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Comparative study of the mechanical properties of sinterized magnetic alloys applied to electrical machines' core

Juliano Soares Barboza [a,*], Lirio Schaeffer [a,1], Luciano Lohmann Cerva [a,2], Jorge Alberto Esswein Lewis Jr. [a,2], Moisés De Mattos Dias [b,3]

[a] UFRGS, Av. Bento Gonçalves, 9500, Porto Alegre, RS, Brazil
[b] ICET, FEEVALE, RS 239, 2755, CEP 93352000, Novo Hamburgo, RS, Brazil

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ABSTRACT

This paper aims at making a comparative study of some soft magnetic material alloys, which are likely to be used in the construction of rotative electrical machines' core or electrical motors. Therefore, this study focus on the building of massive cores, obtained from the conventional powder metallurgy process, also known as sinterized materials. The mechanical properties of hardness and yield stress are analyzed and compared, resulting in an increase of hardness and yield stress due to the influence of diffusion among the elements utilized in the alloys.

1. Introduction

The magnetic cores of electric motors (stator and rotor), with not many exceptions, are currently built from thin metallic blades (sheet) with thickness less than 1 mm, clustered in sheet packs, later submitted to a thermal treatment. In these sheet packs, the adjacent blades are electrically isolated using substances such as oxides. Magnetic cores involved by coils, where alternating currents flow, create an alternating magnetic flux. That is why these cores can be affected by the action of stray currents, also known as Foucault currents. These currents are responsible for considerable loss of power in the cores. The construction of theses magnetic cores made from electrically isolated steel sheet partially decreases the stray currents, reducing the loss caused by Foucault currents. It is important to mention that, in the construction of cores in conventional motors, the steel must be laminated, treated, die forded in disc-shape, packed and submitted to thermal treatment processes and electrical isolation by oxidation [1,2].

However, when the powder metallurgy processes are used, it is possible to build these cores in only one massive block, with a high magnetic permeability (which is an aspect of magnetic steels) and a high electrical resistivity, thus reducing the stray currents [3,4]. The application of this process in constructing electrical motors cores may result in motors bearing several advantages on those with conventional cores. Some of these advantages are: (a) less stages in the core constructing process and less energy use; (b) stator and rotor with greater electrical resistivity and less affected by stray currents; (c) lighter motors, less use of energy and higher efficiency and (d) cheaper raw materials.

When referring to the mechanical aspects, the electric machines in use are submitted to charges which, besides having an opposite resistive turning moment, may result in vibration in the machine-charge system. Therefore, the studied alloys must present the necessary ductility, hardness and mechanical vibration resistance to tolerate the efforts that come from the magnetic fields in the core, as well as to resist the vibrations that are originated when the machine is working.

This study analyzes the sinterized magnetic alloys that can be possibly utilized in the construction of massive cores in rotative electrical machines or electrical motors, evaluating the behavior of mechanical properties such as Brinell hardness and yield stress.

2. Powder metallurgy

There are several production technologies that are used to obtain magnetic materials through metallurgic processes. Among these, it is important to mention casting and powder metallurgy, which is a more recent metallurgy area [5–7].

The four basic stages of the powder metallurgy are: powder manufacture, powder mixture, pressing and sintering. Sometimes, grinding is needed as a fifth step. In powder metallurgy, the powders, after being mixed, are compacted in rigid dies, where they acquire the

* Corresponding author. Tel.: +51 33087040; fax: +51 33166134.
E-mail addresses: juliano.barboza@ufrgs.br (J.S. Barboza), schaefer@ufrgs.br (L. Schaeffer), luciano.cerva@ufrgs.br (L.L. Cerva), jorgelewis@ufrgs.br (J.A.E. Lewis), moisesdias@feevale.br (M. De Mattos Dias).
[1] Tel./fax: +51 33086134.
[2] Tel.: +51 33087040; fax: +51 33086134.
[3] Tel.: +51 35868800; fax: +51 35868836.

