Design and Testing of UMM Vertical Ball Mill (UVBM) for producing Aluminium Powder

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Abstract. UMM Vertical Ball Mill (UVBM) was intended to be the apparatus to produce metal powder with superior characteristic in production rate while retaining good quality of metal powder. The concept of design was adopting design theory of Phal and Beitz with emphasis on increasing of probability of success in engineering and economy aspects. Since it was designed as vertical ball mill, a new way to produce powder, then it need to be tested for the performance after manufactured. The test on UVBM was carried out by milling of aluminium chip for 5 (five) different milling time of 0.5 hours, 1 hour, 3 hours, 5 hours and 7 hours, and the powder product then be characterized for it morphology and size using Scanning Electron Microscope (SEM) and Sieve. The results of the study were the longer of the milling time, the finer of the powder. From the test results of SEM, the morphology of the powder with 5 variations of milling time were most of the powder in form of flake (flat), small round and angular (irregular). The distribution of powder size was best obtained on the variation of milling time 3 hours, 5 hours, and 7 hours with percentage of 200 mesh in size of 22.14 %, 64 % and 91.25 % respectively.

1. Introduction

Powder metallurgy is a process in transforming metal powder or its alloy with certain size and distribution into product without melting process [1]. Aluminium is categorized as light material and has good corrosion resistant, good conductor properties and other superior properties compared to other. Because of its popular application, it is one of the materials available in metal powder stock. Ball mill (BM) is one of the instruments / apparatus to produce metal powder. In terms of the capability, the powder may have micrometers or even nanometers in size. The mill consists of a vial (cylinder tube) to contain the materials and crusher balls. The mill then is rotated or vibrated in high frequency, depend on the necessity. It makes the materials which are trapped between ball crusher and vial wall will be deformed caused by crushing action between ball and vial wall. The deformation of material makes fragmentation of material structures to smaller structure [2].
In industry, BM has important role in industry to produce powder both for big and small scale industry. To produce fine metal powder, it always need a crusher which suitable with its function and design. There are many type of ball mill to produce powder, one of them are Electric Discharge Assisted Mechanical Milling (EDAMM). This type of ball mill combined ball mill action and electric discharge to synthesize and process metal by promoting rapid transformation of freshly fracture particles and ions associated with the generated dusty plasma. Therefore, it works on the principle of interface transformation rather than diffusional transformation. In was proven that ball mill was able to produce powder both SiC and HfCN [3] [4].

In this research, we designed and tested of indigenous design and less advance of UVBM to produce aluminium powder with further goal to produce micro or even nano in size. This effort is important because nano size particles have taken over the material for drugs to be more efficient; cellular phone and laptop which is smaller in size and more efficient; and the car which more eco-friendly, etc.

2. Material and Methods

2.1. Aluminium
Aluminium was founded by Sir Humphrey Davy in 1809, it was first reduced from its ore by H.C. Oersted in 1825. Aluminium also found in alloyed metal to increase its mechanical properties by adding Cu, Mg, Si, Mn, Zn, Ni. The addition also makes the alloys have good corrosion resistant, wear resistant and low expansion coefficient [5]. There are many application of aluminium powder such as for rocket propellant, personal hygiene equipment, boosting reliability of computer, refine several exotic materials, as frame materials for car and aircraft to save weight. Its application includes the parts for structural and non-structural one and is the key for developments of aluminium alloys [6].

2.2. UVBM design and testing
A flow process of design and testing of UVBM is presented in figure 2.
3. UVBM

3.1. Drawing of UVBM
The design process of UVBM was conducted by adopting Phal and Beitz design methods [7] and the steps were depicted in Figure 2.a. The result was depicted in the drawing as presented in Figure 3.

![Flow chart of (a) design of UVBM and (b) testing of UVBM.](image)

Figure 3. A 3D CAD drawing of assembled UVBM.

Figure 3 depicted the designed UVBM with the dimension as follows.
- Ball mill tube was manufactured from stainless steel with dimensions of 180 mm in height, 100 mm in diameter, and 10 mm in thickness.
- Ball crusher has diameter of 16 mm.
- 220 V electric motor (Aliens) with 1400 rpm, reduced to 60 rpm by a pulley drive.
- Pulleys was manufactured from cast iron with dimensions of 13 mm, 78 mm, and 300 mm.
- V-belt was type A.
- Shaft was manufactured from cast iron with 12 mm in diameter.
- And frame was manufactured from steel box with dimension of 30 x 30 x 2 mm.

3.2. Testing of UVBM
After manufactured, a series of testing was performed on UVBM to examine the capability of ball mill to produce metal powder. As shown in Figure 2b, the test was conducted by milling aluminium chips for milling time of 0.5 hours, 1 hour, 3 hours, 5 hours, and 7 hours. The powder products then were examined by Scanning Electron Microscope (SEM) and sieving to reveal its morphology and its size. Data analysis then was conducted to make conclusion on its capability in producing metal powder in size distribution, morphology, and time production.

