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The effect of processing conditions on magnetic and electric properties of composite materials used in nonconventional magnetic circuits

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The using in alternating current of materials for electromagnetic circuits requires them high inductions and low dynamic (eddy-current) losses. These are strongly influenced by the work frequency and induction, and also by the magnitude of density and electrical resistivity of materials. The traditional solution is using of electrical laminated steel sheets. In the last years, research and development of composite materials from organic/inorganic insulated iron powders opened new opportunities for design and dimension of magnetic circuits from electrical devices, of 3D magnetic flux circulation concept. This paper will present the influence of processing conditions (insulating layer type, grain size of iron particle, compacting and curing conditions) on the main characteristics of powder systems used in nonconventional soft magnetic circuits.

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1. Introduction

The steel laminations are traditionally soft magnetic materials used in AC applications. Most of the magnetic structure of existent electrical machines and motors with AC excitations were optimized in the last century for 2D flux circulations in the laminated yokes. Now there are new organic or inorganic insulated iron powders called soft magnetic composite materials [1 - 18], which can be used for these applications.

The soft magnetic composites have also certain limitations: on a part they have maximum permeability and magnetic induction than laminations, on the other part the powder metallurgical procedures used in principal for the obtaining of soft powdered cores are not suitable for all sizes and shapes of these.

Taking into account the advantages and disadvantages of these composite materials including their technical obtaining procedure, in some cases is more profitable from both economical and technological point of view to replace the conventional magnetic circuits with those made from soft magnetic components.

For our applications, in order to be used at low frequencies, these materials must have high induction and permeability and low coercive field. A great importance has the total core losses. The magnetical, electrical and mechanical characteristics depend on the preparation and processing of the material. In addition the materials purity, shape and size of particles influence the overall magnetic response.

Considering the above presented data we tried to develop new soft composite materials using Romanian iron powders and to replace in some applications the classical rotors with a nonconventional rotor obtained from these materials.

2. Experimental

It is known the negative influence of a higher content of some impurities like C, S, and O_2 on the performances in magnetic field of iron laminations and powders.

For experiments, taking into account the purity, a lower content of C (< 0.01 wt.%), S (0.01 wt.%) and O_2, as well as lower losses in H_2 (0.06 wt.%) we selected DP200HD iron powder sort produced by Iron Powder Plant from Buzau. Also, some experiments were performed with HOGANAS powders sorts (PERMITE 75 and SOMALOY 500).

The DP200HD iron powders, with granulation lower than 160 µm were subjected to insulating process: by wetting way by their immersion in an organic polymer solution (thermoplast polymer – ethylene and thermosetting polymer – epoxy resin) or by drying way by mixing together with a polymer binder in a special blender.

The content of polymeric binder, used for powders insulating was of 0.3 - 0.5 wt. %. The differences up to 0.5 - 1 wt. % of organic binder was added during the mechanical blending, operation associated with the introduction of lubricant, namely 0.5 wt. % zinc stearate.

The characteristics of epoxy resin were: granulation lower than 45 µm, softening point of 64 - 74 ºC, curing temperature of 130 - 150 ºC, and curing time of 0.5 - 1 hour.

In order to establish the influence of processing conditions on magnetical and electrical properties of soft magnetic cores, the powder mixtures, so obtained, were processed by powder metallurgy techniques: compacting at room temperature at 2 – 8 tf/cm^2, curing at 120 – 500 ºC for 0.5 – 1 hour, in air. For the thermal treatment the increasing rate of temperature was of 0.8 – 2 ºC/min.

Determination of magnetic properties was realized with Lake Shore 7300 VS Magnetometer both on the powders samples and innelar samples with $ø_e$ = 32.5 mm, $ø_i$ = 25 mm, h = 5 mm compacted at 6 tf/cm^2.

3. Results and discussion

The variation of green density versus compacting pressure for the mixture with 0.5 – 1 wt. % RE, obtained from the iron powder insulated by the dry way during the mechanical mixing is presented in Fig. 1.

It can be observed that by increasing the resin content, the powder compressibility is reduced. In order to obtain high induction it is necessary to realize a high density or to use higher pressing forces for compacting such composite powders.

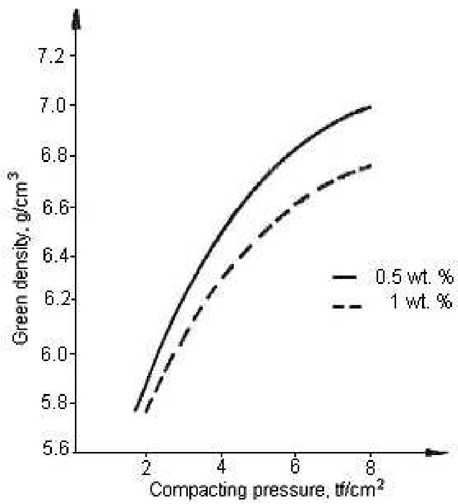


Fig. 1. Green density versus compacting pressure for blending of iron with 0.5 - 1 wt. % RE.

