Development of Tooling for Hydraulic Forming of Ceramic Spheroids Using Alumina

V. Bristot[1], V. Bristot[2], L. Schaeffer[3], V. Gruber[4]

Abstract – *In this study, tooling for hydraulic shaping of ceramic spheroids in alumina was developed based on the process for manufacturing alumina bricks and ceramic tiles, since the only known process to shape ceramic spheres in alumina available on the market so far was that known as isostatic shaping. The purpose of these spheres and spheroids is to use as grinding bodies to process raw materials, reducing the solid matter particles. They were initially developed by making a model with a shaping cavity, obtained using a manual hydraulic press. Using the apparent density and wear results that were achieved using the spheroids produced from a cavity model, a prototype of the tooling was constructed with eight shaping cavities, and installed in an automatic hydraulic press to verify its performance in a real life industrial production situation.*

***Keywords**: Tools; Hydraulic Presses; Manufacturing process.*

I. Introduction

Tooling for the hydraulic shaping of ceramic spheroids in alumina was designed with the help of design methodology techniques. Some care must be taken in working with ceramic shapings based on powder compaction, followed by sintering [1]-[2]. The following requirements were considered: high production efficiency and practical operation. Thus, a procedure was developed for an adaptive design of hydraulic shaping of ceramic spheroids in alumina. The tooling designed has a capability to obtain 8 (eight) spheroids per compaction, i.e., a die with 8(eight) cavities. The design was optimized by experimental planning with a model, and validated in industrial production using a prototype. Spheroids were obtained with physical and mechanical characteristics very similar to the spheres pressed by the usual system for this type of work, namely, by isostatic system [13].

The reference design used was pressing alumina brick for mill linings. The body of the press and the movement of the upper punch plate were kept according to the structure proposed, and the lower punches, upper punches, die box and central crossbeam were. Since the main difference is the new physical format of the shaped material, the tooling that shaped the bricks was replaced by punches and sleeves with a new format, and the central crossbeam of the press was moved to expel the material from the die box cavities. This modification enabled shaping up to 8 (eight) ceramic spheroids in alumina simultaneously. The initial outline of the design is shown in Figure 1. The following were considered for the tooling design: punches and sleeves, thickness of the die box wall, fixation of the sleeves in the die box, the fixation system for the complete die box, the length of the upper and lower punches, and the curvature radius of the lower and upper punches. A sketch of the tooling is shown in Figure 2.

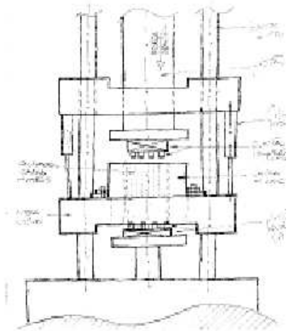

Fig. 1. Initial sketch of the design

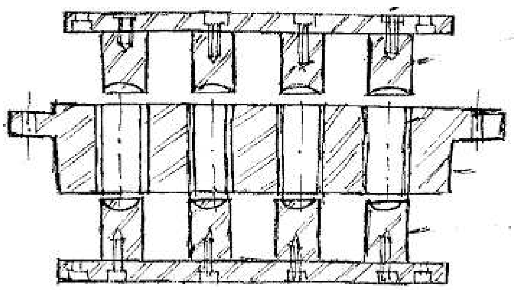

Fig. 2. Tooling sketch

II. Construction of a Model

A model of the system was constructed to test how the tooling shapes the ceramic spheroids of alumina by hydraulic pressing [3] - [4]. The tooling model with a single cavity is shown in Figure 3.

