Analysis of Electrical Resistivity of Iron-Resign Composite Materials from Powder Metallurgy

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Abstract—This paper aims to study the physical properties of composite iron-resin able to be used in cores of rotating electrical machines. A tooling for coupling is designed in a press to execute a hot die pressing. Compression tests were carried out to obtain parts from pure iron powder and thermoplastic acrylic resin, where the resin was varied percentage and subsequent verification density, electrical resistivity and analysis of hardness. Thus, there was a significant increase in electrical resistivity of the specimens, as well as reduced density.

Index Terms—Composite materials, Hot pressing,Iron powder, Powder metallurgy,Resistivity, Resin

1 INTRODUCTION

THE rotating electrical machines can work as engine or generator, and have two basic parts: the cores of stator and rotor. These cores, with rare exceptions, are made from thin metal sheets (low carbon steel) with thickness less than 1 mm, grouped in plates packages. Some better performance machines such as generators are built with silicon steel plates, with a percentage of about 3% silicon. The overall process for making these cores consists basically in a lamination, stamping process for electrical insulation between adjacent plates, packaging and fixation [1].

The rotor and stator cores are surrounded by coils fed by electric current, in some cases, alternating, being subject to the action of induced currents, also known as eddy currents. These currents are responsible for significant loses in the cores. The construction of magnetic cores from steel plates electrically insulated partially reduces the induced currents. This is the solution commonly used in the search for reduction of losses by these currents. Yet another alternative for reducing eddy currents is to increase the electrical resistivity of the core materials [1].

It is important to note that the magnetic losses in electromagnetic devices comprise, in addition to eddy current, the losses caused by hysteresis loop. Thus, currently, are studied alternative materials in the construction of these cores in unique and massive blocks. These alternative materials are present as main features low hysteresis loss cycle and high electrical resistivity. In addition to these two aspects, these materials must also have high saturation induction, magnetic permeability and sufficient ductility to withstand the mechanical stresses and vibration of cores of electric machines [1].

Actually, Soft Magnetic Composites (SMCs) obtained from powder metallurgy process, are being used to replace traditional rolled steel sheets packages which constitute the cores of rotors and stators of rotating electrical machines. The figure 1 shows a SMC particle.

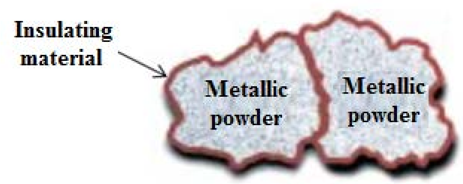


Fig. 1. Soft Magnetic Composite particle - adapted from [2]

The development of new SMCs materials aims to achieve more competitive magnetic properties. The cores of electric machines constructed from isolated particle of iron powder have some advantages over the cores of laminated steel plates, particularly in regard to the isotropic nature combined with unique possibilities of geometry, thereby enabling three-dimensional drawings [3], [4].

The SMC materials are structured basically in two ways: resinated and microencapsulated materials. The resin-coated magnetic powder material consists in mixing a ferromagnetic material, such as pure iron powders, with a phenolic resin, typically thermoset. In this process, powders of iron and resin are mixed, compressed into dies and placed in furnaces for curing the resin. Thus, the resins act as an adhesive and electrical insulation between the iron particles, increasing the electrical resistivity of the material and reducing the eddy current. By the other hand, the microencapsulated material consists in depositing, under the form of thin films, some kind of electrical insulator, such as polymer or oxide in the surface of iron powder particles. The process for deposition of insulation are kept secret by manufacturers. For forming parts, microencapsulated powders are compressed into dies and then placed in furnaces for any kind of thermal treatment. One variation that can occur in both processes mentioned above is hot compression, in which the steps of shaping and consolidation are made simultaneously [3], [4].

The physical properties of soft magnetic composite materials used in rotating electrical machine core comprising: magnetic and thermal isotropy, low losses by eddy currents when fed by high frequency electric current, low relatively losses in a hysteresis cycle when fed by low and high frequency electric current, high electrical resistivity, low coercivity, reduced dimensions and mass of the rotor and stator cores and the consequent reduction of the dimensions of the machines constructed from these composites[5], [6], [7].

