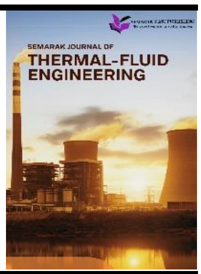
Semarak Journal of Thermal-Fluid Engineering

Journal homepage:
https://semarakilmu.com.my/journals/index.php/sjotfe/index
ISSN: 3030-6639



Design and Development of Small Milling Machine for Powder Metallurgy Application

Md.Nor Anuar Mohamad[1], Wan Nur Azrina Wan Muhammad[2,*], Tuan Nurul Ain Tuan Kamaruddin[2]

[1] Department of Mechanical Engineering, Fakulti Kejuruteraan Mekanikal dan Pembuatan, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat Johor, Malaysia
[2] Department of Aeronautical Engineering, Fakulti Kejuruteraan Mekanikal dan Pembuatan, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat Johor, Malaysia

ARTICLE INFO

Article history:
Received 3 December 2024
Received in revised form 9 December 2024
Accepted 15 December 2024
Available online 31 December 2024

Keywords:
Small ball milling; powder milling; milling process

ABSTRACT

The process of powder metallurgy milling, which reduces solid metal to fine particles to improve its properties, is the subject of this study. The objective is to determine the RPM and time relationship for efficient grinding and to fabricate a small milling machine for powder applications. Particle size, time, and homogeneity requirements are examined. The milling machine is designed in SolidWorks. Aluminium chips are used for test runs. Particle sizes are evaluated at different times using an optical microscope. The Arduino control system and a 12 V DC motor are used. Longer grinding times consistently result in smaller chips. Based on the result, the average of the 5.79 mm chip size measurements made before milling was determined. Following the milling process, the sizes were 0.75 mm at two hours, 0.51 mm at four hours, and 0.27 mm at six hours. The study shows that the efficiency and particle size distribution of powder metallurgy milling can be improved using a small machine with a fixed bar and different types of grinding media. For effective milling, it is crucial to maximize mill rotation, as shown by critical speed analysis. To sum up, the study effectively creates a small milling machine for use in powder metallurgy procedures.

1. Introduction

A manufacturing process called powder metallurgy (PM) includes sintering, mixing, compression, and powder milling. It has advantages like producing materials with homogeneous microstructures and modifying sintering parameters for alloy properties. PM is adaptable, working with a range of materials, shapes, and techniques [1]. Ball milling is a shear force dominated process that uses rotating cylindrical containers filled with powder and steel balls to continuously reduce particle size through impact and attrition [2]. Inefficient milling techniques present a challenge to industries, resulting in inconsistent outcomes and resource waste. It is necessary to have a small, effective milling machine for powder metallurgy to improve the process, use less energy, and boost productivity [3]. Powder composition is significantly influenced by several variables, including

* *Corresponding author.*
E-mail address: wazrina@uthm.edu.my

https://doi.org/10.37934/sjotfe.3.1.1320

container size, milling temperature, powder-to-weight ratio, mill type, speed, and time. These elements are interdependent; for instance, the type of mill, the size of the grinding media, the temperature, and the ratio of powder to ball all affect how long the mill should run [4].

In small scale or laboratory settings, the usual ball to powder weight ratio is approximately 10:1, with 10g of powder being used [5]. It is possible to process almost any material, including low-dimensional structures, organics, pharmaceuticals, and metals. Ball milling can be used to create ceramic materials directly or indirectly [6]. Solid solutions can be significantly saturated compared to thermodynamic equilibrium [7]. Grinding media with standard density are usually porcelain balls, while high density balls have a higher alumina oxide content and are more abrasion resistant. Milling materials' basic qualities include their mass and size, ware rate, influence on particle breakage rate, and energy efficiency of the grinding process [8,9]. A typical 5 m diameter ball mill uses approximately 3 to 4 MW of power and has relatively low energy efficiency. Even slight improvements in efficiency may provide significant economic and environmental benefits [10]. When two grinding balls collide, a small amount of powder gets trapped between them.

