EFFECT OF HOLDING TIME ON MECHANICAL PROPERTIES OF RECYCLING ALUMINIUM ALLOY AA6061 THROUGH BALL MILL PROCESS

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ABSTRACT

The present study is aimed at investigating a Mechanical properties of the milled recycling Aluminium type AA6061 according to the change of the Holding time. Using the milling process and followed by a cold press forging process. In the study, the chip sizes of AA6061 that produced from high speed milling were used. Milling process was used to produce smaller particles of aluminium chips by the planetary ball mill. Mechanical property of the milled recycled chip of AA 6061 was studied. Three values of Holding time were taken (10, 15, 20) min. On the other hand, four types of particle size were chosen (25, 63, 100, mix) µm. The results were showing that the compression strength and Microhardness increased with increasing the Holding time until 20 min after that will be decreased due to the cracks will be taken place. It can be concluded, (20 min) is the best choice for all groups. On the other hand, the type DII (mix) was given the best result for Compression strength and Microhardness compare with others according to particle size.

Key word: Holding Time, AA6061, Ball Mill, Powder Metallurgy, Mechanical Properties.
1. INTRODUCTION

Total primary aluminium consumption in the world was off 50.2 million tonnes in 2013. China is the main user of the primary aluminium worldwide, with 23.2 mil tonnes in 2013. Europe (7.2 mil tonnes) and North America (5.5 mil tonnes) continue to be key regions for the consumption of primary aluminium [1].

In metal industries, waste and scrap metals that remain after manufacturing processes are chip and discards. These waste materials are reused by returning them to smelters. However, during melting processes of materials for recycling, many metals are lost due to occurring oxidation and costs of labour, energy and environmental protection expenditures [2, 3].

In the metal forming process, one of the most important parameters of metal products is the surface quality. Manufacturers always intend to improve the surface quality of metal products by employing all kinds of new technologies. As a main parameter of surface quality, surface roughness have been always a focused factor. On metal forming process, the surface roughness evolution depends on many parameters such as original surface Microstructures (grain size and texture) [4-6].

6xxx Al-Mg-Si alloys have been widely used in automotive body panels as main substitute materials for weight reduction. These alloys have a combination of good formability, good corrosion resistance and remarkable strengthening potential due to the formation of a large number of nano-sized [7]. Metals, compared to other materials, have the highest potential for systematic recycling due to: i) their high economic value, ii) the large scrap volumes, enabling economies of scale, as well as iii) their distinctive feature of excellent recyclability. Nevertheless, the contamination of the metal streams each time that re-circulates from residuals (alloying and foreign elements), especially those for which the removal from the melt is problematic, makes processing more difficult [8]. The chips deriving from the machining of semi-finished aluminium products are very difficult to recycle by conventional methods due to their elongated spiral shape, small size, surface contamination with oxides, machining oil, etc.. In the recent years, some alternative processes have been suggested to recycle aluminium chips by powder metallurgical techniques [9]. The milling process has a big influence on the characteristics of recycled aluminium chip, changing the spherical morphology of as-received chip during the milling process to flatten one due to particle deformation followed by welding and fracturing particles of deformed and hardened enough which allows to receive equiaxial particle morphology again [10].

The research work presented in this paper focuses on understanding the effect of the milling process of aluminium alloy chip and the influence of holding time on the obtaining a good compact sample for testing. Hence the Aluminium alloy compacted samples are compacted by hydraulic press. The value of pressure and mechanical properties are studied on the green compact which clearly shows the outcome of a good compact for testing.
2. EXPERIMENTAL SETUP

2.1. Material
Aluminium metal AA6061 is a silver-white metal that has a strong resistance to corrosion and malleable. Then, it has a widely using in the industry. It is a relatively light metal compared to metals such as steel, nickel, brass and copper with a specific gravity of 2.7 gm/cm$^3$, the mechanical properties for Aluminium AA6061 is shown in Table 1.

<table>
<thead>
<tr>
<th>Yield Strength (MPa)</th>
<th>Tensile Strength (MPa)</th>
<th>Density gm/cm$^3$</th>
<th>Hardness (Vickers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>260</td>
<td>2.7</td>
<td>107</td>
</tr>
</tbody>
</table>

Zinc stearate will be used as a binder to make the compaction process easier.