3.3. Characterization of powder

3.3.1. Morphological analysis by SEM. Figure 4 shows SEM microphotograph of grinded aluminium alloy (powder) by varying of milling times of 0.5 hours, 1 hour, 3 hours, 5 hours, and 7 hours. It was shown that most of the powder is in flake form and small fraction has circular, oval or irregular shape. In time variation of 0.5 hours, it can be seen that powder size is bigger and coarser than other time variation and mostly in flake shape. When the milling time getting longer, then the powder become finer. For milling time of 1 hour, the powder also became finer even though the shape still in flake. 3 hour of milling time variation made the powder became finer and other shape of powder, i.e. oval, circular and irregular, start to form. For last two time variations, i.e. 5 and 7 hours, the trend was also observed. More powder has finer size and the shape also varied in form of oval, circular and irregular shape. Also, it was observed that the thickness of the powder become thinner. The shapes for time variation of 5 hours were dominated by flake and irregular shape while for time variation of 7 hours was flake.

![Figure 4. SEM of aluminium powder with milling time variations of](a) 0.5 hours;(b) 1 hour;(c) 3 hours;(d) 5 hours; and (e) 7 hours.)
3.3.2. Powder size analysis by SEM.

![SEM images of aluminium powder](image)

Figure 5. SEM of aluminium powder for size analysis with milling time variations of
(a) 0.5 hours; (b) 1 hour; (c) 3 hours; (d) 5 hours; and (e) 7 hours.

Determination of powder size was conducted by SEM and sieving. Figure 5 show SEM microphotograph of aluminium powder with 5 milling time variations of 0.5 hours, 1 hour, 3 hours, 5 hours, and 7 hours. It can be seen that the size of powder was varied because of deformation effect caused by crushing force from crusher ball on aluminium. The tabulation of size of powder was given in Table 2 and the distribution was presented in Figure 6 above. From the table, the average size of powder from time variation of 0.5 hours, 1 hour, 3 hours, 5 hours, and 7 hours was 2028 µm, 753.6 µm, 259.6 µm, 158.4 µm, and 135.2 µm respectively.

| No. | Dimension of Powder (µm) |
|-----|--------------------------|
|     | 0.5 hour | 1 hour | 3 hours | 5 hours | 7 hours |
| 1   | 2400     | 494    | 556     | 147     | 89.2    |
| 2   | 2040     | 694    | 480     | 205     | 256     |
| 3   | 1900     | 1200   | 58      | 298     | 179     |
| 4   | 1950     | 562    | 112     | 58      | 52.5    |
| 5   | 1850     | 818    | 92.3    | 84      | 99.3    |
| sum | 10140    | 3768   | 1298.3  | 792     | 676     |
| mean| 2028     | 753.6  | 259.6   | 158.4   | 135.2   |
Graph in Figure 6 above shows mass percentage of metal powder for time varying of 0.5, 1, 3, 5, and 7 hours using 24 ball crusher of 16 mm. From the graph, it was shown that longer milling time gives finer size distribution. The centrifugal force act on rusher ball initiated by rolling ball mill’s vial makes balls fell into the powder in the top curvature of ball mill and gave crushing effects. This crushing effect made chips deformed and broke into powder. The longer of milling time made crushing effect become obvious and finer powder was produced in larger number.

Another method of ball mill, i.e. horizontal one [8], produced finest powder at 500 rpm, followed by 700 rpm and 450 rpm. The crusher ball which gave finest one were 5 crusher balls with diameter of 42 mm, then 8 crusher balls with diameter of 27 mm, followed by 6 crusher balls with diameter of 42 mm then 6 crusher balls with diameter of 27 mm, and the last ones were 4 crusher balls with diameter of 42 mm and 7 crusher balls with diameter of 27 mm, the results from this results is better as depicted in Figure 7 below. The main differences in the process was for vertical ball mill gave stronger crusher effect compare to horizontal one so that finer powder produced.

![Figure 7. Comparison between our research and Oksaria’s [8] one on percentage of sieving mass.](image)

4. Conclusion

Regarding the results of the research, it can be concluded that longer the milling time will give finer powder. The morphology of the powder shows that the dominant shape was flake followed by circular and angular (irregular). Milling time of 7 hour produced finest powder with flake shape. Size distribution of 5 (five) different milling time shows different trends and mainly caused by deformation on aluminium chip caused by crusher balls.
The size distributions of powder product are as follows. On 5 (five) variations of milling time, i.e. 0.5 hours, 1 hour, 3 hours, 5 hours, and 7 hours the average size were 2028 µm, 753.6 µm, 259.6 µm, 158.4 µm, and 135.2 µm. The finest size distribution was on 7 hours of milling time, followed by 5 hours and 3 hours with mesh 200 were 91.25%, 64%, and 22.14% respectively. Compared to another type of ball mill, i.e. horizontal one, the trend for size distribution were similar with the longer time to mill and more crusher ball employed will give finer powder but our design give faster time.

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