Around 1000 particles with an aggregate weight of roughly 0.2 mg are typically trapped during each contact [11]. As the particle size reduces, so does the milling efficiency. It is expected to stop once the grain size reaches a certain limit. This is due to the force provided to the powder as two milling balls approach each other, causing the slurry to flow away from the balls before they collide. Smaller particles are more likely to get stuck in the slurry flow [12,13]. This study aims to fabricate a small milling machine that can be used for powder milling applications and to determine the relationship between milling speed and the time needed to ensure the effectiveness of grinding. An optical microscope will be used to conduct a time analysis and test the milling machine's performance using aluminium chips to determine the particle size after milling at 181 RPM.

To address inefficiencies in conventional ball milling methods, this study integrates novel design features to improve energy efficiency and grinding performance. The proposed small milling machine incorporates a two-axis rotation mechanism, allowing for enhanced cascading and shearing effects, which are crucial for particle size reduction and uniform distribution. Furthermore, the utilization of mixed grinding media optimizes energy transfer by combining the impact force of larger balls with the surface contact area provided by smaller balls, mitigating issues such as agglomeration. This research provides innovative insights into the interdependence of key milling parameters, including rotational speed, grinding time, and grinding media configuration. By systematically analyzing these variables, the study ensures consistent and scalable results, making it particularly relevant for laboratory and small-scale powder metallurgy applications. Additionally, the findings address the challenges of balancing operational complexity and energy efficiency.

2. Methodology

Small milling devices typically consist of a cylindrical vessel installed on suitable bases at both ends, allowing the vessel to rotate around the centre axis. The mill is powered by an DC motor positioned at the base of the little mill and operated by a long, high-density mild steel shaft. In our model, a gear pulley system is used, with one connected to the motor, the primary power source, and the other attached to the shaft rotating the cylindrical vessel. Because a critical speed is required to grind the mill, the motor's velocity is reduced using the gear ratio. The milling process occurs during rotation when the mill is charged with the starting material and the grinding media because of kinetic energy transfer from the moving grinding media into the ground material [14]. The balls utilized as the grinding media range in diameter from 3 to 5 mm. To grind small amounts of metal into powders, a mill with a feature that indicates a very quick rotation is needed. Along with the mass, density, and ball size distribution of the grinding media balls, other factors are considered, including the mass, volume, hardness, density, and size distribution of the material charged in the mill [8]. The impact of the grinding environment on the generation of fine particles and the width of the particle size distribution generated in a small mill. As a result, measurements are made to determine whether powder has been produced. Figure 1 shows that the system of the small milling machine works, and this prototype used an open system.

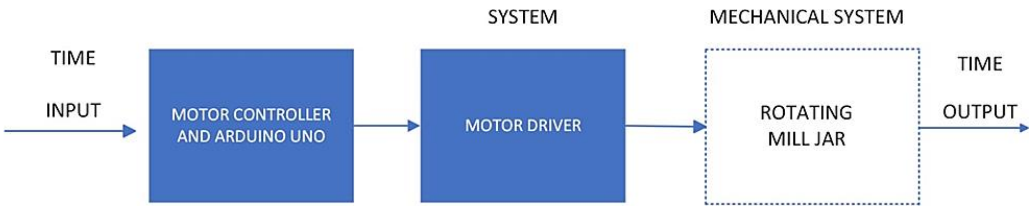


Fig. 1. Block diagram of the small milling machine for powder metallurgy

The components were then put together in this experiment to create one system. The foundation of the entire system was designed and constructed. Purchases were made for the engine, gear pulley system, stainless steel balls, and mill jar. The following tools and supplies made up the setup (Table 1):