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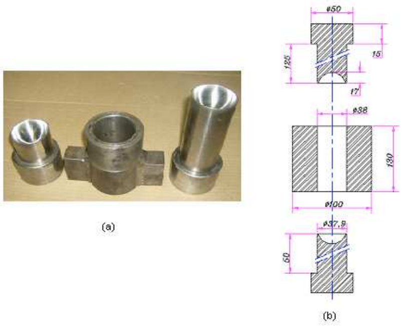


Fig. 3. Tooling model: (a) physical system; (b) schematic view

Powder pressing is very competitive because of its capability of producing pieces in their final or near final format, thus avoiding expensive finishing stages, or requiring less finishing work compared to other techniques [5] - [6]. This is possible because the piece becomes rigid already in its final shape. This means that the powder mass must be given a geometrical shape [7]. Thus, the powder is pressed against a die that reproduces an inverted form of the shape that is to be produced. When the mold is removed, the powder retains the shape [8] - [9]. Obviously the rigidity of the molded part is limited, but it should be rigid enough to be manipulated at later stages, until it is rigidified by thermal treatment [10] - [11] - [12]. In this way, using a manual hydraulic press (Figure 4) with a 400 kgf/cm^2 (39,226.4 KPa) capacity, the tooling model was placed in the appropriate position in the press, and the cylindrical cavity of the die was loaded manually. The amount of ceramic powder required, introduced in the cavity, varied until it reached the condition needed to obtain a 38 mm diameter spheroid raw, i.e., without sintering, and its was conceived by trial and error. After a few attempts, the ideal cavity loading condition was achieved, 58 grams of mass. In the compaction. The same same compaction pressure used to press bricks for linings was also utilized, 120 kgf/cm^2 (11,767.92 KPa), since thus we would ensure the conditions required to perform the work function, because both the lining brick manufactured by hydraulic pressing and the spheres produced by isostatic pressing have the same technical characteristics.

In Figure 5 we have a representation of how the uniaxially shaped spheroid will look in the tooling model.

Fig. 4. Manual hydraulic press

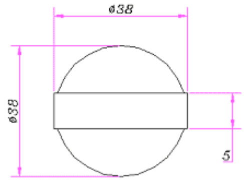


Fig. 5. Representation of the shaped spheroid in the model tooling

The main difference between the spheres produced in an isostatic press (Figure 6) and the new proposal for an hydraulic press (Figure 7), is that after hydraulic shaping, a kind of “collar” is formed on the spheroid. This occurs because there is a space between the upper punch and the lower punch at the time of shaping.

Fig. 6. Sphere produced by isostatic shaping

Fig. 7. Collar formed on the spheroid after hydraulic shaping

Table 1 shows the comparison of products obtained by the different processes.

TABLE I
COMPARISON OF APPARENT DENSITY AND WEAR OF THE SPHERES/SPHEROIDS OBTAINED BY THE DIFFERENT PROCESSES (MODEL)

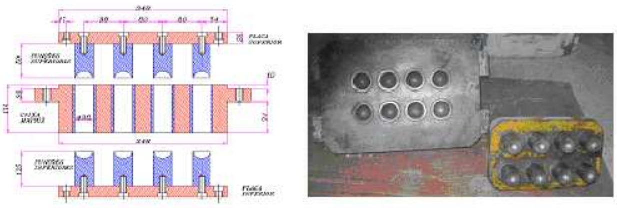
Description	Isostatic Shaping	Hydraulic Shaping (model)
Apparent density [g/cm^3]	From 3.58 to 3.64	From 3.60 to 3.64
Wear [%] (Mill test of 96 hours work)	From 8.0 to 10.0	From 8.0 to 8.8

III. Prototype Construction

After the excellent results obtained using the tooling model presented, it was decided to manufacture a prototype for the industrial production of ceramic spheroids in alumina using hydraulic shaping.

The same physical characteristics of the outer part of the die box in bricks (Figure 8) for the spheroid one, preserving the loading method, fixing the die box and expelling the pressed material were maintained. Since the test had already been performed using the model created, a die box for spheroids was made as shown in Figure 9.

