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Development of a High-Energy Mill for Powder Metallurgy

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Abstract— This paper aims the development of high-energy milling equipment for use in powder metallurgy. This kind of mill is used to obtain prealloyed powders and/or reduction size of powder particles. After the steps of project and the construction, a preliminary test was performed using sand in a percentage of 2:1 with stainless steel balls. The result of test show that the average diameter distribution of sand particles has reduced approximately 50%.

Index Terms— High-energy milling, Mechanical alloying, Particle reduction size, Powder metallurgy,

1 Introduction

POWDER metallurgy is a manufacturing process that has found increasing application and great development, mainly because of very low waste of raw materials. It is called so used as raw material metal powder. It can also be used as a raw material a metal and ceramics composite materials. The main steps of powder metallurgy are: powder production, mixing, compacting and sintering. When necessary, after the sintering step can occur secondary operations like machining, milling and others. Currently the powder metallurgy is consolidated as a highly advanced, efficient, economic and ecological process. Powder metallurgy presents as main advantage the high use of raw material, which comes to exceed 95%. The losses by conventional machining, for example, may reach 50%. The raw material savings is directly reflected in the cost of manufacturing, allowing the product have many economical advantageous compared to other fabrication processes used for obtaining it. Another advantage is related to low transformation energy that is employed, consuming little electricity. This factor ensures powder metallurgy to the concept of environmentally friendly manufacturing process [1], [2].

The metal powders can be produced via a number of different methods. Powders may be prepared by crushing, grinding, chemical reactions or electrolytic deposition and almost any metal can be turned into powder. The main metal powders used are pure Fe and many other elements can be added to turn into an alloy, like P, Co, Si, Ni, Cu and others. Some powders may be purchased ready for use (prealloyed), or obtained by mixing the constituent powders. However, this action may result in non-homogeneous mixtures, resulting in products with parts of both elements and the league. An alternative for industrial prealloyed powders is the development of the desires alloy using a process called mechanical alloying, a post-processing technique that allows production of homogeneous alloy from blended elemental or prealloyed powders. This technique realizes the processing of powder particles in high-energy mills. Different types of high-energy milling equipment are used to produce mechanically alloyed powders. They differ in their capacity, efficiency of milling and additional arrangements for cooling, heating, etc. The commonly used mills are planetary, balls, shaker, attritor, among others. The main advantages of the use of mechanical alloying are the production of powder in big quantities and easily control the processing parameters [3], [4], [5], [6], [7], [8].

All types of materials, almost without limitation, can be synthesized or processed by mechanical alloying. Numerous studies and patents report on the mechanical alloying of materials with an increase in the mechanical, magnetic or catalytic properties. For production of magnetic alloy with high permeability by powder metallurgy, such as Permalloy (FeNi alloy) and Supermalloy (FeNiMo alloy) this process have great importance for obtaining one or more phases and consequently the alloys desired. During the last years, different aspects of processing like grinding time, the effect of particle size, sintering temperature and time, additives and alloying elements effect has been the subject of intense research [9], [10].

One of the major type of high-energy mill used in the mechanical alloying is the attritor mill. An attritor is a ball mill capable of generating higher energies and consists of a vertical drum with a series of impellers inside it. The impellers are set progressively at right angles to each other and have the function of energize the ball charge, causing the powder size reduction because the impact between balls, between balls and container wall, and between balls, agitator shaft, and impellers. This mill works at speeds around 300 rpm. For the preparation of powder, the constituent powders are weighed in the proper proportions and placed inside the drum together with steel balls. For metal materials such as ferrous metals which oxide easily, the drum must have inert atmosphere, such as argon [6], [9], [10].

