

Effect of Hot Extrusion through Mathematically Contoured Die on Mechanical and Tribological Characteristics of the AMC Prepared through P/M Route

Sambit Kumar Mohapatra^{1*}, Kalipada Maity², Sataya Brata Ghadei³, Akhtar Khan⁴

¹School of Mechanical Engineering, KIIT University, Bhubaneswar, Odisha 751024, India

^{2,4}Department of Mechanical Engineering, NIT Rourkela, Odisha 769008, India

³Mahindra & Mahindra Ltd., Tamil Nadu 603004, India

*E-mail : sambit.mohapatrafme@kiit.ac.in

Abstract. Thermo mechanical treatment of the components prepared by powder metallurgy route instigates the extensive research, due to its ameliorated impacts on the properties. In this research aluminium matrix composites (AMCs) {Al (92) - Mg (5) + Gr (1) + Zn (2)} have been prepared by following powder metallurgy route with dual axial cold compaction and subsequent sintering. Hot extrusion was considered as the secondary processing operation for the AMCs. Mathematical contoured die was utilised for the extrusion to avoid severe surface defects. Comparative analysis of different mechanical as well as tribological properties of the specimen before and after extrusion was focused. Extrusion engenders significant amount of improvements of the properties those are attributed to excellent bond strength and uniform density distribution due to high compressive stress. To furnish the suitable explanation scanning electron microscopies have been performed for the wear surfaces.

Keywords: AMC, Cosine Die, Extrusion, Powder Metallurgy, Tribology.

1. Introduction

Materials having high specific modulus, specific stiffness and good tribological properties have the significant implications in the automotive, aerospace, hand hold tools, defense and sports sectors. Aluminium matrix composites (AMCs) are the aforementioned segment of materials, have(P/M) been encroached the manufacturing industry to fulfill the current demands [1]. Powder metallurgy route of composite manufacturing is one of the suitable techniques adopted. This route of manufacturing provides the facility of all proportions of the compositions and unlimited combination of the constituents [2, 3].

Aluminium base products are utilized in different thrust areas due to its enhanced and tailorable properties which could be achieved by composing it with different ceramic reinforcements [4, 5]. For improving the properties of the AMCs the bond formation between ceramics with matrix element along with its distribution need to be taken care of. The bond strength depends on the wettability of the matrix materials which is improved by the implication of pressure at different temperature environments as a secondary treatment like extrusion[6], forging, rolling etc.. Secondary thermo-mechanical treatments helps to enhance mechanical and tribological characteristics of the product [5, 7]. Homogeneously distributed solid lubricant like graphite helps to improve tribological property with conciliating hardness and flexural strength [8-10]. The proportions of the reinforcements always carry the major deciding factor for achieving a specific property.



The P/M process of manufacturing the components instigates the investigators to tailor the proportions of the compositions, different variables of process parameters, implications of different secondary treatments for analyzing the correspondent change in the product behaviour [11]. The main concern in AMC manufacturing process through P/M route is formation of oxide layer around the particles. Removal of the layer for a better bond formation can be achieved by inducing shearing action by the implementation of a secondary thermo-mechanical treatment [12]. For extrusion of P/M specimen, shear faced dies does not perform well in concern to flow characteristics and surface properties. Hence a mathematical contoured die is used for the extrusion operation.

Here in this research an AMC composition has been selected for preparing the cylindrical specimen by P/M route along with subsequent thermo-mechanical treatment: hot extrusion. To ameliorate the process, the specimens have been extruded through a mathematical contoured cosine die. The melioration of different mechanical and tribological characteristics due to secondary hot extrusion operation has been investigated by comparative analysis.

2. Experimental procedure

2.1. Specimen manufacturing

The composition with weight proportions of Al (92) + Mg (5) + Gr (1) + Zn (2) was selected for the specimen preparation. A centrifugal blender at 200 RPM was utilized for preparing homogeneous blend of the composition. Different densities of the blend were checked prior to cold compaction. The double action compaction process was followed for preparing the green sample. For achieving a good flow of the powder, zinc stearate was used as lubricant. With slow rate of rise the blend was subjected to a maximum pressure limit of 275 MPa with ten minutes of dwell period. Green specimens were sintered in an argon atmospheric tubular furnace. Dwell periods of 20, 30, 90 minutes at 110°C to remove water vapour, 450°C to remove zinc stearate lubricant, 590°C to form the metallic bond were maintained respectively.

