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DESIGN OF PLANETARY MILL WITH FRICTION WHEELS

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Abstract. *Fast grinding is a growing need in the technological industry, several methods and equipment provide this service, such as the planetary mill, which is a centrifuge machine that combines rotation and revolution. It optimizes and increases power of both milling mechanism: friction and mechanical shock, therefore being considered a high-energy process. Planetary mill based on friction wheels transmission was designed and a prototype was built and performed. Different friction wheels materials were tested. The grinding was performed through milling of a coarse calcined alumina powder, where was experimented different combinations of transmission ratio, revolution speed, material of the jar and ball (media) size. Tempered steel presented the best durability and reliability as friction wheel. Optimized design and experimental configuration of alumina milling resulted in sub micrometric powder in just 1 hour. The transmission based on frictional wheels permitted an economical and compact design, presenting high performance and safety.*

Keywords: *planetary mill, friction wheel, grinding.*

1. INTRODUCTION

Planetary Ball Mill is a centrifuge machine (Fig. 1) in which jars (containing dry or wet feed material and ceramic media) rotates around its own axis (rotation) and the main axis (revolution). Its milling is considered a high-energy process together with other milling processes such as jet mill and attritor. The milling mechanism depends on mechanical shock and friction between the media/jar and powder particles. In optimized configuration, this equipment presents low material loss, very good homogenization and particles with high superficial area, everything fast generated (dos Santos and Costa, 2006; Mio , *et al*., 2004).

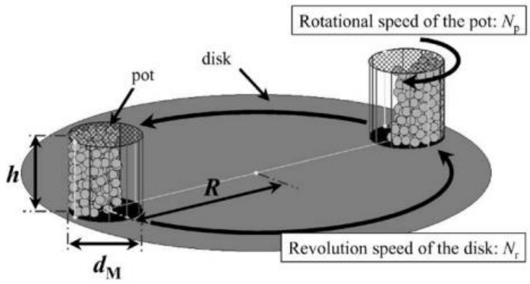

Figure 1. Schematic of a planetary ball mill (Mio, *et al*., 2004).

The motion transmission is one of the features that most distinguishes patent projects (Blanchard, *et al*., 2013; Chen, *et al*., 2000; Gouko, *et al*., 2014). Different patents claim for planetary mills with belt transmission, friction transmission between the jars and a fixed external ring or even two independent electric motor to drive rotation and revolution.

The present work aims to develop a low cost planetary mill based on friction wheels transmission, seeking the best grinding conditions and suitable material for friction wheels.

2. MATERIALS AND METHODS

Planetary mill designed boundaries: maximum revolution speed of 700 rpm; maximum mass of each set (jar, its holder and content) of 1 kg; speed ratio (revolution/rotation): 1/-1 or 1/-2.

2.1 Friction wheels

Considering a transmission with the following characteristics and the Eq. (1) to calculate the normal force (P) between the friction wheels and Eq. (2) to calculate the rolling pressure (k) (Niemann, 1971).

$$P = (7.16 \cdot 10^{5} \cdot N \cdot S_{r})/(r \cdot n \cdot \mu) \tag{1}$$

Where N is power (CV), 1 CV; S_r is safety coefficient to slip, 1.5; n is rotation (rpm), 700 rpm; r is radius of friction wheels (mm), 20mm.

$$k = P/(2 \cdot Q_{L} \cdot B) \tag{2}$$

Where: Q_L is radius of curvature (mm), 10 mm and B is thickness in contact (mm), 3mm.

The rolling pressure of different materials were calculated and compared with its maximum theoretical value ($k_{\lim}$) and it is presented in Tab. 1. Even though the low friction coefficient and the high normal force between the friction wheels, the pair of tempered steel friction wheels is the only one which has $k < k_{\lim}$.