Fig. 8. Die box of alumina bricks for linings



(a) (b)

Fig. 9. Tooling for hydraulic shaping of alumina spheroids: (a) schematic view; (b) physical system

The prototype tooling behaved as planned, and basically, because it was a prototype, the loading of the mass into the die box sleeve was performed using a cup, and actuation of mechanical movement (beginning of pressing) was done manually by a starter button to begin the shaping process. This was done to ensure the necessary conditions for automatic pressing by the press after the *start*.

Table 2 shows the apparent density and wear results of the sphere obtained in isostatic shaping compared to the spheroids formed using the hydraulic method of the prototype.

TABLE II
COMPARISON OF APPARENT DENSITY AND WEAR OF THE SPHERES/SPHEROIDS OBTAINED USING THE DIFFERENT PROCESSES (PROTOTYPE)

Description	Isostatic Shaping	Hydraulic Shaping (prototype)
Apparent density [g/cm^3]	From 3.58 to 3.63	From 3.60 to 3.63
Wear [%] (Mill test of 96 hours work)	From 8.0 to 9.5	From 8.0 to 8.9

Figure 10 shows the spheroids already shaped in the prototype before their removal from inside the die box sleeves.

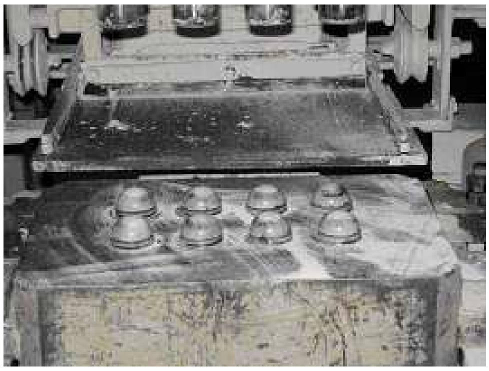


Fig. 10. Spheroids formed in the prototype

Figure 11 shows the difference between a spheroid produced with the new technology by hydraulic shaping and a standard sphere produced by isostatic shaping. In both cases, the spheroids have already been sintered.

Fig. 11. Shaped and sintered spheroids (left) hydraulic shaping; (right) isostatic shaping

IV. Project Discussion and Considerations

After the spheroids formed by this new method were obtained, everyone who followed the development was pleased at the more spherical shape of these grinding bodies compared to the spheres formed by isostatic pressing. Technical comparisons of the two bodies were also performed, showing results that were equal to or superior to the previous method.

What still needs to be improved in the esthetics of these spheroids is the “collar” which is seen after forming, since at first sight it awakens suspicion, because it appears to be fragile. But this is overcome by proving the work done by these bodies when used.

Comparing the production between hydraulic shaping and isostatic shaping, it was found that the volume of production with the new method is superior to the traditional 20 % to 25%, since the level of complexity of mass loading in the cavities, the pressing time and extraction of the formed pieces in the isostatic modality is much higher, which leads to a smaller amount produced.

V. Conclusion

Considering the objectives, these were the main conclusions:

- For the hydraulic shaping of ceramic spheroids in alumina, the method proposed in this case, the same powder could be used as the one employed to manufacture alumina spheres obtained by isostatic shaping, and in the alumina bricks for linings. It was not necessary to change the formulation and its production process;

- The tooling developed in the industrial hydraulic presses is easy to adapt;

- The same burning curve of the product originating in the traditional form was maintained when sintering the spheroids of the methodology proposed;

- The spheroids obtained with the proposed tooling presented the same or a better performance than those formed in the traditional isostatic modality. This was proved by spheroid wear and density tests, which are considered essential. On this occasion they proved to be within the standards required to perform their function;

- It was also concluded that although the physical shape of the spheroids formed by the proposed tooling presented a kind of "collar", this did not influence the final product obtained which benefited from these grinding bodies.

It should be mentioned that this methodology may be changed as regards fixation of the die box and the lower and upper punches due to the different structural characteristics of each equipment, but the principle to obtain the shaped piece can be the same described in this article.

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