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Analysis of the Mechanical Properties of the Sintered Composite FeCuC in Two Different Atmospheres

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Abstract: This study aimed to analyze the mechanical properties of the compound FeCuC when compacted at varying pressures and sintered in two different types of furnaces. Besides the different models of furnace, the working atmospheres were varied: one is being composed with argon gas and another constituted with a balancing nitrogen and hydrogen. Atmospheres vary with the amount of production and the type of equipment used. The compound generated is used in the manufacture of rings for mechanical seals and is currently manufactured by the sintering process in passing furnace. The sintering was performed in a static furnace with argon atmosphere and compared with the same compound sintered in passage furnace with hydrogen and nitrogen atmosphere. The analysis of the properties of the tested material was performed with the aid of metallography using a scanning electron microscope, which verified the particle size distribution, chemical elements and pores present. Brinell hardness and Vickers micro hardness tests were also used to analyze the properties of this material after completion of the two processes. Thus, the research carried out has shown that variations may occur in the mechanical properties when processed in different furnace types and different sintering atmospheres.

Key words: Sintering furnaces, FeCuC, work atmosphere.

1. Introduction

The competitiveness in the industry referred to the need to pursue innovation more quickly and efficiently [1]. The term innovation, which is originated from the Latin "innovation" presents as meaning the renewal. It is believed, however, that the innovation is the application of creativity, i.e., they first have to be creative and then innovative [2]. The evolution of products and processes requires faster action and more dynamic technology solutions. Powder metallurgy is a process that satisfies productivity with compliance with environmental requirements and the rational use of material resources. Powder metallurgy is also characterized by manufacturing and getting smaller batches of parts [3]. Another peculiarity of this process is the possibility of the manufacture of complex parts with the same level of quality than those obtained in other manufacturing processes [4, 5]. A sintered composite can be in different kinds of furnaces and also with different atmospheres, when processed by this manufacturing method. The paper is organized as follows: Section 2 describes the materials and methods; Section 3 presents the results; and Section 4 gives the conclusions of the paper.

2. Methods and Materials

The compound that was used to analyze the influence of different modes of sintering presented as

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balancing the iron participation with 65%, copper with 34.8%, and 0.2% graphite. Furthermore, there was added 0.8% solid lubricant zinc stearate. The solid lubricant has the function of reducing the wall friction in the matrix and decreasing the forces involved in compaction.

For a good understanding of the behavior of the material in powder metallurgy is particularly necessary to know the physical properties of the constituent elements in the compound. Table 1 shows the physical properties of the atomized iron powder that was used in the balance of the generated compound.

Similarly to iron powder, Table 2 shows the physical properties of electrolytic copper powder used in the balance of the compound generated.

However, for the graphite powder and zinc stearate, present in smaller percentages were disregarded its influence on the physical properties of the compound generated. Compressibility and compaction are parameters that indicate and describe the behavior of metal powders as they are compressed. The ability of a powder densification is related to compressibility [8, 9]. Already compaction is defined as the stability of the structure of the pressed compacted to a certain working pressure. To form the compound, pieces were bidirectionally compressed in a cylindrical die diameter of 13 mm using a hand press with the pressing capacity of 15 tons. Fig. 1 shows the tool set to the respective compressed parts.

For the present study, two different furnace types have been used. One of them, a Sanchis vacuum pit furnace is capable of raising the temperature to 1,500 °C for sintering. The other, a sintering furnace with conveyor belt 10 meters long with three heating zones and two cooling boilers. The type of furnace and different atmosphere may promote different properties in the compressed and sintered part [10]. Table 3 shows how the parts were sintered in their respective furnaces.

The hardness test applied in the analysis of the material was performed [11]. However, also the Vickers micro hardness method was used to check the hardness of the material. This method was duly suitable for sintered according to standard ISO 6507 [12] and its procedure governed by the standard ISO 4498 [13]. The parts went through metallographic test according the standard ABNT NBR (Norma da Associação Brasileira de Normas Técnicas)—15454 [14].

Generated specimens were subjected to testing and SEM (scanning electron microscopy) analysis of electronic data systems. Such assays allow quantification of the elements present in the compound and a more detailed analysis of micrographic structure of the material [15].