Table 1: Calculated and maximum value of rolling pressure for wheel materials

Friction Pair	Friction Coefficient (μ)	P (kgf)	k (kgf/mm^2)	$k_{\lim}$ (kgf/mm^2)
Polymeric Material/Steel	0.8	9.6	0.16	0.02
Pressed Material/ Steel	0.4	19.2	0.32	0.10
Tempered Steel/ Tempered Steel	0.12	63.9	1.06	2.90

2.2 Mill validation tests

Calcined Alumina APCG (Øspherical equivalent, 4.2 microns) was chosen for experimental to be considered a reference as hard powder material. The polymeric jar, having Ø40 x h50 mm (62.8ml) was 1/3 vol filled with: alumina powder 24g, distillated water 14g, Ammonium Polyacrylate as deflocculant 0.24g and other 1/3 vol filled with zirconia balls (5 mm of diameter) as media (120g). The milling time was set to 10 minutes and in different conditions, varying revolution speed and speed ratio (Tab. 2).

Table 2: Experimental Parameters

Sample	Speed Ratio (revolution/rotation)	Revolution Speed (rpm)
A	1:-1	287
B	1:-1	456
C	1:-1	626
D	1:-2	287
E	1:-2	456
F	1:-2	626

The condition (E) was chosen to vary other parameters (Tab. 3): time, ball diameter and material of the jar; maintaining the dimension of the jar, filling ratio and content.

Table 3: Experimental Parameters

Sample	Ball Diameter	Material of the Jar	Time (minutes)
G	5	Polymeric	30
H	3	Polymeric	10
I	3	Polymeric	30
J	3	Alumina	30
K	3	Alumina	60

3. RESULTS AND DISCUSSION

Figure 2 shows the sketch of Planetary Ball Mill. The material that achieved the best durability and reliability was the tempered steel, as predicted in the literature. Even though it has a small coefficient of friction, it has the maximum lifetime due to its high rolling and wear resistance (Niemann, 1971).

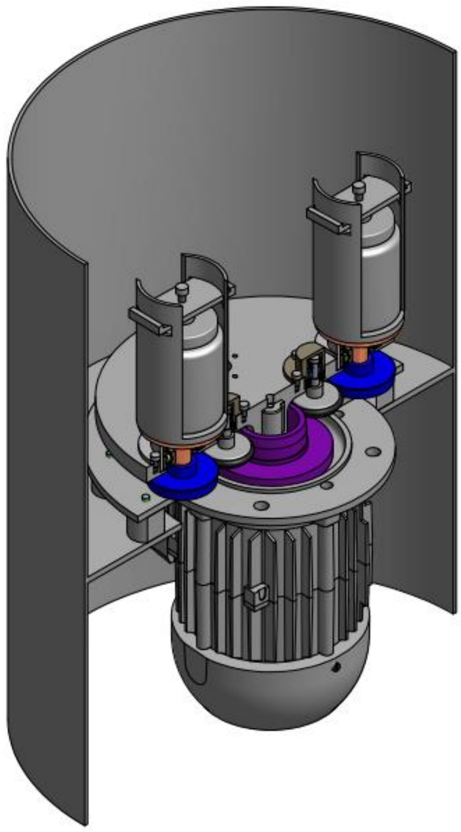

Figure 2. Sketch of the planetary mill.

Figure 3 shows milling curves corresponding to Tab. 2. Considering the same revolution speed, the speed ratio (revolution/rotation) of 1:-2 has always performed better than the speed ratio of 1:-1. The best milling conditions were E and F (respectively 456 rpm and 656 rpm, both with speed ratio of 1:-2). They performed very similarly and thus follow what was predicted by Chen et al., 2015 that the increase in speed does not always provide finer products.

