Hot Extrusion of Reinforced Aluminum Powder Compacts

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Abstract Metal working Process is carried out to enhance the strength and density of green powder compacts. Hot Extrusion process is performed on aluminum powder compacts reinforced with copper wires, 1, 2, 3 and 4 wires. The temperatures selected for extrusion process are below recrystallization temperature 350°C and over 450°C. Graphite lubricate is used as it is good lubricate when works in elevated temperatures. The process gives observable enhancement in both density and strength. The consolidation density reached nearly to 98% of the theoretical one, especially for specimen extruded at 450°C. The flow behavior of reinforced wires differs from that of green aluminum due to change in thermal conductivity.

Keywords: hot extrusion, green compacts, flow behavior, consolidation


1. Introduction

Due to superior properties of reinforced Metal matrix with strength reinforcements, it has considerable attention in comparison with most of monotonic materials [1,2,3].

In last year’s, metal matrix composites (MMCs) have a wide and large applications in many industry sections, among others in aircraft industry, the automotive, and electronics and electrical engineering, as well as in armaments, etc. [4,5,6]. There are three types of reinforcement material in the composites industry; fibers, particles and dispersions [7,8].

Powder metallurgy gives various types of aluminum based composites specific advantages such as corrosion resistance, light weight, high thermal and electrical conductivities and non-magnetic characteristics. Extrusion process has reasonably been used in powder metallurgical consolidation methods [9]. Mostly, extrusion can be defined as an act of ejection of metal by mechanical force [10] through well defined opening geometries. Mainly, to give a suitable degree of softness and plasticity, the metal is heated in a hot working operation. Various types of aluminum based powder metallurgical composite can be developing with this metal working process [9].

Enhancement of consolidation process to obtain improved densification for powder metallurgical process, this can be achieved with metalworking process which is widely, performed with hot extrusion process. Thus, the compacted product can be implemented in structural applications [11,12]. Other than the application to alloy powders or pure metal is limited [13]. Both the adhesive and abrasive resistance has been improved with the addition of hard particles to aluminum powders [14,15,16].

The main goal of the paper is to perform hot Extrusion process to get improved densification of aluminum powder reinforced compact. It is aimed to study the extrusion behavior on metal matrix product.

2. Experimental Work

2.1. Material Behavior and Characterization

A commercial aluminum metal powder with a mean size of 80 grit/inch supplied by ADWIC code number 8010075, molecular weight of 26.98 is used for all...
specimens as a matrix (base material). Figure 1 shows the powder particles shape. The aluminum powder matrix is combined with copper wires of 2 mm constant diameter as reinforcement material; Table 1 shows the mechanical properties of the used copper wires.

<table>
<thead>
<tr>
<th>Test Material</th>
<th>Compaction velocity</th>
<th>Yield strength, MPa</th>
<th>Ultimate strength</th>
<th>K Material Coef. MPa</th>
<th>Hardening exponent n, -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>5</td>
<td>65.699</td>
<td>80.211</td>
<td>101</td>
<td>0.068</td>
</tr>
<tr>
<td>Copper reinforcement</td>
<td>87.631</td>
<td>176.842</td>
<td>255</td>
<td></td>
<td>0.175</td>
</tr>
</tbody>
</table>

The compaction process is carried out on the compaction set up shown in Figure 2. The compaction velocity was 5 mm/min. The process continues to the maximum compaction load value then the load is released. The details of the manufacturing process are not the study case. Figure 3 shows arrangement of copper wires in the compacted specimen product.

![Figure 2. Schematic drawing of the compaction apparatus](image1)

![Figure 3. Arrangement of reinforcement wires: a) 2-wires, b) 3-wires and c) 4-wires](image2)

![Figure 4. Schematic drawing of the extrusion assembly](image3)
2.2. Extrusion Process

The ability to perform hot extrusion process on pre-compactd aluminum billets is so difficult due to the weak bond between cold compacted powder particles.

2.2.1. Extrusion Tooling

The simple sketchmatic drawing of the extrusion assembly is shown in Figure 4. The main elements of extrusion assembly are; the container, die, material, and extrusion punch.

2.2.2. Die geometry and Material

A very hardened steel is used which it is a disc having a conical orifice of 45° Semi-cone angle, merging into a throat of 3 mm length and then into a relief to avoid the frictional resistance between the extruded rod and the die exit. The die is of an inlet diameters of (12) mm, 50 mm outer diameter and 30 mm height. Figure 5 shows the used die.

![Figure 5. Schematic drawing of the used dies](image)

2.3. Extrusion Conditions

Hot extrusion tests are carried out at elevated temperature of 350°C, 450°C and extrusion ratio equal to 4. A thermocouple is inserted into the hole within the container wall and the temperature is indicated using digital thermometer. Punch travel speed is maintained at about 5 mm/min. This enables reading of extrusion load with enough accuracy. After each test, the container bore, die, billet, punch and dummy block are lubricated using graphite in burnt vehicle oil and then cleaned to remove any stick material of aluminum, using emery papers. While Graphite in burnt vehicle oil is used in hot extrusion process, as it is suitable for elevated temperature working conditions.