The green density, established on the cylindrical samples of ø = 11 mm and h = 2 mm, varies from polymer to polymer, and depends on the insulating powder route. These were put in evidence, also, by the histerezis loops established on the powders mixtures samples.

The histerezis loops for different samples of powders mixtures are shown in Fig. 2. The type and the content of binder have a great importance on the remnant magnetization values. The values for the main magnetic parameters determined from these histerezis loops are presented in Table 1.

In Fig. 3 are shown the histerezis loops obtained on the compacted samples from different mixtures of powders.

Table 1. The physical characteristics of insulated iron powders mixtures.

Mixture type	Bulk density, g/cm^3	M_S, emu	H_{Ci}, Oe	M_r, emu
DP 200HD < 160 µm + 0.5 wt.% PE (wet)	2.56	28.9	73.3	0.617
DP 200HD < 160 µm + 0.5 wt.% RE (wet)	2.75	36.5	159	0.226
DP 200HD < 160 µm + 0.5 wt.% RE (dry)	2.19	41.9	101	0.508
DP 200HD < 160 µm + 1 wt.% RE (dry)	2.18	39.3	97.5	0.476
PERMITE 75	2.90	21.8	111	0.411
SOMALOY 500	3.20	37.8	75.6	0.374

Note: PE - low density polyethylene
RE - epoxy resin modified with 10 wt.% acrylic polymer of ROMACRIL PAS 25 type

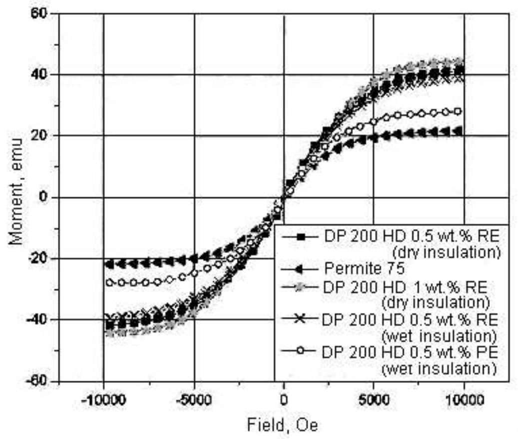


Fig. 2. The representative comparison between histerezis loops obtained on some mixtures samples from insulated iron powders.

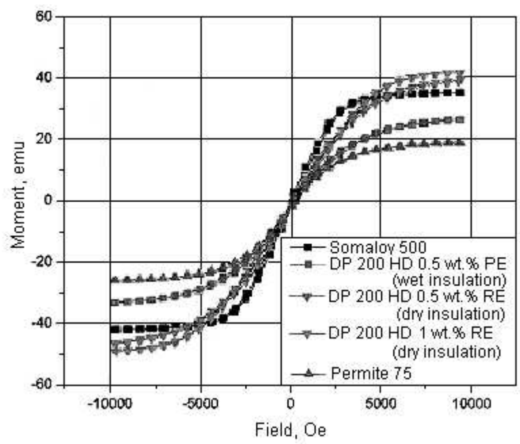


Fig. 3. The histerezis loops of composite powders mixtures samples, after compaction at 6 tf/cm^2 and Curing.

It is evident the influence of compacting and curing conditions. The histerezis loops surface is reduced and the obtained values for magnetization are higher. It can be seen also the influence of insulation procedure: wet or dry route.

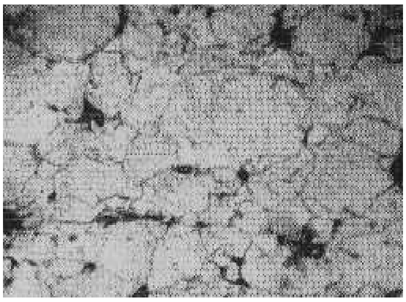
Table 3 presents the main characteristics obtained for the researched composite materials. In accordance to the results it can be appreciated that the powders DP 200 HD lower than 160 µm, processed with 0.5 wt. % polymer (RE or PE) are placed like performances between PERMITE 75 and SOMALOY 500.

From the microstructural point of view, the researched composite materials, compacted and curred, are presented in Fig. 4.

