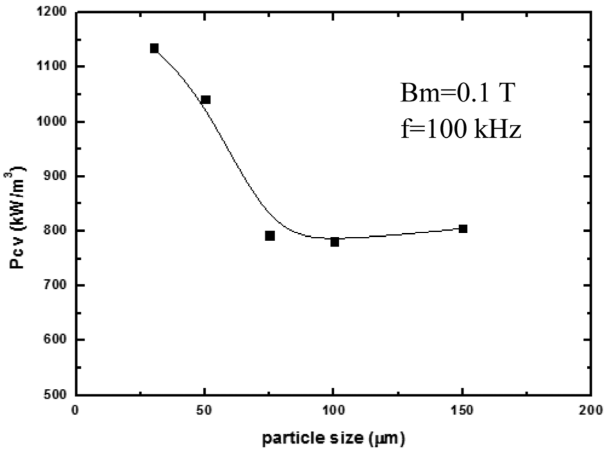

Fig. 4. The dependence of the core loss P_{cv} of FeSiB powder cores on particle sizes of FeSiB powders at $B_m = 0.1$T, $f = 100$ kHz.

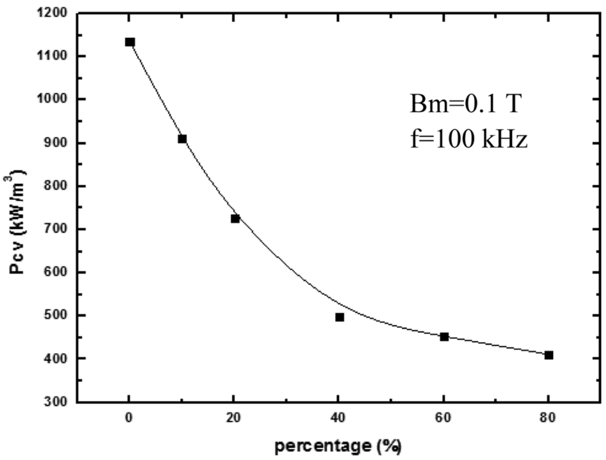

Fig. 5. Variation of P_{cv} of the amorphous compound powder cores with FeCrMo's percentage in the amorphous compound powders at $B_m = 0.1$ T, $f = 100$ kHz.

powders. For the core made of compound powders containing 60 wt.% FeSiB crushed powders (50-150 μm) and 40 wt.% FeCrMo atomized powders (30-45 μm), P_{cv} at 100 kHz for $B_m = 0.1$T was only 500 kW/m^3, which was a very low loss comparable to that of previously developed FeSiB powder cores.

Fig. 6 shows the dependence of the core loss on flux density over the frequency range of 25-100 kHz. It can be seen from the figure that the core loss versus flux density curves show good linearity in the range from 25 to 100 kHz. This powder core was made of amorphous compound powders containing 60 wt.% FeSiB crushed powders and 40 wt.% FeCrMo atomized powders. The decrease in Pcv can be explained by the combination of relatively higher resistivity and lower coercivity of FeCrMo metallic glassy powders compared with that of FeSiB amorphous powders.

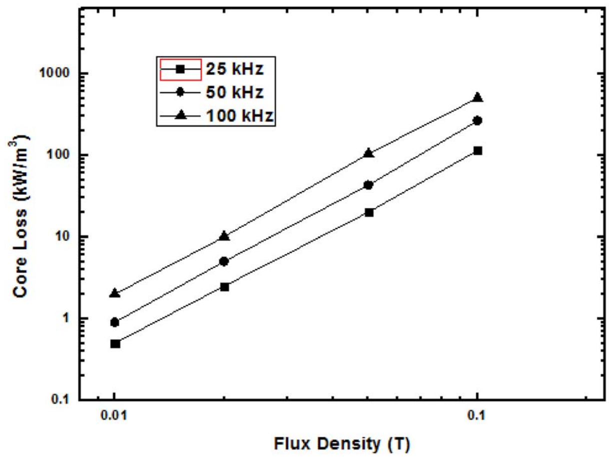

Fig. 6. The dependence of core loss P_{cv} on flux density at different frequencies.

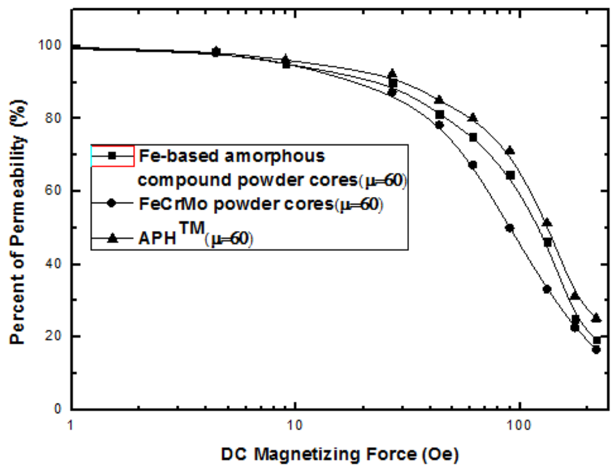

Fig. 7. (Color online) The dependence of permeability change on bias field at 100 kHz for different kinds of magnetic powder cores.

Relatively higher resistivity results in the decrease in eddy current loss, and lower coercivity benefits the decrease in hysteresis loss.

Fig. 7 shows the dependence of percent of permeability change on the bias field at 100 kHz. The Fe-based amorphous compound powder cores (FeSiB:FeCrMo = 3:2) shows comparable permeability change performance with APHTM (μ = 60) powder cores [8] over the bias field range to 100 Oe, while has significantly better performance than FeCrMo powder cores at the bias field range to 100 Oe. The improvement of percent permeability is attributed to the relatively higher *Bs* of FeSiB compared with that of FeCrMo.

4. Conclusions

The new Fe-based amorphous compound powder cores made of the compound powders containing FeSiB crushed amorphous powders and FeCrMo water-atomized metallic glassy powders were fabricated. This Fe-based amorphous compound powder cores exhibit superior magnetic properties. Extremely low core loss was ontained by using FeCrMo water-atomized metallic glassy powders as a substitution of FeSiB powders smaller than 50 μm. When the mass ratio of FeSiB/FeCrMo equals 3:2, the core loss of 500 kW/m^3 at B_m = 0.1T and f = 100 kHz was obtained, and meanwhile the DC-bias properties of the new Fe-based amorphous compound powder cores were obviously better than FeCrMo powder cores, just decreased by 10% compared with the APH^{TM} powder cores [8]. In addition, with the increasing of the ratio of that of the FeCrMo metallic glassy powder, the core loss tends to decrease.

The amorphous compound powder cores in this study are expected to be used for downsizing of choking coils or fly-back transformers operating at high frequency and high power range.

Acknowledgment

This wosk was supported by the National Hi-Tech Research and Developmemt Program (Grant No. 2001AA327030) and Science and Technology. Program of Beijing (Grant No. D0405003040121).

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