2 Material and Methods

The main characteristics of the materials studied in this paper are related to the electrical resistivity. Preliminary tests were carried out considering only the electrical resistivity. After defining the geometry of the test specimens, a device that allowed the heating of the die and the control of temperature, simultaneously with the application of compaction pressure was prepared. The specimens were prepared from pure iron powder with percentages between 3% and 15% of acrylic resin. The characterization of materials studied can be performed from the measurements of height, thickness, length, volume, mass, density, resistance and electrical resistivity of the specimens.

2.1 Die and Tools

To evaluate the resistivity, a specific die pressing was used which allowed to obtain specimens in the form of bars, where the length is greater than the cross-sectional area. The figure 2a, shows the geometry of the specimen and the 2b figure shows the die used, which the cavity can be seen at the center and the side punches.

Fig. 2.Bar shape specimens - (a) geometryand (b) die and punctures

The tooling designed to heat the iron-resin composite consisting of a support for fixing the upper punch (figure 3a), and a holder for the die cavity (figure 3b).

Fig.3. Support for fixing the upper punch in the press - (a) top - (b) bottom

For heating the die were used eight 100W resistances the temperature measurement was used a K type thermocouple. The resistances and thermocouple are placed in the holder as shown in figure 4, both of which are set resistances and thermocouple, connected in a temperature controller device model N1040, manufactured by Novus. The power control is performed from a 10A solid-state relay.

Fig.4. Mounting bracket for holding the die - (a) without the 100W resistance and (b) with the 100W resistance

The support clamp of the die was stabilized in a table composed of a base, pin support for the table and coils. The figure 5a shows the pin secured to the base and coils and figure 5b shows the tooling mounted, in which can be seen that there is still a third piece, which serves as a support to another die support (which electrical resistances).

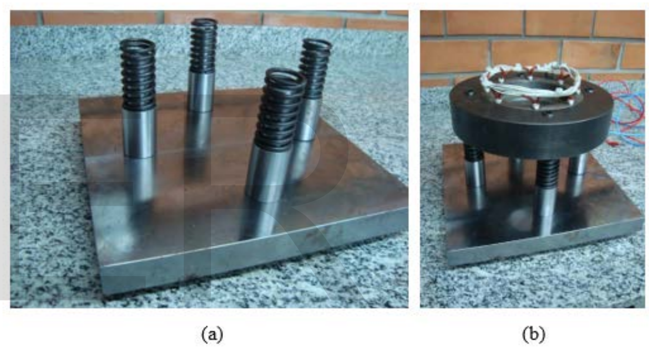


Fig.5. Tools for hot pressing - (a) partially assembled with the details of the coils and (b) details of the resistances

2.2 Final Stage

The elaboration of composites to obtain the specimens were made by mixing pure iron powder with acrylic resin. Were prepared five kinds of composites pure iron base with 3%, 5%, 7.5%, 10% and 15.0% by weight of acrylic resin. The composites were prepared using as base powder pure iron powder from Höganäs Brazil Ltda. According to manufacturer's certificate, the iron powder used was ASC100.29, with 99.4% of the particle size between 45μm and 150μm. The iron powder was mixed using a double cone mixer rotating at 60 rpm for 20 minutes for dispersion of the constituents.

The compaction of the specimens was performed with a pressure of 600 MPa in a hydraulic press with 30 ton capacity. Considering the area of the die, resulting in a force of 8 tons during the pressing. Was used the process of double-acting compression floating die. This process allows the centralization of the neutral axis of the part, thus avoiding the density variation along the specimen.

During the application of compacting pressure, the temperature was maintained at 120ºC. The specimen remained under these temperature and pressure conditions for around 1 minute. The figure 6 shows the tooling assembled in the press, the figure 7a shows details of the assembled tooling and the figure 7b shows the controller during heating.