2.2. Thermo-Mechanical treatment

The sintered specimens were subjected to a thermo-mechanical treatment: extrusion. The cylindrical specimens were extruded to a square shape through designed contoured cosine die. The cosine contour for round to square die in one quadrant is shown in Figure 1. The specimens were extruded at the temperature range of 400-450°C. For metal matrix composite extrusion flow characteristics plays an important role for the properties hence shear faced dies are not suitable [13]. To provide homogeneous flow characteristics, a specially designed cosine contoured die was utilised for minimising the surface defects. Figure 1 depicts the cross sectional variation of the profile generated by MATLAB. The profile is engraved indigenously on a tool material (H-13) in three dimensions.

2.3. Physical, mechanical as well as tribological depiction

Apparent, tap, green, sintered, theoretical and extruded densities were checked at different stages during the process. Both sintered and extruded specimen densities were assessed by adopting Archimedes' principle.

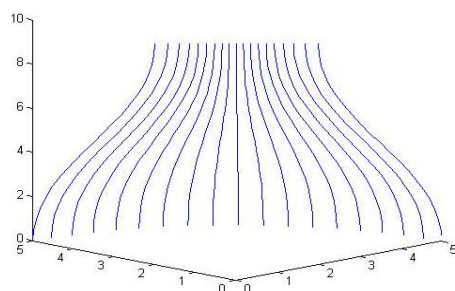


Figure 1. Cosine profile for round to square die in one quadrant

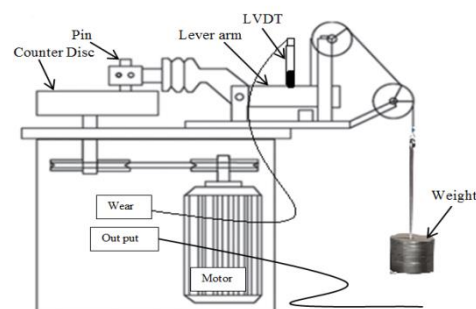


Figure 2. Schematic of two-body wear testing apparatus

Transverse rupture strength (TRS) of both types of specimens like sintered as well as extruded was found by 3-point bend test. The test was conducted with the ram travel rate of 2 mm/min by considering 30 mm span specimen in the universal testing machine (Instron -5979)

Pin-on-disc type two-body wear testing apparatus was employed to assess the wear characteristics of both the P/M as well as extruded matrix alloy. The cylindrical pins of dimension $\varnothing 10 \times 25$ mm were prepared for the sintered specimens and $(6.3 \times 6.3 \times 25)$ square bars with flat surface contact were considered for the extruded type. The EN-31 steel of hardness Rc 60 and the average surface roughness of $02 \mu\text{m}$ (Ra) was employed as the counter object. The schematic of the wear testing apparatus is shown in Figure 2. Three variable parameters were considered for the analysis and the values chosen for the study are tabulated in Table 1. Each experiment is continued for ten minutes duration. The wear measurement in terms of weight loss was performed precisely with an average accuracy of 0.1 mg.

Table 1 Variable parameters opted for test

Variable parameters	Level-1	Level-2	Level-3
Normal load (L), (in N)	40	60	80
RPM of the counter body (N),	200	400	600
Track diameter (D), (in mm)	50	70	90

3. Results and discussion

3.1. Physical depiction

Physical properties like shape and size of the powder have a great influence on flow characteristics during cold compaction, hence density of the specimen get affected and consequent effects diminish mechanical and tribological properties. Among different suitable techniques like LASER diffraction, sieve analysis and microscopy along with image analysis, to measure the shape and size of the particles, latter one is used in this work. The shape of the powder is clear by the scanning electron microscopy (SEM) images depicted in Figure 3. The size and shape of the composition are listed in Table 2.