Table 1
List of apparatus and materials used to fabricate small milling machine

Description (m)	Amount (unit)
62 mm inner diameter of mill jar	1
8 mm inner diameter ball bearing	2
53.32 outer diameter flat gears	3
15.08 mm of outer diameter small gear	4
Set of 3 mm, 4 mm and 5 1 mm high-density stainless-steel balls	1
Pulley belt	2
12 V DC Geared Motor	1
1 metres of wooden board	1
Packet of screws	5
8 mm outer diameter stainless steel shaft	2
Tachometer 1	1
Arduino Uno Rev 3	1
Potential meter 1	1
Power source 1	1
Motor driver 1	1

It is widely acknowledged that the relationship between the critical rotation speed and the jar's diameter and ball radius is linear. Show, however, that the critical rotation speed varies considerably on the percentage of jars that contain balls and approaches a number asymptotically as the percentage of jars that contain balls gets closer to one [12]. Eq. (1) provides the key speed necessary for the jar.

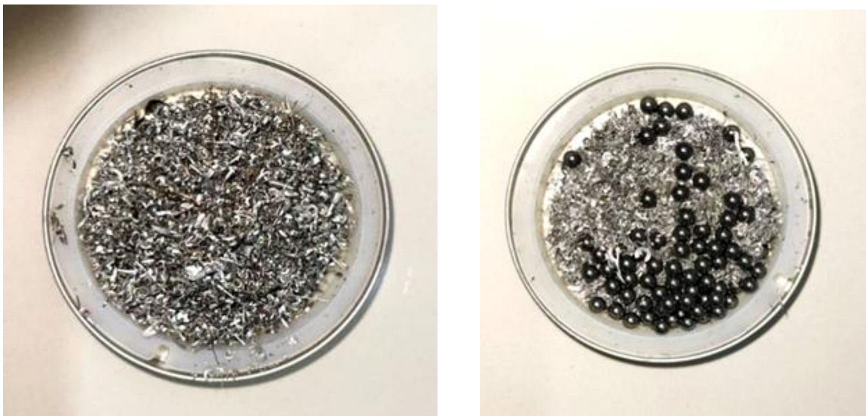
$$C.S = \frac{265.45}{\sqrt{I.D - d}} \quad (1)$$

C.S. stands for critical speed, I.D. for internal jar diameter, and d for media size. Every measurement is in inches, and the speed is in revolutions per minute (RPM). Determining the optimal jar RPM typically takes between 55% and 75% of the essential speed [15].

3. Results

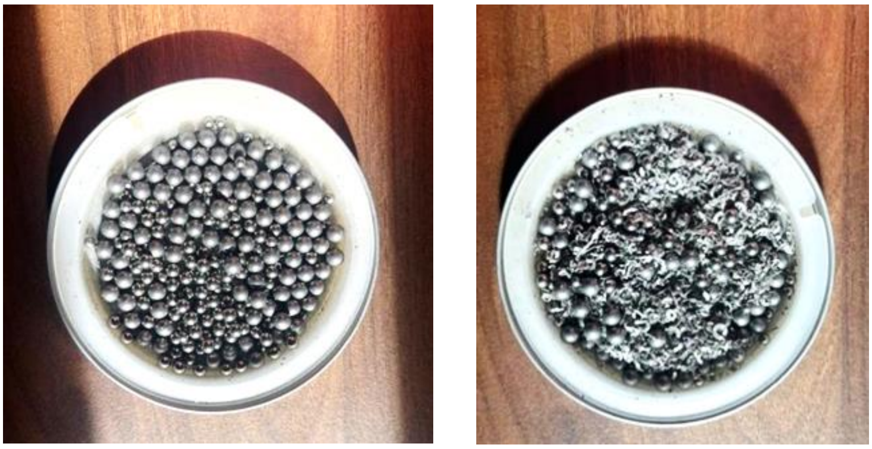
Balls were inserted into one-quarter of the mill jar for the milling tests, and aluminium chip inserts were inserted into the other half, leaving the other quarter vacant for the cascading effect. Because of the different diameters of the grinding balls, the theoretical RPM of 163.46 was raised to 181 RPM to achieve cascading.