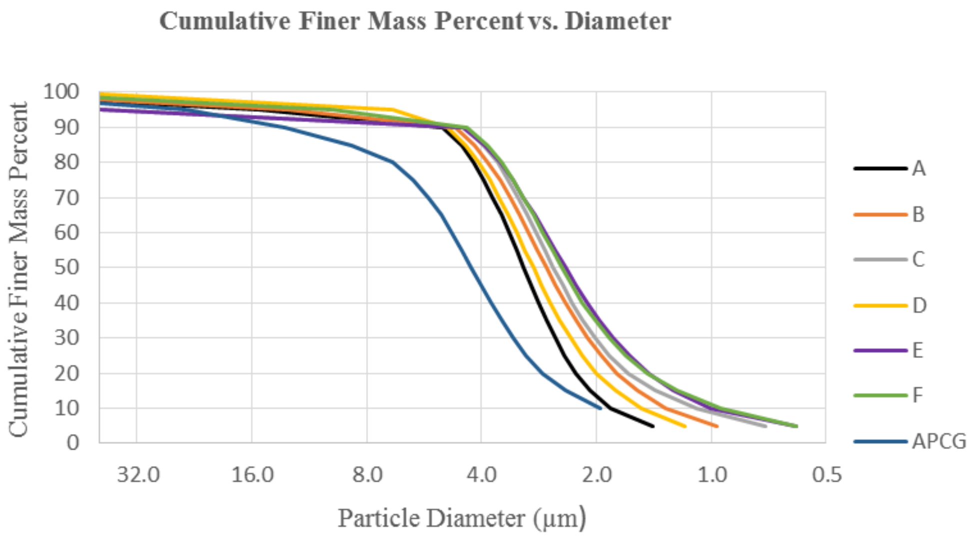

Figure 3. Milling curves corresponding to Table 2 (comparing speed ratio and revolution speed).

Grinding were performed using transmission ratio of 1:-2, revolution speed of 456 rpm and varying other parameters such as media size and material of the jar (Tab. 3). The milling curves comparing ball media diameter are shown in Fig. 4 (conditions E, G, H and I from Tab. 1 and 2). The result follow what was predicted by Fukumori, 1998 that smaller media lead to smaller particle sizes. Figure 5 presents the effect of the material of the jar (conditions I and J from Tab. 2), using jars of polymer and alumina, ball media size of 3 mm and 30 minutes milling. The ceramic jar participates most actively in grinding and thus performs better.

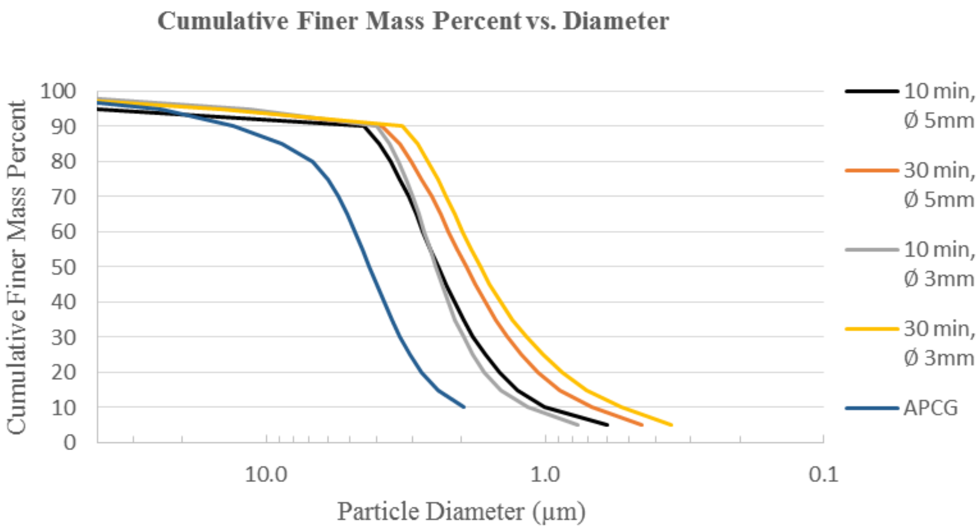

Figure 4. Milling curves comparing ball media diameter.

