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Influence of Vitroperm Content on the Energy Losses in Composite Materials Based on the Mixture of Two Ferromagnets

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Soft magnetic composites offer several advantages such as 3D isotropic magnetic properties and relatively small energy losses, finding use in electrical devices like electromotors, transformers or sensors. The aim of this work was to investigate the dc and ac magnetic properties of composites based on the mixture of two different ferromagnets: iron based material Somaloy® 700 and Vitroperm® 500 alloy. The analysis of total losses into dc losses, classical losses and excess losses showed that the classical and excess losses were negligibly small. The specific resistivity was increasing with the increasing fraction of Vitroperm (VPM). The coercivity exhibited maximum at 20% of VPM.

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1. Introduction

Soft magnetic composites (SMCs) have been used in various applications due to their special properties like low core losses, isotropic magnetic properties and high electrical resistivity. SMCs consist of small ferromagnetic powder particles surrounded by an insulating film [1, 2].

The aim of this study was to investigate the contributions of the dc losses, the classical and the excess losses to the total losses in the frequency range from dc to 100 Hz (where the contributions of losses are best observable) of composite materials based on the mixture of two different ferromagnets.

2. Results and discussion

In this work we investigated samples consisting of mixture of materials: Somaloy® 700 [3] (polycrystalline iron powder covered by insulating film) provided by Höganäs AB, Sweden, and Vitroperm® 500 [4] (VPM) alloy in the form of flakes (originally amorphous transformed into partialy nanocrystalline after annealing) provided by Vacuumschmelze, GmbH & Co. KG, Germany. The SMC samples were prepared by conventional powder metallurgy in the form of a ring (outer diameter of about 24 mm, inner diameter of 18 mm, height about 1.5 mm) and a cylinder (outer diameter of about 10 mm, height about 1.5 mm) by mixing Somaloy powder with weight fractions of 5, 10, 20, 30 and 50 wt.% of VPM powder. Mixed powder was compacted in a cylindrical die at uniaxial pressure of 800 MPa and then cured at temperature of 530 °C for 60 min. in an electric furnace in air. Parameters of the samples are in Tab. I.

The morphology of samples was documented using SEM (TESLA BS 340). The photographs of materials before pressing and also the structure of final composites are shown in Ref. 5. The dc and ac hysteresis loops (up to 100 Hz) were measured by fluxmeter-based hysteresisgraphs, only a fraction of magnetic material was taken in account. The coercivity was measured by Foerster Koerzimat. The four contact method was used for the specific electrical resistivity measurements.

Parameters of the samples. TABLE I

Sample	S95 5VPM	S90 10VPM	S80 20VPM	S70 30VPM	S50 50VPM
Somaloy to VPM ratio	95:5	90:10	80:20	70:30	50:50
Porosity (%)	1	4	10	13	18
Density (g/cm^3)	7.61	7.33	6.86	6.62	6.12
W_{dc} (J/m^3) *	57.3	65.7	75.0	76.6	68.8
W_c^{inter} (J/m^3) *	0.057	0.071	0.080	0.062	0.020
W_c^{intra} (J/m^3) *	0.28	0.26	0.24	0.21	0.15
W_{exc} (J/m^3) *	7.07	7.17	14.38	13.13	13.03

* Energy loss separation for $B_m = 0.2$ T and $f = 100$ Hz.

The total energy losses W_{tot} (in J/m^3) dissipated in magnetic material are the sum of three components: dc losses W_{dc}, classical losses W_c and excess losses W_{exc} [6]. The dc losses W_{dc} are represented as the area of dc hysteresis loop, the classical losses W_c are caused by the eddy currents induced by changing magnetic flux, and the excess losses W_{exc} are related mainly to number of moving domain walls during the magnetization process [7, 8]. We distinguish intra-particle (for insulated particles) and inter-particle (for non-perfect insulated particles) eddy currents. The inter-particle classical losses W_c^{inter} can be expressed [6, 9]:

$$W_c^{inter} = \frac{(\pi d_{eff} B_m)^2}{\beta \rho_R^{bulk}} f, \quad (1)$$

where d_{eff} is effective dimension for eddy current, B_m is maximum flux density, f frequency, ρ_R^{bulk} specific resistivity and β is geometrical coefficient, which for rectangular cross-section is $\beta = 6/\left(1 - 0.633\,(b/a)\tanh(1.58a/b)\right)$,

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a and b are the lengths of sides of the rectangle [9], $b \leq a$. For the calculation of intra-particle classical losses W_c^{intra} Eq. 1 can also be used with the specific resistivity of magnetic material ρ_R instead of ρ_R^{bulk} and for spherical magnetic particles ($\beta = 20$ [2]) the particle diameter as d_{eff}.

