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A short review on the effect of compaction pressure on properties of materials obtained via powder metalurgy

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ABSTRACT

The compaction pressure is a parameter that plays an important role not only on compaction process itself, but also in post-processing (sintering, post-sintering, etc.). The compacted powder is kept together mainly by adhesive forces, which magnitudes influence the properties of the material obtained via powder metallurgy (PM) route. Therefore, this paper presents a short review on the effect of compaction pressure on properties of materials obtained via PM. This includes the state of the art on this topic, displaying the research evolution of this area. The review starts with definitions and concepts about PM and compaction pressure. The following section presents the progress on research about the relationship between compaction pressure and material properties. The next section shows a discussion about possible tendencies and opportunities of research in this growing area. The final section of this paper corresponds to the conclusions drawn.

Keywords: Compaction pressure, Material properties, Powder metallurgy.

1 INTRODUCTION

Powder metallurgy (PM) consists of a manufacturing process that transforms a solid pure metal, alloy or ceramic in terms of dry particles into a component or a product in its definite shape with mechanical properties that eventually allow it to avoid post-processing (THÜMMLER; OBERACKER, 1993).

In the context of PM process, compaction subprocess plays an important role because the pressure imposed to the powder is one of the most influencing input data to a great sort of properties (MAHDI *et al*., 2016). Powder mixtures must be turned into blends, which should have capability to adequately flow concomitantly with high green strength, and compressibility.

Its importance requires specific tooling and apparatus to run the process, which must have strength enough to resist the acting stresses, deformations, and geometric features to run the entire process. Parameters related to the interface between tooling and powder influence directly and/or indirectly the compaction stage (BREWIN *et al*., 2008).

In the case of post-processing (sintering, post-sintering, etc.), in which the highest density is desired, the uniformity of the compaction mainly determines the accuracy of the sintered part. The required properties must be achieved without significant dimensional changes. With the aid of compaction modeling (CM) theory, stresses can be calculated, and properties can be estimated to simulate the resulting product even without performing experiments. Therefore, CM is also relevant to optimization of green properties in the context of the geometric characteristics. The most relevant items to be considered in CM are: (a) properties of the green part; (b) interaction between tooling and powder; (c) kinematics of pressing; (d) powder properties (BREWIN *et al*., 2008).

One of the characteristics that influences the capacity of compaction is the powder granulation. For example, when the powder is fine enough and has a rounded geometry, it flows more easily. These characteristics imply in a more uniform powder distribution, and deformation behavior that fills the voids. This induces a higher density of the compacted part.

Other characteristics that deserve attention is related to fill and flow analyses. This is mainly performed by using metallography or simulations. This aims at optimizing the kinematics of filling process and the die design. Furthermore, the stress state is commonly non isotropic (complex).

In what refers to defects associated to inadequate compaction pressure, some can be here highlighted: (a) tooling failure due to overloading or fatigue; (b) cracks from unloading and spring back effect; (c) shear cracks in the die; and (d) heterogeneous density distribution.

In the next section, the state of the art on the effect of compaction pressure on properties of materials obtained via powder metallurgy route is presented.

2 STATE OF THE ART ON THE EFFECT OF COMPACTION PRESSSURE ON PROPERTIES OF MATERIALS OBTAINED VIA POWDER METALLURGY

The aluminum alloy A6061 was obtained from (25, 60, 100, mix) μm. Three specimens of each granulation were obtained, corresponding to 5, 7, and 9 tons of compaction pressure. The sintering was performed at 552°C in twenty minutes of holding time. All the groups subjected to the experiment presented an increased compression strength when the compaction pressure was increased (134 MPa). (MAHDI *et al*., 2016).

Magnesium and aluminum, which presents difficulties in sintering because of their high chemical reactivity, are subjected to a warm compaction method. The effect of compaction temperature (301 to 423 K) was observed on the sinterability. The sintering was carried out in argon environment, in which two phenomena concomitantly occur: (a) the increasing compaction temperature increased the contact between the particles; (b) plastic deformation of the particles favored the densification (IWAOKA; NAKAMURA, 2011).

Copper samples were produced by powder metallurgy and sintered to verify the effect of compaction pressure on microstructure, density, and hardness. Pressures of 500, 600, 700, and 730 MPa were applied on powder, and 750°C for 1.5h were the main parameters of sintering. The experiments concluded that the increase in the compaction pressure induces the reduction of the porosity (DIXIT; SRIVASTAVA, 2018).

PM route was selected to produce copper-tungsten carbide composite applying compaction pressures from 100 to 600 MPa to verify properties and microstructure. Electrical conductivity, hardness, and density were measured according to the pressure applied, resulting in their progressive increase as the compaction pressure gradually increases (MAHANI; ZUHAILAWATI, 2013).

Sintered iron powder magnetic and density properties are reported (BAGLYUK *et al*., 2009). For the condition of porosity higher than 6.5%, the porosity itself is the main parameter that influences the magnetic flux density of the sintered. For values lower than 6.5%, the residual strain is the most influencing factor.