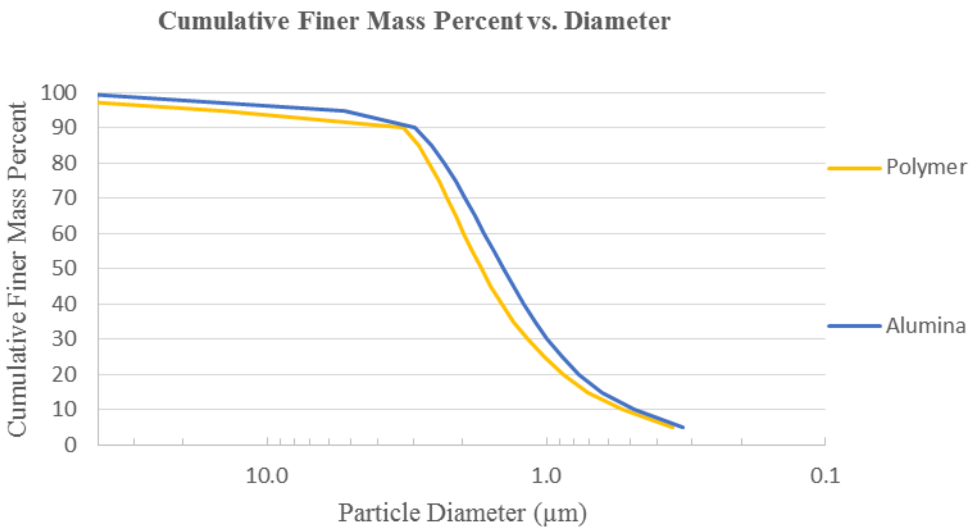

Figure 5. Milling curves comparing the material of the jar.

The best grinding conditions were maintained (transmission ratio of 1:-2, revolution speed of 456 rpm, diameter of the media of 3 mm and jars made of alumina) and sub micrometric alumina was reached in just one hour (Fig. 6).

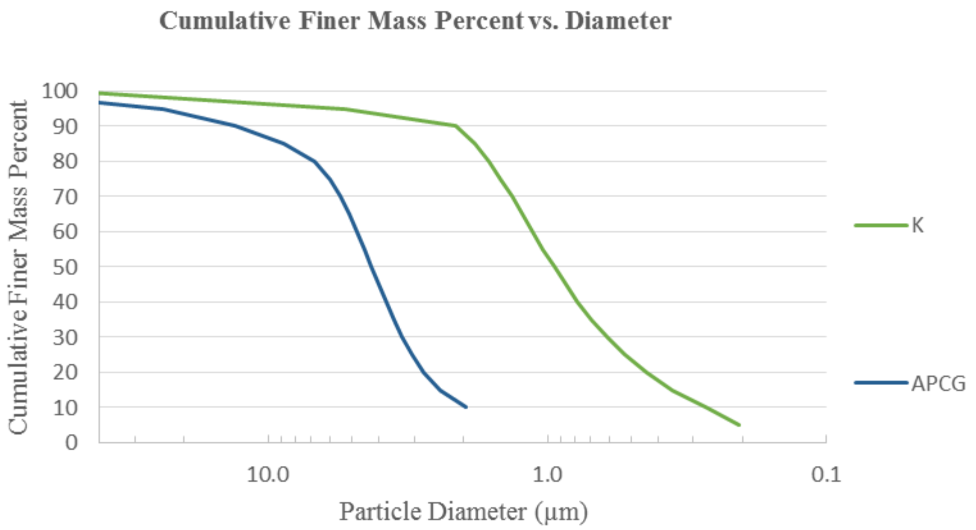

Figure 6. Milling curves of sub micrometric alumina powder reached in one hour.

4. CONCLUSIONS

The optimized design and experimental configuration: transmission ratio of 1:-2, revolution speed of 456 rpm, diameter of the media of 3 mm and jars made of alumina performed to alumina powder milling resulted in sub micrometric size in just 1 hour. The transmission based on frictional wheels made of tempered steel permitted an economical and compact design, presenting high performance and safety.

5. ACKNOWLEDGEMENTS

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