2.4. Compression Test

Compression test is performed using computerized universal testing machine (model WDW-100) at 1mm/min cross head speed, according to ASTM Stander [18]. The is carried out on the produced compacted specimen. Load and displacement are recorded on the machine attached computer.

3. Apparent Density Measured

It can be also called compressibility or compaction ratio [19], it can be calculated by measuring the theoretical density of the composite then measuring the actual density of compacts.

Theoretical density of the composite [20]

\[
\rho_{ch} = \rho_w \times V_w + \rho_m \times V_m
\]

Where:

- \(\rho_{ch}\) = Composites theoretical density.
- \(\rho_w\), \(\rho_m\) = Copper wire (reinforcement) density, matrix (aluminum powder) density, respectively.
- \(V_w\), \(V_m\) = Copper wire volume fraction and matrix (aluminum powder) volume fraction, respectively.

The actual density after measuring the final product volume \(V_c\) and the composites mass \(M\).

\[
\rho_{actual} = \frac{\text{compacted – mass}}{\text{compacted – volume}} = \frac{M}{V_c}
\]

Where:

- \(V_c\) = Actual composites volume.
- \(M\) = Actual composites mass.

Then the relative density \(\rho_{relative}\) is calculated for each produced specimens as.

\[
\rho_{relative} = \frac{\rho_{actual}}{\rho_{theoretical}}
\]

4. Results and Discussion

The extrusion temperatures were selected to be 350°C and 450°C because these temperatures are in the range, which provides the metal with suitable plasticity. The upper hot working temperature is the temperature at which hot shortness occurs, or for pure metal is the melting point. Because of the extensive deformation produced in extrusion, considerable internal heating of the metal also results. Therefore, the top working temperature should safely below the melting point or hot shortness range, Extrusion product are shown in Figure 6.

![Figure 6. Extruded billets at elevated temperatures](image)

Variation of extrusion pressure with ram travel for reinforced aluminium composites at different billet temperature (350°C and 450°C) was shown in Figure 7. It is established that extrusion pressure decreases with temperature increments, this is attributed to metal
softening so flow stress or deformation resistance decreases with billet temperature increment as hot working results in a decreasing in the energy required to deform the metal. Also one can observed that there are a rapid increase in the extrusion pressure at the first stage of the curve, this is due to the compression of billet to fill up the extrusion container. The second stage starts where the metal begins to extrude through the die opening and after the maximum load has been reached, the extrusion pressure falls as the billet length decreases until a minimum is reached, then rapidly increases again. This last pressure increment occurs because only a disk of the billet remains and the metal must flow radially toward the die aperture.

**Figure 7.** Effect of billet temperature on extrusion pressures of Al-composites: a) Al-compacts, b) 1-wire Al composite, c) 2-wire Al-composites, d) 3-wire Al-composites and e) 4-wire Al-composites

**Figure 8.** Relative density variation with type of billets: [a) Al-compacts, b) Al-1wires, c) Al-2wires, d) Al-3wires and f) Al-4wires ] composites
The extrusion process enhances clearly the billet compressive strength, this is resulted from increasing density. Figure 8 shows that relative density increases with temperature increment for all extruded billet. Hot working results in a rapid diffusion, which aids in decreasing the chemical inhomogeneities of compacted billets. Blowholes and porosity are eliminated by the welding together of these cavities, and the coarse columnar of the billets are broken down and refine into smaller equiaxed recrystallized grains. These changes in structure from hot working result in an increase in ductility, toughness and strength. Enhancement of mechanical properties in extrusion can also be attributed to increasing bonding between particles resulted from hot working and friction welding which results from high extrusion ratio that generates high shear stress between particles. Figure 8 shows enhancement of compressive strength in extrusion than in compacted case this is owing to high plastic deforming pressure. Compressive strength in the pervious figures is increasing with temperature increment, however, in Figure (9 a) there is a reflexive trend, strength is decreasing with temperatures, Aluminum powder compacts behaves due to high extrusion pressures as solid aluminum under hot working condition, and therefore, softening due to annealing occurs in aluminum billets without reinforcement, so ductility increases. Therefore, (Figure 8 a) shows that relative density increases with temperature to a value very close from solid aluminum relative density. The ratio of the difference between compressive strength of the extrusion billets at the studied temperature is reduced clearly with increasing of reinforcement, this may be due to change of specific thermal conductivity of copper reinforcement and matrix, therefore reinforcement take increasing amount of heat according to number of reinforcement.

Figure 9. True stress-true strain enhancement with extrusion process of Al-composites: a) Al-compacts, b) 1-wire Al composite, c) 2-wires Al-composites, d) 3-wires Al-composites and e) 4-wires Al-composites

5. Conclusion

The extrusion at elevated temperatures is found applicable and produces good products. The green product relative density is enhanced to reach nearly 98% of actual one. The compressive strength of the aluminum powder compact is enhanced well compared to green ones. The metal working process at elevated temperature above the recrystallization temperature is the more suitable to produced nearly full consolidated powder compacts. Due to change of specific thermal conductivity of copper reinforcement and matrix, reinforcement takes increasing amount of heat according to number of reinforcement.

References