2.2. Chip production
Firstly, chip was produced by using CNC milling machine, type HSM (SODICK – MC430l), Feed rate (1100 mm/min), Depth of cut (1.0 mm), cutting velocity (345.4 m/min).

2.3. Chip cleaning and drying
Aluminium chip particles were cleaned by ultrasonic bath apparatus. Type Fritsch (ultrasonic cleaner labarette 17). The duration was 1 hour for each patch. After that, it is treated with acetone solution for 20 min. Finally, the drying process was used by furnace type (Kuittho Linn High Therm) for 1 hour.

2.4. Milling process
After that, the chip was milled by planetary ball mill type (Retsch PM100) under conditions of the speed (350 r.p.m) and time (20) HR. The ratio of ball to powder (r.b.p) was 20:1.

2.5. Aluminium particles sieving
Aluminium particles sieving was used by vibrator apparatus type (Fritsch analysette 3) with maximum interval time 5 second. Three sizes were classified (25,63,100) µm. Table 2 shows the classification of specimens according to particle size. So, table 3 shows the classification of specimens according to applied to the Holding time.

<table>
<thead>
<tr>
<th>All</th>
<th>Particle size (25 µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BII</td>
<td>Particle size (63 µm)</td>
</tr>
<tr>
<td>CII</td>
<td>Particle size (100 µm)</td>
</tr>
<tr>
<td>DII</td>
<td>Mix (78.5% (25 µm) + 21.5% (100 µm) )</td>
</tr>
</tbody>
</table>

Table 2 classification of specimens according to particle size
Table 3 classification of specimens according to applied to the Holding time

<table>
<thead>
<tr>
<th>Applied to Holding time (10 mins)</th>
<th>Mix (78.5% (25 µm) + 21.5% (100 µm))</th>
</tr>
</thead>
<tbody>
<tr>
<td>AII1</td>
<td>CII1</td>
</tr>
<tr>
<td>BII1</td>
<td>DII1</td>
</tr>
<tr>
<td>AII2</td>
<td>CII2</td>
</tr>
<tr>
<td>BII2</td>
<td>DII2</td>
</tr>
<tr>
<td>AII3</td>
<td>CII3</td>
</tr>
<tr>
<td>BII3</td>
<td>DII3</td>
</tr>
</tbody>
</table>

2.6 Mixing theory

The high performance of the percentage of particle size is referred to as milled particle size bulk having mechanical properties exceeding that of normal strength of milled particle size. Figure 1 shows the concept of mixing method for particle size.

![Figure 1](image)

**Figure 1** the concept of mixing method for particle size

Figure (4.28) shows the relationship if the particle size is 100 µm has been taken. Thus, The area of particle size is \( A = \pi r^2 \) (7850 µm²). The the area of all four particles is (31400 µm²). The area of the square is (40000 µm²).

The ratio of particle size to the square = \( \frac{\text{The area of particle size}}{\text{The area of square}} \)

\[
= \frac{31400}{40000} = 0.785
\]

In this sample, the content is \( (78.5\% (100\mu m) + 21.5\% (25\mu m)) \)

2.7. Mixing and compaction

Ball mill machine was used for mixing the powders (1hr for time) and (300 r.p.m for speed) to make sure that the distribution was completed. The composition of mixture to produce the samples between (AA6061) and (Zinc stearate) was regular along the size that equal to 99% of AA6061 and 1% of zinc stearate.

Cold compaction of powder blends was performed in this study. Cold compaction was performed at room temperature (RT). In cold compaction, the mixed powder with a given amount of lubricant was pressed by uniaxial hydraulic operated press, The die was supported by two circular blocks of iron to allow uniform movement of the die.
during compaction, The cleaned surfaces of die wall and tools (upper and lower punch) were sprayed with a lubricant-saturated solution

2.8 Sintering process

Sintering process is to provide extra bonding between atoms. The atomic diffusion takes place and welded areas formed during compaction will increase the connection by sintering process. The sintering will be controlled over heating rate time; temperature and atmosphere are required for reproducible results.