Fe-2.5Ni-0.5Mo-2Cu-0.4C, obtained via PM at high velocity compaction in a lubricated die wall, is studied. As the velocity and die wall lubrication are increased, the sintered density, green density, and force to start and conduct the process are also increased (LIU *et al*., 2020).

Ti6Al4V powder was cold compacted at several pressures to be sintered at 1200°C with a holding time of 2 hours. A higher strength was associated with a higher compaction pressure. A comparison with other Ti powder compacts with the same porosity range presented higher strength. This is manly due to failure in interparticle bond regions, which could be observed in the microscope (GÜDEN *et al*., 2007).

Al-6Cu-5Zn alloy was obtained by different PM conditions, with pressures of 200, 400, and 600 MPa, and sintering. Temperatures of 410, 560, and 615°C were set to sinter the samples in a nitrogen environment. At 410°C, for low pressure (200 MPa), no diffusion was verified, while for 400, and 600 MPa diffusion has partially occurred. At 560°C, liquid phase sintering started to appear in small regions. At 615°C, liquid phase sintering effectively occurred, however with better results for the compaction pressure of 600 MPa (LEE; AHN, 2015).

Al6061 was obtained by PM route applying values of compaction pressures of 300, 340, 380 MPa. Sintering was conducted under 450°C for half an hour with argon environment. The microstructure revealed that the highest compaction pressure corresponded to the lowest porosity, to the lowest wear rate, to the highest hardness (ALAMGIR; SIDDIQUE, 2017).

The microstructure and properties of Ti-1Al-8V-5Fe (Ti-185) were analyzed under several compaction pressures. By observing the results from the experiments, yield strength, hardness, green density, sintered density, and densification rate increased with the increase in the compaction pressure (ZHANG *et al*., 2019).

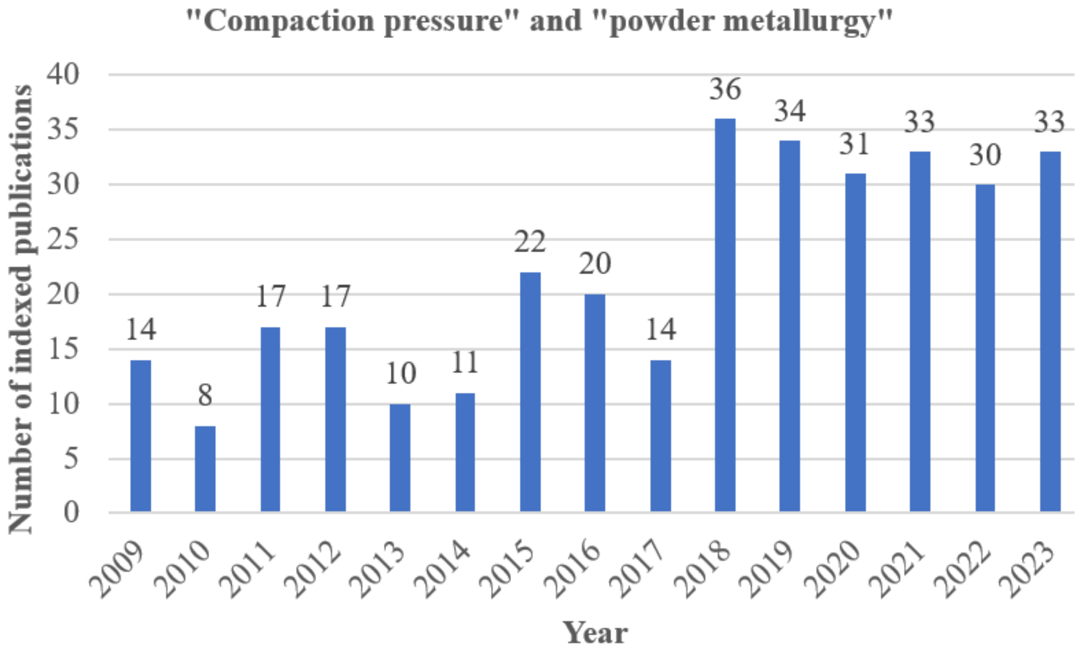
0, 5, 10, 15 and 20 wt% lead powder mixtures and Aluminum-10 wt % Fly Ash were compacted in the range [200, 400] MPa. The spring back effect, green density, and ejection pressure increased with the increase in compaction pressure. On the other hand, porosity and ejection pressure decreased as the compaction pressure was increased (REDDY et al., 2010).

3 DISCUSSION

This section addresses possible trends and opportunities in the effect of compaction pressure on properties in PM route by showing the bibliometric research extracted from (CAPES, 2024).