The material is shown in Figure 2 both before and after a two-hour steel ball grinding session. Even though the first stage simply used a single-size steel ball (Figure 2(a)), it was only partially effective, exposing bigger particles and suggesting opportunities for development. The technique was improved by switching to a different-sized grinding medium, as shown in Figure 3. This addressed agglomeration and uneven grinding, leading to a more efficient milling process [16].



(a) (b)

Fig. 2. Experiment for the first trial (a) Before (b) After grinding



(a) (b)

Fig. 3. Experiment for the second trial (a) Various of stainless-steel ball (b) Mix of stainless-steel ball and chip

Different sizes of grinding media were shown to have significantly improved grinding in the extended second test. Improved efficiency and better particle distribution are seen in Figure 4. The lack of grinding media demonstrated the effectiveness and supported the significance of the selected combination. To optimize the milling process even more, Figure 5 illustrates introducing a fixed bar at a certain period that acted as a catalyst to increase impact and shear forces for the reduction of particle size.

Fig. 4. Result from the second trial

Fig. 5. Bar fixed were added into the mill jar

Figure 6 showed a considerable improvement in particle breakup due to the added bar, which increased grinding efficiency. The six-hour operation showed that longer grinding durations with more media lead to higher energy efficiency for breaking up particles in the mill jar [13]. In summary, achieving the ideal balance in a customized procedure is similar to optimizing the relationship between RPM and grinding time. Through trial and error, it is determined that the RPM and grinding time of the milling machine must be adjusted for optimal efficiency. Achieving the required particle size and uniformity by careful balancing and using the ideal time to RPM ratio (163.46 RPM) determined by theoretical calculations based on Eq. (1). Results for this study were obtained with the different parameters of the mixing time. Figures 7 and 8 shows the samples before and after milling, respectively, using an optical microscope with 0.7X magnification.

Fig. 6. The final product of the grinding process

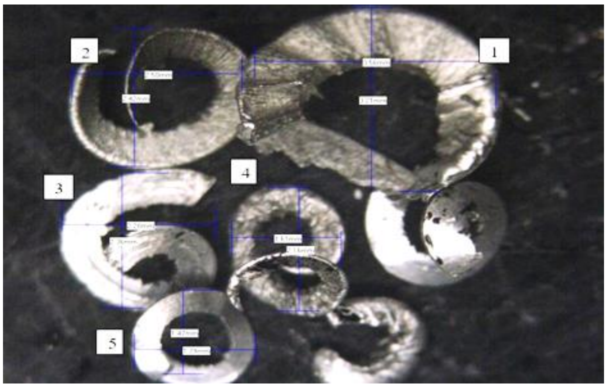
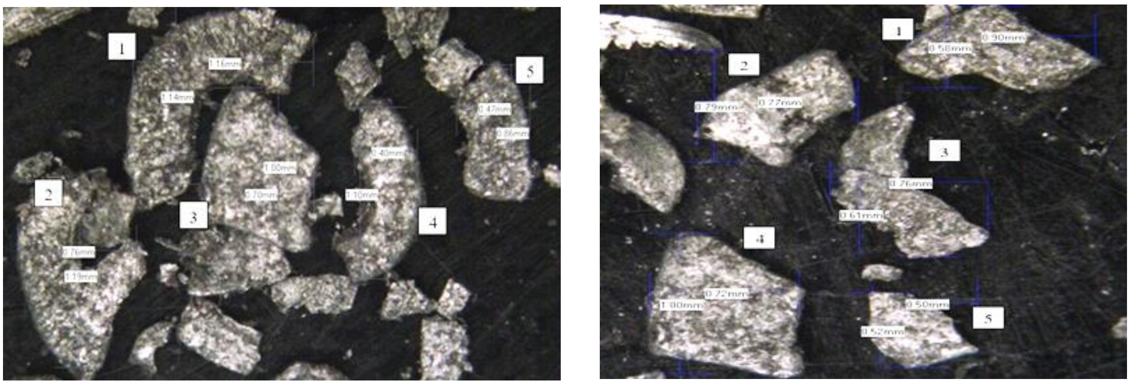
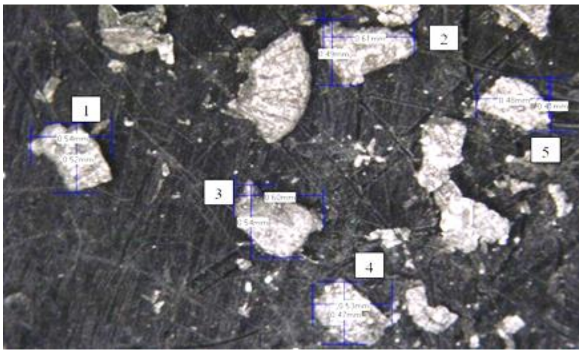