Table 1 Physical Properties of iron powder [6].

Physical Properties			
	Tests results	Minimum specification	Maximum specification
Bulk density	2.85 g/cm^3	2.85 g/cm^3	3.16 g/cm^3
Runoff	35.9 s/50g	-	40.90 s/50g
Green density	6.69 g/cm^3	6.55 g/cm^3	-
Green resistance	1,015 Psi	725 Psi	-

Table 2 Specifications of electrolytic copper powder [7].

Tyler scale	Sample values	Chemical analysis Cu (%) 99.9 min.
+100	1.19	
-100 + 200	82.09	
-200	16.60	Class AG01
Bulk density (g/cm^3)	1.42 a 1.55	
Loss H_2 (%)	Max. 0.2	
Runoff s/50g	75	

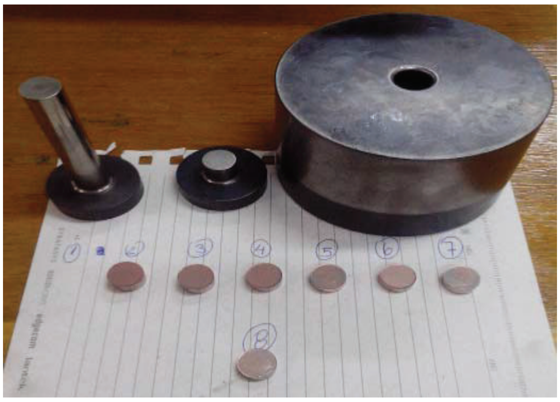

Fig. 1 Compression set.

Table 3 Sintering plan.

Compound	Sintering temperature (°C)	Atmosphere	Type of furnace
65Fe34,8Cu0,2C	1,150	Air	Pit
65Fe34,8Cu0,2C	1,150	N_2-H_2	Conveyor belt

3. Results and Discussion

Eight samples with standard matrix of each one of the two generated composites for this study were tested. The samples started with an initial volume corresponding to the product of the area times the filling height of the die cavity which was used to conduct this assay. Fig. 2 shows a tendency to increase in bulk density due to the applied force and pressure in the two different compounds generated.

It was realized in the compressibility curves of the sintered composites produced in both types of furnaces that the densities as a function of pressure started with high values, from the lowest to the highest pressures. Observing these graphs is the observed similarity in these results. The analysis performed on the compounds after sintering at different conditions showed the different properties that were presented by the SEM analyzes. Figs. 3a and 3b respectively show the micrograph of the sintered compound produced in pit furnace with argon and in conveyor belt furnace with nitrogen and hydrogen. After sintering of the compounds in different ways, a microscopic analysis by scanning and a chemical analysis by EDS (energy dispersive x-ray spectroscopy) under controlled conditions of temperature at 20 °C (±5) and relative humidity ≤ 65% were performed. These analyzes showed whether there was an influence of the gas atmosphere and the sintering furnace in the tested specimens. Figs. 3a and 3b show the results obtained in these assays.

By the figures presented, it was noted that sintered parts both in pit furnace and in conveyor belt furnace had a good sintering of copper and iron, with a small amount of pores. It was noted, however, in Fig. 4b that copper diffused in higher quantities in the conveyor belt furnace when compared with the result of the sintering in pit furnaces. This may be related to the sintering atmosphere, sintering method and cooling. The quantitative analysis of the elements present in the compounds shown in Figs. 4a and 4b shows whether or not the influence of the sintering way.

Figs. 4a and 4b show the distributions of iron and copper which were very similar in both methods of sintering. There are variations in the amount of iron and copper in different regions of the parts. This

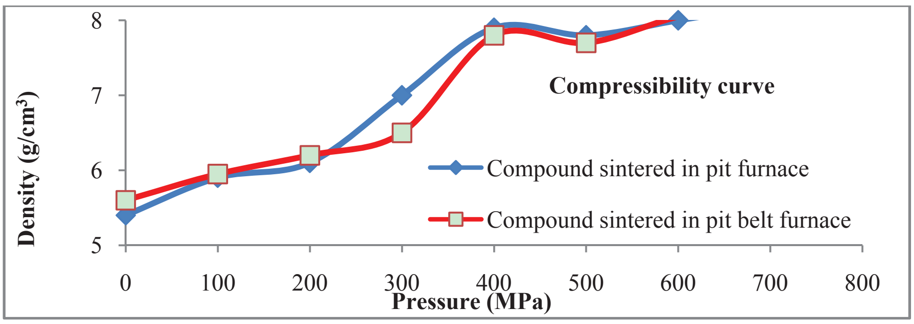

Fig. 2 Compressibility of sintered compounds produced in pit furnace and in conveyor belt furnace.