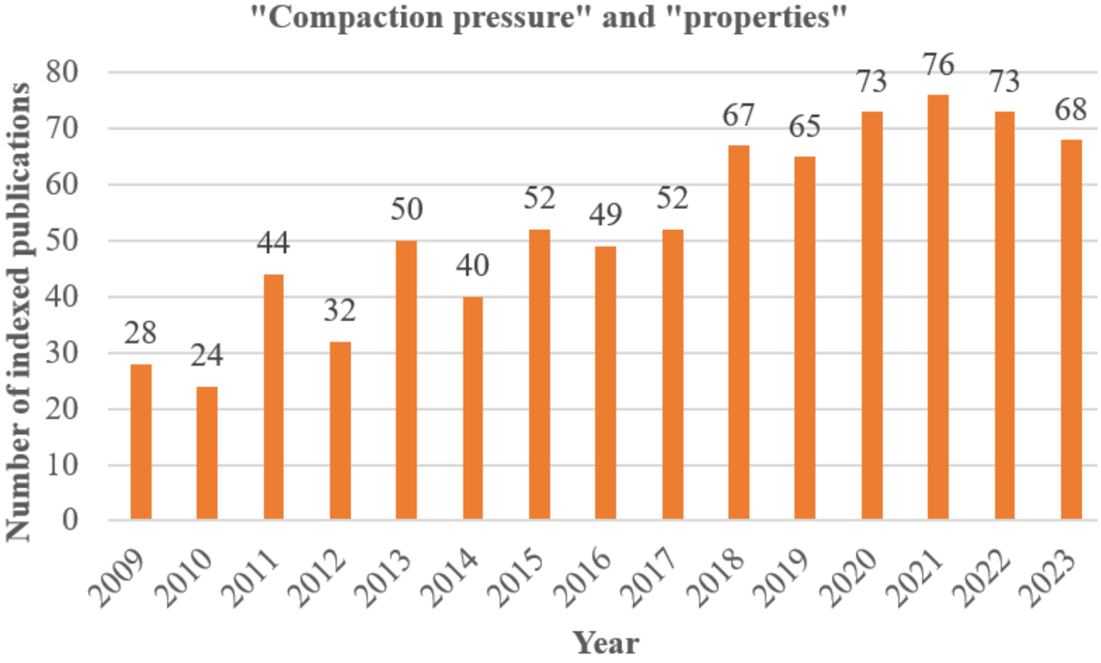
Aiming at verifying the relevance and tendencies of the search words and identifying research gaps and/or opportunities to contribute to the area, bibliometric research was then performed, which results are shown in Fig. 1 and Fig. 2). Both plots refer to the period between 2009 and 2023 and correspond to the number of indexed publications that include the selected research words in CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, 2024) information repository. “Compaction pressure and powder metallurgy”, and “compaction pressure and properties” were the selected searched words, which are presented in Fig. 1, and Fig. 2, respectively.

Figure 1: Indexed publications from 2009 to 2023 with “compaction pressure” and “powder metallurgy” in the title or abstract fields.



Source: CAPES, 2024.

Figure 2: Indexed publications from 2009 to 2023 with “compaction pressure” and “properties” in the title or abstract fields.



Source: CAPES, 2024.

According to Fig. 1 (“compaction pressure” and “powder metallurgy”), the number of indexed publications starts in a lower level and stabilizes in a patamar until 2017. The behavior of the plot increases to a higher level from 2018 to 2023. In just one year (comparing 2018 with 2017), there was an increase of approximately 157% in the number of publications. Even in the face of the possibility that the number of publications is not growing, a higher level of publications (*plateau*) was reached.

Less abrupt than the plot of Fig. 1 is the behavior of the number of indexed publications per year shown in Fig. 2 (“compaction pressure” and “properties”). In this case, for example, the number of publications doubled between 2010 and 2013. From 2010 to 2018, the number of publications increased approximately 179%.

By analyzing both Fig. 1 and Fig. 2, it can be estimated that there were reaching levels separated by specific time intervals and that the next growth in these areas of research tends to occur after passing the last level, which can be found at the beginning, in intermediate phases or at the end of its construction.

4 CONCLUSIONS

This paper presented a short review on the effect of compaction pressure on properties of materials obtained via powder metallurgy. This included a brief description about the referred research area, as well as the progress made, tendencies, and possible research opportunities. The main concept relies on the fact that if the compaction pressure increases, the porosity decreases. Based on this, increasing the compaction pressure: (a) compaction strength increases; (b) electrical conductivity increases; (c) hardness increases; (d) magnetic flux increases; (e) force to start and conduct the compaction process increases; (f) Wear rate decreases; (g) yield strength increases; (h) spring back effect increases; (i) ejection pressure increases.

The number of indexed publications were compared in a fifteen-year period (from 2009 to 2023) in view of the most pertinent research words, providing the analysis of tendencies, growth rates, and contribution opportunities of each research word.

Therefore, based on the information reported in this paper, although many contributions have been made to expand the knowledge boundaries related to the effect of compaction pressure on properties of materials obtained via powder metallurgy, this research area is still promising due to its large scope in terms of feasible experiments and combination of elements.

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