Fig. 7. Microstructure before milling



(a) (b)



(c)
Fig. 8. Microstructure after milling (a) 2 hours (b) 4 hours (c) 6 hours

Figure 9 illustrates a consistent reduction in particle size as milling progresses, demonstrating the efficacy of the designed small milling machine in powder metallurgy applications. The particle size decreases significantly from 0.75 mm² at 2 hours to 0.51 mm² at 4 hours and to 0.27 mm² at 6 hours. This trend aligns with findings in mechanical alloying and powder metallurgy studies, which report that extended milling times result in repeated fracturing and cold welding of particles, ultimately reducing their size [17-19]. The observed particle reduction aligns with findings in mechanical alloying and powder metallurgy studies, which report that extended milling times result in repeated fracturing and cold welding of particles, ultimately reducing their size. the graph's results suggest that the milling machine's design supports consistent energy transfer to the powder particles, a critical factor in achieving efficient comminution. The continued size reduction over time indicates the optimized configuration of the milling machine, ensuring energy input sufficient to overcome material hardness and promote particle deformation and fracturing [20].

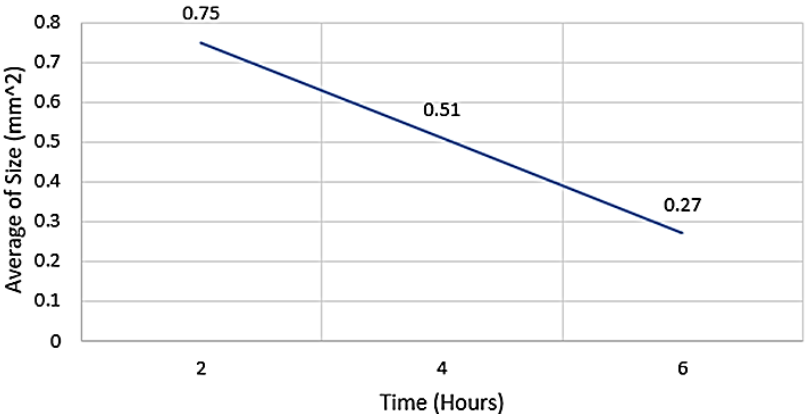


Fig. 9. Graph average particle size (mm^{-2}) against time (hours)

4. Conclusions

These studies clearly show that the two primary goals of the small milling machine design were achieved. The first objective was accomplished with success which is to fabricate a small milling machine that can be used for powder milling application. The small milling machine can completely grind the aluminium chip into powder through a test run. The electrical system is also working smoothly based on the testing done. The study's second objective is to determine the relationship between RPM and the time needed to ensure the effectiveness of grinding is achieved. The longer the grinding process takes, the more motion of particle breakage will occur as more grinding media will send more energy to crush the aluminium chips. The kinetic energy provided to the grinding media and the processed materials is directly influenced by the rotational speed of the milling machine's rotating parts, like the ball mill. Based on the result, the average of the 5.79 mm chip size measurements made before milling was determined. Following the milling process, the sizes were 0.75 mm at two hours, 0.51 mm at four hours, and 0.27 mm at six hours.

Acknowledgement
This research was not funded by any grant.

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