2 Materials and Methods

2.1 Dimensional Project of the Mill

The dimensional project was carried out based on the existing models of attritor mills, consisting of a water-cooled stationary drum, a rotating shaft with impellers for agitation the mixture of powders and steel balls, a 2HP 2 poles three-phase electric induction motor for the rotate the shaft and two pulleys with bels, one coupled to motor and other to shaft. The pulleys have different diameters, with a 3:1 ratio, which reduces the shaft rotating speed and provides an increase in torque. The 2 pole motor used has a rated speed of approximately 3,550 rpm, allowing the shaft rotating at speed of 1,200 rpm. The laboratory attritor mill can works up to 10 times faster than conventional ball mills. The rotating speed control was done using a variable-frequency drive. The walls of the grinding chamber are hollow and have two connections for water, one for input and one for output to do the drum cooling. The chamber also has two connections for input and output of inert gas. The inert atmosphere chosen was argon. Figure 1 shows the internal details of the attritor mill.

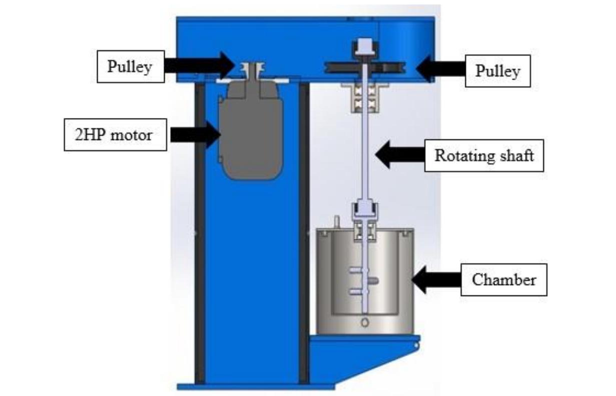

Fig. 1. Internal details.

2.2 Assembly

The mechanical assembly of components designed was held in a company specialized in the assembly of metal structures (machining and welding). The figure 2 shows the mill during assembly of parts and figure 3 shows details of the camera cover, where shows the gas seal connectors and shaft connection.

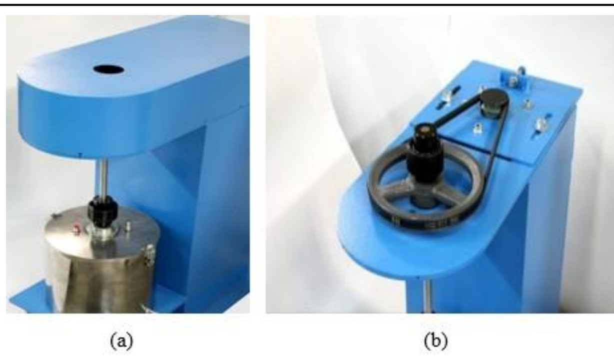

Fig. 2. Mill assembly - (a) metallic parts and (b) pulley assembly.

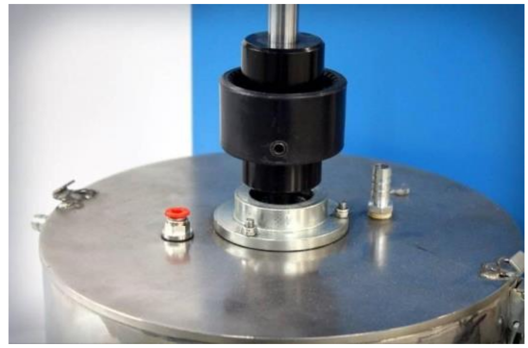

Fig. 3. Gas seal cover details.

The control of rotation speed was done by a variable-frequency drive. This drive is a useful solution to control AC motor speed and torque by varying motor input frequency and voltage. The drive model used is 10 CFW for 2 KW manufactured by Weg. Figure 4 shows the completed assembly with the drive installed at the side of the attritor mill.

Fig. 4. Final assembly with variable-frequency drive.

3 Results and Discussion

The initial test of the attritor mill was carried out grinding sand. First, was observed the quality of the insulation between the water-cooled stationary tank and the interior of grinding chamber. The mill was left open without the upper cover and water was placed in the hollow portion of the chamber. It was noted that there was no leak. Then, through the AC motor drive, the mill was turned on with no material inside the chamber, varying the speed until 600 rpm, remaining with the water flow. It was observed that the mill working was smooth and without trepidation. In the following, were placed in the mill chamber 200 cm^3 of medium sand and about 100 cm^3 stainless steel balls with average diameter of 8 mm. Then the chamber was closed and also with the water flow maintained, the gridding was started at 300 rpm speed for 5 minutes. Subsequently the steel balls and sand were removed, where it was observed that there was no leakage or heating of the chamber walls. After the test, some adjustments are needed, especially in the part of shaft that was inside the drum. For this reason, the mill returned to the company that held its assembly in order to correct these minor changes.