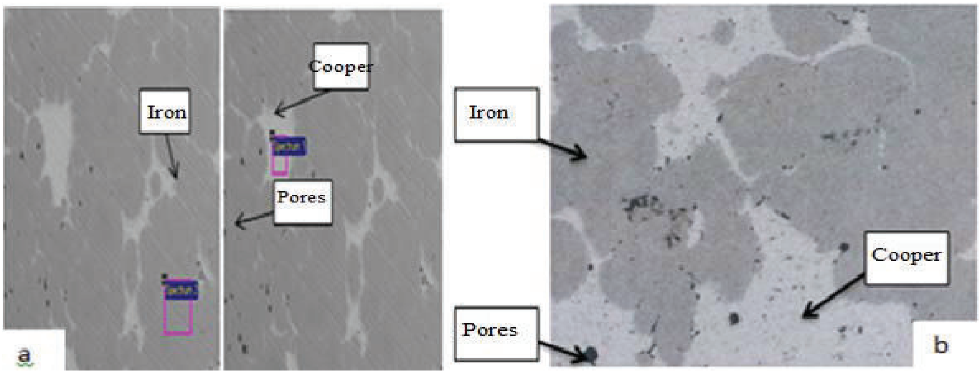

Fig. 3 SEM of the sintered composite in pit furnace and in conveyor belt furnace 350 x increases ((a) and (b)).

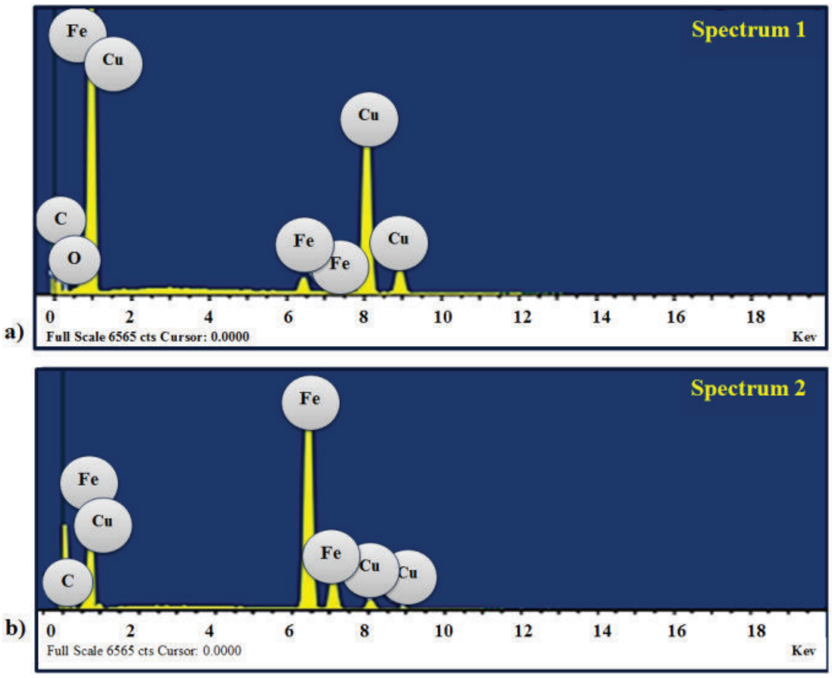

Fig. 4 (a) Quantitative spectral analysis of the compounds 1 and 2 sintered in pit furnace by chemical microanalysis by EDS process; and (b) quantitative spectral analysis of the compounds 1 and 2 sintered in conveyor belt furnace through chemical microanalysis by EDS process.

phenomenon stems from the fact that the copper is in liquid phase when sintering occurs, promoting regions of greater amount of this material.