Table 2 Physical characteristics of the selected powders

Selected Powder	Supplier of the powder	Average particle size	Overall Particle shape	Purity / Assay of the powder
Magnesium	Loba Chemie	140 μm	Flakey type	99.0%
Aluminium		45 μm	Spherical, elliptical and sub-rounded	98.0%
Graphite		20 μm	Rounded and Flakey type	98.0%
Zinc		22 μm	Spherical as well as sub-rounded	98.0%

Apparent or bulk and tap densities were computed. To improve the compatability, negligible weight percentage of zinc stearate was added with the blend. 30-35% enhancement of density occurs due to tapping, depicted in the Figure 4 which indicates a good flow characteristics of the blend. A proper consolidation of particles in green compact was observed at the compaction pressure of 275 MPa. A non-dimensional densification parameter ascertains the effect of sintering in terms of shrinkage or growth mentioned in Equation 1 [14].

$$\text{Densification parameter} = \frac{(\text{sintered density} - \text{green density})}{(\text{theoretical density} - \text{green density})} \quad (1)$$

Shrinkage and swelling or growth were affirmed by Positive and negative densification parameter respectively. The green specimens possess swelling behavior in this case, which has an adversarial impact on the properties. To overcome the effect as well as improve the properties a thermo-mechanical intervention i.e (extrusion) was considered as a secondary operation. The improvement of density due to the secondary treatment is calculated. 50% reduction of cross sectional area by extrusion causes 15-20% improvement in density. All densities are presented in

Figure 4 where theoretical density occupied the highest among all. The calculated data of densification factor, different densities, porosities are listed in Table 3.

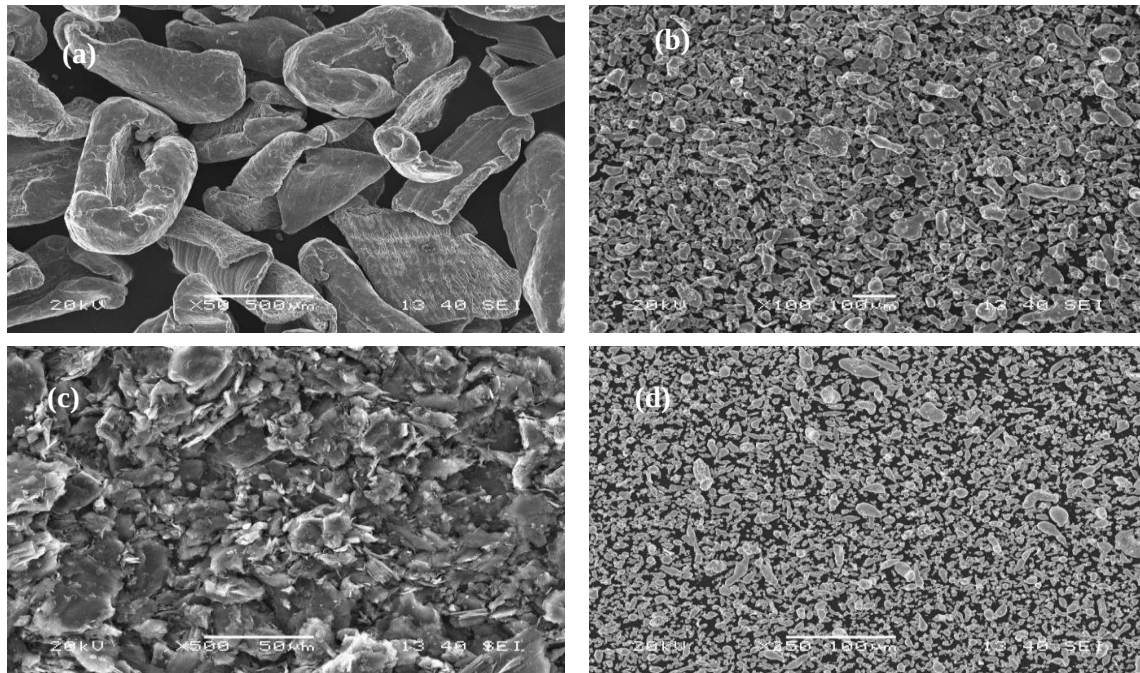


Figure 3. Scanning electron micrography of (a) Magnesium (b) Aluminium (c) Graphite and (d) powder