The equipment used during sintering process is tube furnace as shown in Figure 2, the inert gas used during the process is Argon gas. Then, enter the specimen metal (Aluminium and metal carbide) into the tube furnace, The temperature used is followed by sintering profile Figure 3. Sintering Temperature was taken according to the rule.

Sintering Temperature = (0.7-0.9) Tm
Hence: Tm = melting point

![Figure 2 Sintering furnace.](image2.png)

![Figure 3 Sintering procedure.](image3.png)
3. RESULTS AND DISCUSSION

Compression strength, Microhardness and Microstructure were investigated in this study. The surface of a manufactured part generally has properties and behaviour that is considerably different from those of its bulk. Although the bulk material generally determines the component’s overall mechanical properties, the component’s surface directly influences several important properties and characteristics of the manufactured part. The compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Some materials fracture at their compressive strength limit, others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Compressive strength is a key value for design of structures.

3.1. Effect of holding time on compression strength

The Holding time is the main parameter that affect on the compressive strength of the compacted specimen. Figure 4 describes the relationship between the Holding time and compression strength for all the suggested samples. Three values of Holding time were used. The values were 10, 15 and 20 mins. It is noted that the compression strength increases with increasing of holding compaction pressure for all the suggested samples (AII, BII, CII, DII).

The relation between Holding time and compression pressure was Direct proportional. Then, when the holding time was increased that’s mean the compression strength to become stronger.

The maximum value was upon the mix (DI) which equal to (155) Mpa due to there are very little of pores because it has various particle sizes of powder While (BII) and (CII) have one size of particle therefore they have more pores. Then, the compression strength were (112) and (111) Mpa respectively. Hence, (AII) has little of pores due to the particle size was smaller. Hence, the compression strength was (148) Mpa.

![Figure 4](relation between Holding time and compression strength for AII, BII, CII, DII)

3.2. Effect of Holding Time on Microhardness

Eight values for each sample was taken to calculate the average. Figure 5 shows the results of Vickers Microhardness tests of the four groups. (AII, BII, CII, DII).

These groups were noted. The biggest one was (DI) because it has a large amount of grain boundaries, therefore it has big value of hardness which was (64HV). While
Effect of Holding Time on Mechanical Properties of Recycling Aluminium Alloy Aa6061 Through Ball Mill Process

(CI) has the lower one, which was (51HV) due to it has big particle size and pores. Whereas (AI) and (BI) have values between them which were (54HV) and (52HV) respectively. Generally, the relationship between Holding time and Microhardness is Direct proportional. It is observed that the Microhardness increases with increasing holding time.

![Graph showing the relationship between Holding time and Microhardness for the groups (AII, BII, CII, DII).](image)

Figure 5 the relationship between Holding time and Microhardness for the groups (AII, BII, CII, DII).

3.3. Effect of Holding Time on Microstructure

Figures 6,7,8,9 show the microstructure of groups (AII, BII, CII, DII). Three values of time were taken which was (10,15,20) min . It is observed from these figures, the less time has more pores and it has concluded lowest compression strength, so the higher Time can be seen on microstructure has lower pores, higher bonding and higher compression strength. That means, the increasing of Holding time leads to an increase in the strength and Microhardness of compacted metal.

![Images showing microstructure of AII (25 µm powder) with varying holding times.](image)

Figure 6 effect Holding time on Microstructure of AII (25 µm powder)
Figure 7 effect Holding time on Microstructure of BII (63 µm powder)

Figure 8 effect Holding time on Microstructure of CII (100 µm powder)
CONCLUSION

In this work, the chip sizes of AA6061 that produced from high speed milling are used and the mechanical property of the recycled chip of AA 6061 was studied. The mechanical properties test was used to maximize the ultimate compression strength for different particle size. Four groups were used for this study (25,63,100, mix of them) µm. It can be shown that the mix group (DII) has a bigger value for this study. On the other hand, three specimens were used for each group (10,15,20) min. It can be concluded that the longer holding time will be higher the Ultimate compression strength value and higher Microhardness value.

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Figure 9 effect Holding time on Microstructure of DII (mix powder)
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