The particle size analysis of the sand was performed using a mechanical shaker for sieve analysis before and after milling. Table 1 shows the result of analysis before milling and the table 2 the result of analysis done after milling. The figure 5 and 6 given a comparison between the particle size results.

TABLE 1
PARTICLE SIZE ANALYSIS BY SIEVING - BEFORE MILLING

Sieve number	Sieve opening [mm]	Mass of sand retained before milling [g]	Cumulative mass retained before milling [%]
10	2.00	30.9	10.3
14	1.41	18.3	16.4
18	1.00	15.6	21.6
35	0.50	6.9	23.9
Catch pan	-	228.3	100

TABLE 2
PARTICLE SIZE ANALYSIS BY SIEVING - AFTER MILLING

Sieve number	Sieve opening [mm]	Mass of sand retained after milling [g]	Cumulative mass retained after milling [%]
10	2.00	16.2	5.4
14	1.41	12	9.4
18	1.00	9.3	12.5
35	0.50	2.7	13.4
Catch pan	-	259.8	100

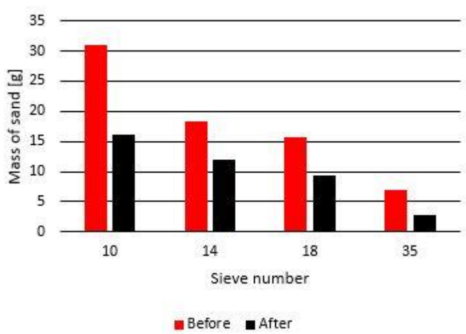

Fig. 5. Particle size analysis for sieves 10 to 35 mesh.

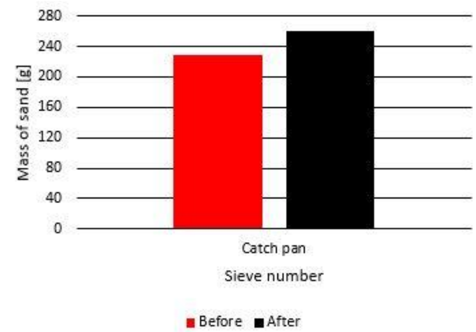

Fig. 5. Particle size analysis for catch pan.

4 CONCLUSION

The search for technologies that enable sustainable development causing low environmental impact, has driven the advancement of the use of powder metallurgy. Requiring lower power consumption and providing opportunities for a high utilization of raw materials, the powder metallurgy search producing metal parts with superior features compared with the traditionally fabrication process.

The technique used for powder production influences directly the physical properties of the materials. The morphology and particle hardness influence on the compressibility of the powder. Irregular morphology particles attenuate the formation of asymmetrically opposing forces in contact points between particles, which results in shear deformation and, consequently, cold welding powder particles. The flattened particle morphology provides a higher capacity for deformation during compaction of powders.

Many techniques of powder production have been developed which permit large production rates of powdered particles, often with considerable control over the size ranges of the final grain population. One of the processing techniques most used for obtaining a homogeneous alloy is the mechanical alloying. This technique utilizes as raw material elemental or prealloyed mixed powders and a high-energy milling equipment like an attritor mill.

In order to develop the knowledge about the mechanical alloying was designed and built an attritor mill for production of powders in laboratory scale. The mill project was carried out from observation of existing mills models. The construction of the mill proved satisfactory because not presented problems of leakage or trepidation, needing only small adjustment in its shaft where the edges of the impeller need to be rounding.

The result of particle size analysis by sieving described in Table 1 shows that, even with the little milling time used in the test, a significant reduction in the average diameter of the sand particles was done. There was a decrease in the percentage of sand retained in all the different sieves and, consequently, an increase of 12.1% in sand mass that was in the catch pan, proving that the attrition mill worked successfully.

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