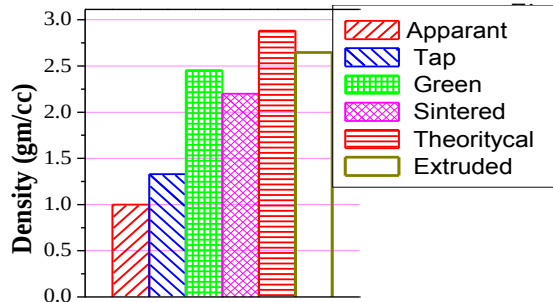


Figure 4. Density plot

Table 3 Porosity analysis

Parameters	Data
Densification factor	-0.742
Improvement in densification due to extrusion	17.35 (%)
Porosity of the AMC before extrusion	22 (%)
Porosity of the AMCafter extrusion	8.53 (%)

3. 2. Mechanical depiction

Ram travel rate of 3 mm/min was considered for compression test of sintered specimens. The compression test was performed in the Instron-setec series UTM at room temperature. The ultimate stress in average found is 409MPa, depicted from the stress versus strain plot in Figure 5. For determining hardness, ten readings were taken at different locations and the average was calculated. The same procedure was followed for both sintered as well as thermo-mechanically treated specimen. The hardness in average found was 82.3 HRV and 115.7 HRV for sintered and extruded specimen respectively. The thermo-mechanical treatment induces large thermal and internal stresses, which establishes improved properties.

The Transverse rupture strength (TRS) in MPa was estimated for both sintered circular section and square extruded section. TRS of the sintered P/M specimen is comparatively very low as shown in Figure 6, which could be attributed to the less bond strength as well as presence of porosity. Bond strength improves due to the uniform distribution of liquid Zinc by the application of high pressure on the matrix at high temperature condition during secondary treatments.

3. 3. Wear morphology

Two-body dry sliding wear test was conducted for both types of specimens. By considering three variables in three levels as in Table 4, an L_9 orthogonal array was formed to analyse the wear rate

in terms of mass loss. The mass loss is converted to volume loss per unit sliding distance and the same is plotted in Figure 7 for two types of specimen comparatively for all the nine runs. It was observed wear rate is reduced by the implication of secondary treatments to the P/M specimens. The improved bond strength avoids erosion of the pin material and consequent three body wear [10].