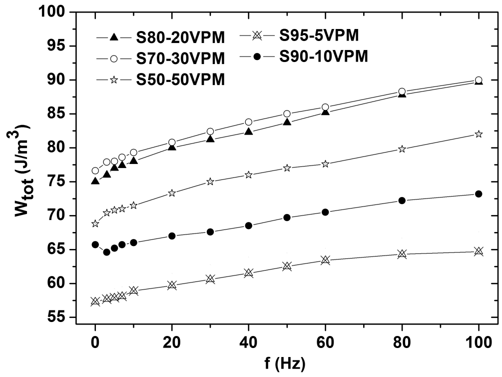

Fig. 1. Total energy losses as a function of frequency at $B_m = 0.2$ T.

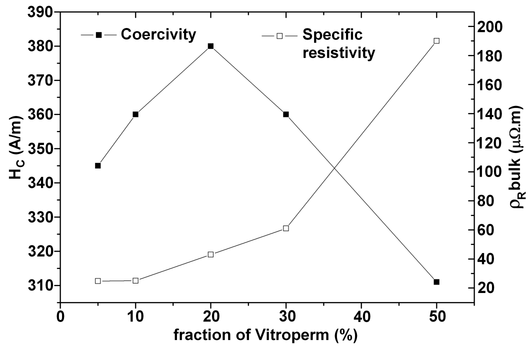

Fig. 2. The coercivity and specific resistivity vs. VPM fraction.

The dependencies of total losses versus frequency (dc – 100 Hz) at maximum flux density of 0.2 T are depicted in Fig. 1. The dependencies are not linear, which means that numbers of moving domain walls are not constant [7]. We see that with the increasing VPM content the energy losses increase, but the sample with the highest VPM fraction (50%) exhibits lower losses than samples with 20 and 30% (in spite of higher porosity – Tab. I). In Fig. 2 the coercivity H_c and the specific resistivity ρ_R^{bulk} as functions of VPM content are shown. H_c exhibits maximum at 20% of VPM and ρ_R^{bulk} increases with the increasing VPM content, which is useful for lowering the inter-particle classical losses.

Total energy losses were separated into four components (Tab. I). The inter-particle and intra-particle classical losses were calculated from Eq. 1, where required values of ρ_R^{bulk} are mentioned in Tab. I, ρ_R is specific resistivity of iron in Somaloy (tabular value: 0.098 $\mu\Omega$·m [3]) and specific resistivity of nanocrystalline VPM in the form of ribbon (tabular value: 1.2 $\mu\Omega$·m [4]). Particle diameters were obtained by SEM, whereby observed value for spherical particles of Somaloy is 120 μm. Flat irregular shaped particles of VPM with random orientation and dimensions 200×200×20 μm were abstracted by cubic form with edge 90 μm long. The excess losses W_{exc} are the difference between the total losses and the sum of classical and dc losses. We see that dc losses are the majority component in comparison with other components (together representing the dynamic losses), from which W_{exc} are dominant. That is explained by the quite low numbers of moving domain walls [8]. Both the components of classical losses are negligibly small and are furthermore decreasing with increasing VPM fraction, which is valuable especially at higher frequencies.

3. Conclusion

In this work the dc and ac magnetic properties of SMCs based on the mixture of Somaloy® 700 and Vitroperm® 500 (VPM) were investigated. Total energy losses were analysed into components (dc losses, classical losses and excess losses) and compared in relation to VPM to Somaloy ratio.

We conclude that with the increasing VPM content the specific resistivity was increasing and the coercivity showed maximum at 20% of VPM. In sample with 50% of VPM the total energy losses were lower than in samples with 20 and 30% of VPM. Classical losses were negligibly small and were decreasing with the increasing VPM fraction.

Acknowledgments

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