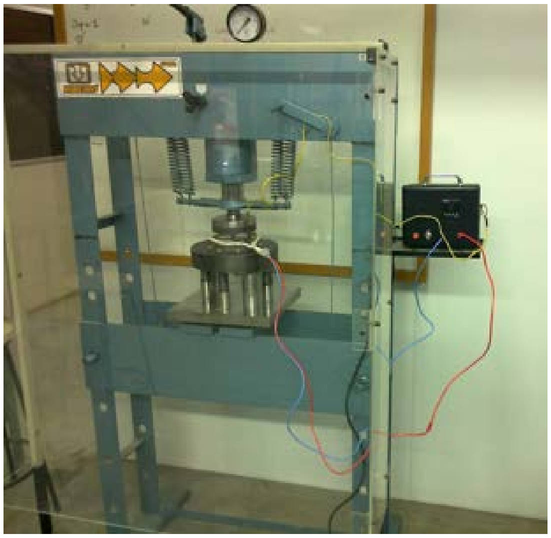


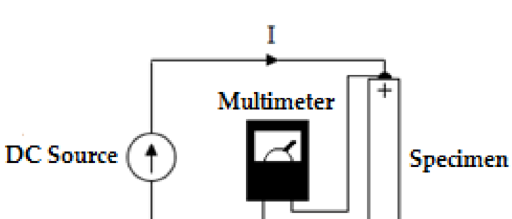
Fig.6. Tooling mounted on the press

(a) (b)

Fig.7. Details (a) tooling mounted in the press - (b) operation controller

2.3 Determination of Electrical Resistivity

Electrical resistivity is a measure of the opposition of a material to the flow of electric current. The lower is the resistivity of material, more easily allows passage of an electric charge. The determination of this property made from the calculation of the electrical resistance. Using a multimeter, the electrical resistance of the specimens was directly measured. However, for very low electrical resistance measurements, the multimeter shown inefficient. To solve this problem, it is necessary to use a device: direct current is applied to the specimen and then measured the voltage on it. The figure 8 shows the circuit for voltage measurement. Therefore, the specimens for determining the resistivity should be in the form of a thin and long bar.



From the Ohm's law:

$$R = V/I \rightarrow \rho = R \cdot A/l = (V \cdot A)/(I \cdot l) \qquad (1)$$

where ρ is the electrical resistivity [μΩ·m]; R is the electrical resistance [Ω]; V is the applied voltage [V]; I is the applied electric current [A]; A is the cross section area of the bar [m^2] and l is the length of the bar [m] [8].

3 Results and Discussion

Possible materials to be used in the construction of stator and rotor cores must have high electrical resistivity. By producing an SMC component, should be taken very carefully so that the insulation between each grain of powder is not broken. Create an interconnection between isolated grains will result in an intensification of the eddy current losses. The determination of the resistivity of the resinous molding was performed from the simple measurement of the electric resistance of the samples in the form of specimens [9], [10], [11], [12].

3.1 Electrical Resistivity of the Specimens

The compaction resulted in two specimens for each percentage of resin. The figure 9 shows the obtained specimens. The results of an evaluation for determining the resistivity of all test specimens that were produced was show in the table 1, which expose the measured electrical resistance values and parameters to calculate the resistivity. The resistance of the specimens was measured from the application of a 1A current with consequent determination of strain on the specimens. Thus, the resistivity was calculated from equation 1.

Fig.9.Specimen obtained from the compression of the hot iron acrylic-resin composite

Property	Fe3%Re	Fe5%Re	Fe7,5%Re	Fe10%Re	Fe15%Re

Height [mm]	6,56	6,91	7,22	6,10	8,00
Thickness [mm]	5,14	5,10	5,10	5,09	5,12
Length [mm]	30,14	30,09	30,07	30,02	29,98
Mass [g]	5,57	5,44	4,87	4,07	4,11
Volume [cm³]	1,02	1,06	1,11	0,93	1,33
Density [g/cm³]	5,48	5,14	4,40	4,37	3,35
Resistance [Ω]	8,87	12,30	53,92	97,03	433,09
Resistivity [10^{-3} Ω/m]	9,92	14,39	65,97	100,19	591,94