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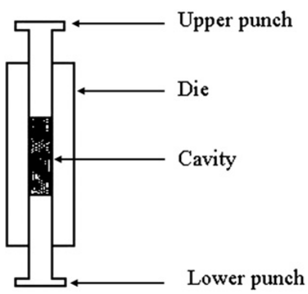

Fig. 1. Double-acting compaction dye for pressing magnetic materials.

Fig. 2. Matrix to obtain the samples.

form of the cavity of the die. After that, the powders are put in sinterizing furnaces, to acquire consistency and mechanical strength. It is crucial to state that powders with different chemical natures are easily obtained by homogeneous mixtures [5–7].

Fig. 1 shows schematically double-acting compaction die, used to press magnetic material powder:

3. Sample preparation

The steel powder samples used in this work are provided by Höganas do Brasil Ltda. To evaluate the mechanical properties, a die for making the samples in the form of a cylinder was produced. The samples were used to evaluate mechanical properties such as Brinell hardness and yield stress. The sample preparation begins with the mixing process, using a conventional mixer in a shape of cone with balls.

The alloys are prepared mixtures of powdered metal of pure iron with P, S, Ni and Mo and iron-based prealloyed powder with P and Ni.

Fig. 3. Sample used to characterize the mechanical properties.

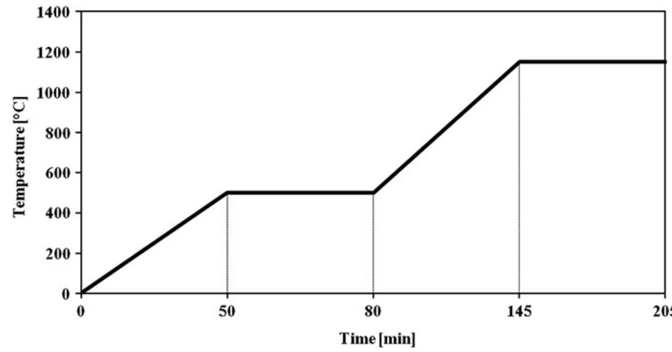

Fig. 4. Sintering curve as a function of the time.

3.1. Compaction

The sample compaction was held in a universal mechanical testing machine of the brand KRATOS, with a capacity of 100 kN (1000 kgf). This press has a censored ton indication which comes from a load cell connected at the top of the press. The samples were compressed to a pressure of 600 MPa, where 1 Pa=1 N/m^2. Considering that 1 t is approximately 10,000 N, the result is the following:

$$600\text{MPa} = 6\times10^8\,\frac{N}{m^2} = 6\times10^4\,\frac{\text{ton}}{m^2} = 6\,\frac{\text{ton}}{\text{cm}^2}$$

Considering the area of cross section of the matrix, 41 mm^2, it resulted in a compaction pressure of 21.88 kN. The Figs. 2 and 3 show, respectively, the picture of the matrix and the sample.

3.2. Sintering

The sintering was carried out in a muffle furnace, within a controlled atmosphere. The sintering temperature was around 1.150 °C, and the sintering time was 60 min. The heating rate was approximately 10 °C/min, and all the parts were kept in the furnace for slow cooling to room temperature. Before the sintering temperature is reached, the parts were maintained during 30 min at 500 °C to burn lubricant (zinc stearate). Fig. 4 presents the heating curve used in this work as a function of the time.

3.3. Finishing and density of samples

Due to the relatively small average size and the pieces complex formats, it requires special procedures and precautions, different from casting and wrought. Considering the inherent properties of the piece, it demands special considerations of all secondary operations, mainly cleaning and chipping. The measures of density were made at room temperature by the relationship between mass and volume of the

Table 1
Sintered samples density

Sample	Sintered alloy	Compressed density [g/cm³]	Sintered density [g/cm³]
01	Pure iron	6,87	6,87
02	Fe-0,45%P	6,79	7,06
03	Fe-0,8%P	6,74	6,99
04	Fe-1%P	6,84	6,47
05	Fe-3%Si	6,49	6,30
06	Fe-50%Ni	6,85	7,02
07	Fe-81%Ni-2%Mo	6,79	8,04
08	Fe-6%Si	6,08	5,64
09	Fe-50%Ni (prealloyed)	7,02	7,06