For the Brinell hardness test, a load of 60 kgf was used with a sphere of 2.5 mm diameter. The results in Brinell shown in Table 4 were performed in samples of each composite that underwent the highest compression pressure.

Because it is sintered materials, it was careful considered the existing porosity, thus performing the test in the regions observed lighter or gray color. The reliability factor of the results obtained is 95% for an uncertainty of 5% [16]. It was found that the Brinell hardness of the sintered parts in conveyor belt furnace was slightly higher than the parts processed in the pit furnace.

In order to obtain more information of the mechanical properties of the material, the Vickers hardness test was performed on the sintered parts as shown in Table 5.

Because it is a material having porosity, a more reliable verification of hardness was necessary for evaluation of a micro region. The micro region analyzed and the most relevant to the proposed study was the region of the light spots or gray coloring.

Table 4 Verification of Brinell hardness of the sintered composite samples.

Compound	Applied pressure (Mpa)	Applied load (g)	Hardness (HB)
Sample sintered in the conveyor belt furnace	800	5.0	87
Sample sintered in the pit furnace	800	5.0	80

Table 5 Checking Vickers hardness of sintered composite samples.

Composite sintered	Applied pressure (Mpa)	Time of application of the force of the indenter (s)	Applied load
Conveyor belt furnace	800	10	0.1
Pit furnace	800	10	0.1

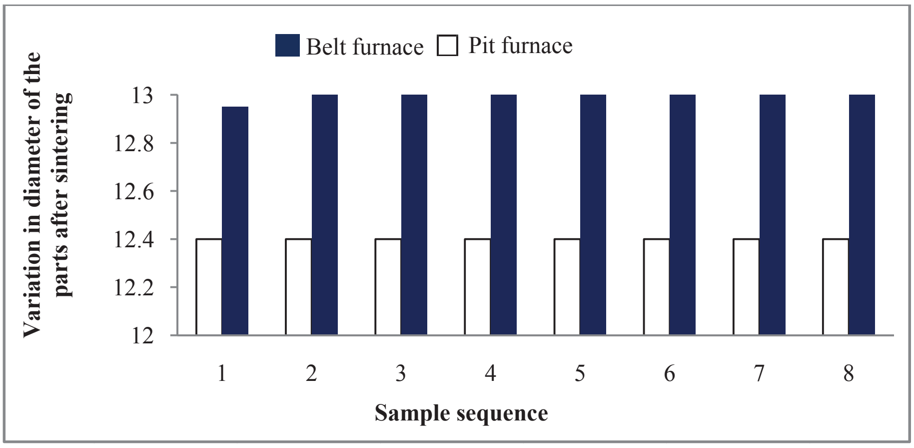

Fig. 5 Dimensional variation of the external diameter after sintering.

The results obtained and presented in the Table 5 show that there was a small variation in hardness between the different sintered. The sintered parts in conveyor belt furnace tend to have slightly higher hardness to those performed in pit furnace. In fact, the process of sintering in passage furnace leads to such situation due to cooling mode and also because the used gases promote a reducing and non-oxidizing atmosphere.

The dimensional behavior of external diameter after the sintering process for the generated compound was checked. Fig. 5 shows the diameter of the parts after sintering.

Fig. 5 shows how the behavior of the diameters of the parts was after their sintering processes. It was noticed a strong variation of the diameters of the compounds sintered in pit furnace, rich in argon. This strong variation was not observed in the parts that were subjected to the sintering process in passing furnace.

4. Conclusions

This study showed that when a compound sintered in different types of furnaces may behave differently. The sintered present results of Brinell hardness and Vickers micro hardness greater when made in passing furnace. Otherwise, analyzing the microstructure of materials by testing SEM, it was seen that the sintered parts in the passage furnace allowed of larger regions with formed copper than those parts sintered in pit furnace. With regard to the dimensional variations, an important observation could be reported in this work. Finally, after sintering, the dimensional discrepancies diameters were observed in the sintered parts by two different processes. The parts that were sintered in pit furnace showed stable variation of the external diameter, but with 0.6 mm below the nominal value given by the compaction die. The parts sintered in passage furnace showed little dimensional variation in diameter, being almost all of them with a value given by the compaction die, i.e., 13.00 mm ± 0.10 mm.

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