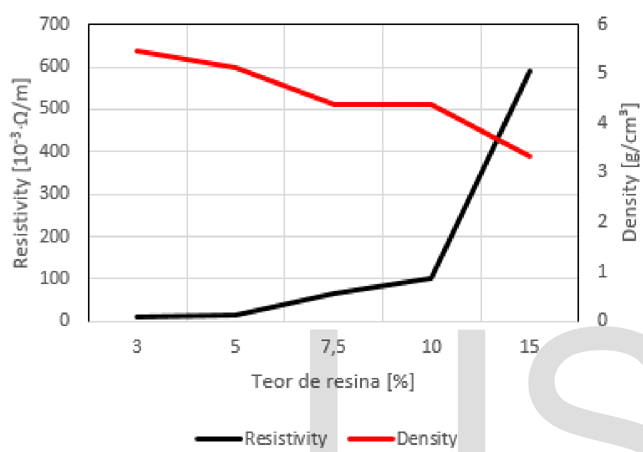


Fig.10.IInfluence of resin content in resistivity and density

From the results it can be seen that increasing the percentage of resin has led to a lower density parts, and a higher electrical resistivity. Figure 10 shows the behavior of the density and resistivity of the alloys according to the resin content for each alloy. In most cases, the resistivity of a metal element increases when impurities are added, since these impurities cause distortions in the crystal lattice. For this reason, higher resistivityis obtained in alloys composed of two or more materials. For a better comparison, according to references, sintered pure iron has electrical resistivity between 0.11 and 0.2 · 10-6Ω ·m. Comparing pure iron sintered with Fe3% Re is an increase in electrical resistivity around 5,000,000%.

The resinated organic coating material has a role in iron powder particles, which also produces high electrical resistivity. This type of material is generally magnetically isotropic because of its porous nature, being beneficial for electromagnetic devices. The magnetic circuit may be intended to route dimensional flow and different topologies may be exploited to develop high performance machines because the magnetic flux not be forced in the plane, as well as laminated sheets which are commonly used in the manufacture of electrical machines and transformers [1], [9], [12], [13].

4 Conclusions

Stators and rotors cores of electrical machines are usually constructed with laminated and insulated plates, in order to restrict the circulation of induced currents. The process of making these cores involves a series of steps costly and generates a lot of scraps. Seeking more ecological and economically viable alternatives, we used the powder metallurgy for making these cores and as raw material soft magnetic composite materials. These materials obtained from powder metallurgy procedures are being extensively studied in the search for the replacement of traditional steel plates laminated packages that make up the cores.

Losses due to eddy currents on a solid core are significantly larger than the losses in the cores made from electrically isolated plates. However, the reduction of induced currents can be obtained by increasing the electrical resistivity of the material, since the electrical resistivity and electrical current are inversely proportional to physical quantities, in this case possible to obtain high performance electric machines.

The study of soft magnetic materials focused on the evaluation of the electrical resistivity behavior depending on the resin content added to pure iron powder. After defining the geometry of the specimens, a device that allowed to heating the compression die and control the temperature, simultaneously with the application of compression pressure it was prepared. Samples were prepared from pure iron powder with percentages between 3% and 15% of thermoplastic acrylic resin. The characterization of materials studied can be performed from the measurements of height, thickness, length, volume, mass, density, resistance and electrical resistivity of the specimens.

From the preliminary tooling tests, we observed that it consolidates the specimens composite iron-resin, and the temperature remains stable during the process. Evaluating the values obtained, it was found that the density decreased and the resistivity increased with the percentage of resin increase, and this was due to the increase of a thickness film involving the iron powder particles (encapsulation) as the resin acts as electrical insulator. With increase of the resin, eddy current losses tend to decrease. However, the specimens showed very low hardness. Mechanically composites have their behavior governed by the resin, where, in addition to acting as an insulator between the iron particles is the agent that gives mechanical stability to the material. Therefore, the specimens after cure has not fragile structure due to atomic diffusion occurring in sintering. For this reason, new composite shall be tested with the use of other types of resins and different times and temperatures, since the application of a material such as the core component of electric machines require that the forward compatible properties such as appropriate hardness and ductility.

With the results of the study, it is concluded that the material presents promising results for its application as a core of electrical machines. This proposed method is feasible for the application in the manufacture of stators and rotors, requiring the studies of the conventional process replacement viability for each product type.

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