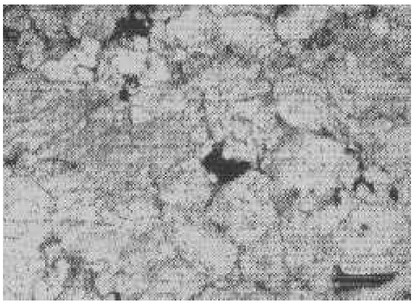
The microstructural analysis was realized with a Carl Zeiss Jena, NU 2 microscope. The structures were estimated on specimens prepared according to the recommended metallographic procedures to correctly emphasize the size and morphology of the phases (NITAL: attack).

Table 3. The main characteristics obtained for the researched composite materials.

Composite type	Blending type	M_S, emu	H_{Ci}, Oe	M_r, emu	Density, g/cm^3	Ms, G	$C_{v(Fe)}$ %
DP 200HD + 0.5 wt. % RE	wet	55	65.2	0.882	6.86	1491.30	89.72
DP 200HD + 0.5 wt.% RE	dry	35.3	87.2	0.350	6.90	1703.28	89.72
DP 200HD +1 wt.% RE	dry	44.2	71.4	0.698	6.71	1331.83	87.30



a)



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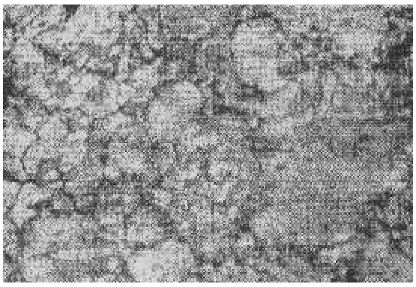

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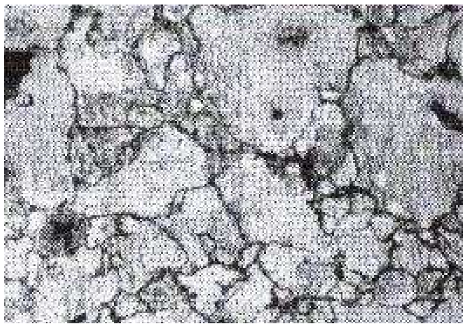
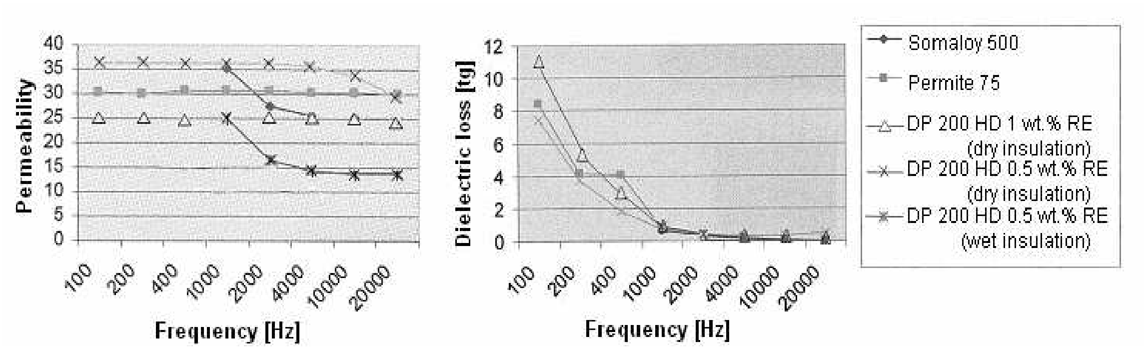


d)

Fig. 4. The microstructural aspect of the samples of: a) Fe DP 200HD + 0.5 wt.% RE (wet insulation), b) Fe DP 200HD + 0.5 wt. % RE (dry insulation), c) Fe DP 200HD + 1 wt.% RE (dry insulation), d) SOMALOY 500, x 300.

It can be observed that the structure presents a grain size distribution. The structures of the samples with 0.5 wt. % RE are rather comparable. These materials have a compact structure, with rounded grains. The SOMALOY material presents a better marked contour of grains and thicker intergrains regions. Other electrical performances obtained for these materials are presented in Fig. 5.



a b

Fig. 5. The variation of permeability, (a), and dielectric loss versus frequency, (b).

4. Conclusions

The characterization from magnetical, electrical and microstructural point of view of researched composite materials on DP 200 HD iron powder basis, offered us the possibility to conclude that the main factors, which determine the physical and mechanical properties of soft magnetic composite materials depend on the technological procedure. The properties obtained for the researched materials are in the same field of magnitude with another soft magnetic composite (SOMALOY, PERMITE 75), which is in present on the market. However, only functional experiments can determine the optimal composite and the optimal application.

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