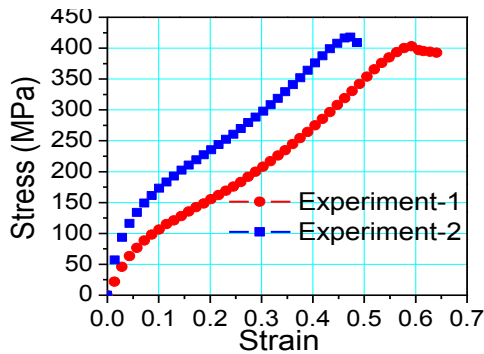


Figure 5. Stress versus strain

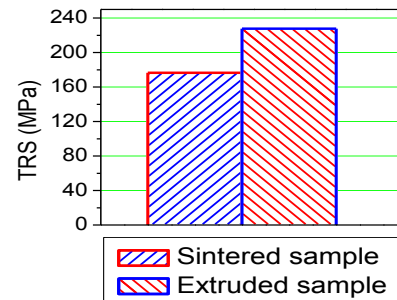


Figure 6. Transverse rupture strength

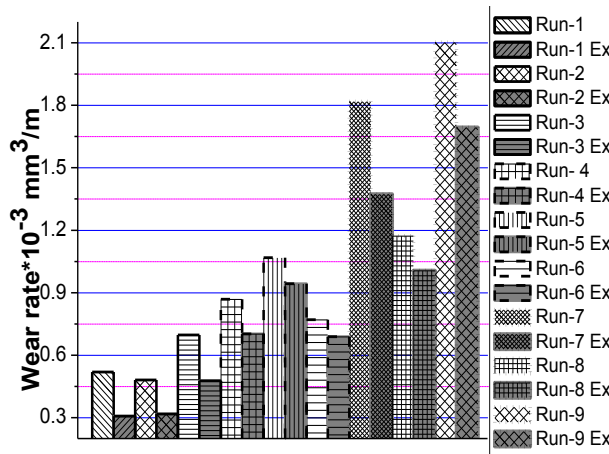


Figure 7. Wear rate for L₉ array

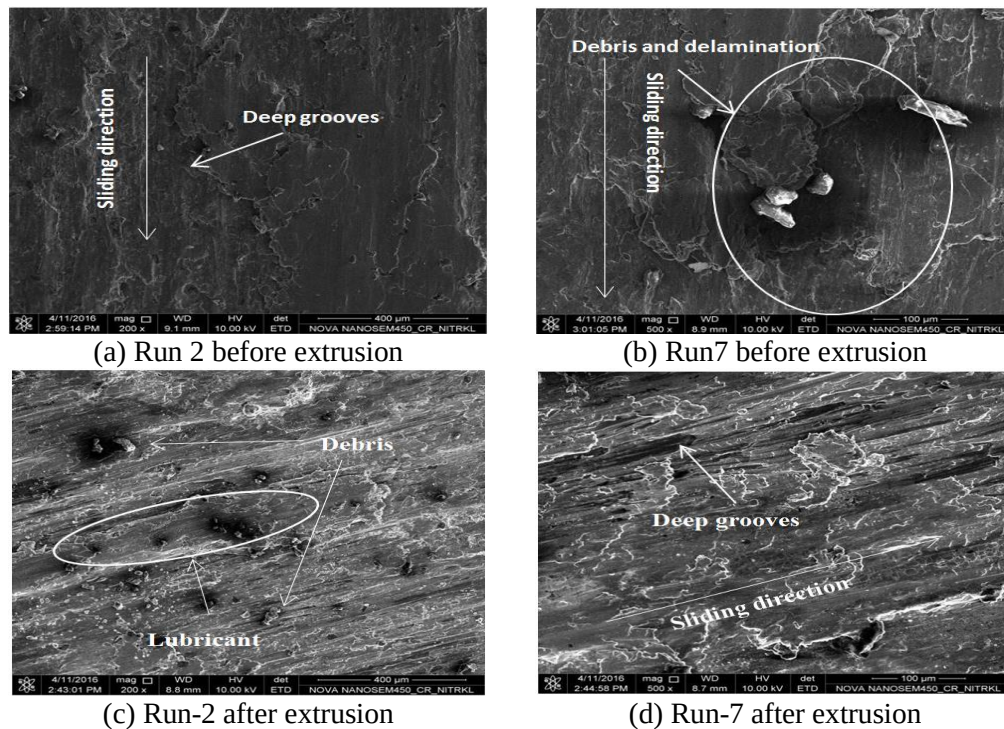
Table 4 L₉ array adopted for wear characterisation

Run	Normal Load (N)	Track Diameter (mm)	RPM of the counter body
1	20	50	200
2	20	70	400
3	20	90	600
4	40	50	400
5	40	70	600
6	40	90	200
7	60	50	600
8	60	70	200
9	60	90	400

Randomly selected worn surfaces were captured for FESEM images. Specimen surfaces for run-2 and 7 are shown in Figure 8. It was observed delamination as well as combination of three i.e. adhesion, delamination and abrasion is the predominating mechanism of wear for high sliding velocity with heavy loading conditions. Presence of porosity before the accomplishment of secondary treatments causes severe erosion, crack formation and fracture of the specimen. Shear deformation of the surface occurs by the continuous sliding over the crack. Presence of graphite at the tribosurface works as a solid lubricant, which minimizes friction and wear. Due to low melting point of zinc at adversarial conditions thermal softening and adhesion also come into picture.

4. Conclusion

Effect of the secondary thermo-mechanical intervention i.e. extrusion, considering a three dimensionally designed mathematically contoured die on the P/M specimen was investigated successfully. It was observed, the liquid phase sintering and its distribution due to hot extrusion causes a significant improvement of mechanical as well as tribological properties. Minimal amount of surface defects and smooth flow characteristics obtained by zero entry and exit angled die extrusion made the extrudate stronger. Wear rate of extrudate composites for every test conditions were lower in comparison with the P/M specimen without thermo-mechanical treatment. Presence of graphite ameliorates the wear resistance property by compromising with a little strength. A mixed type of wear (oxidative, adhesive, abrasion and delamination) pattern is observed in AMC surfaces.

**Figure 8.** Wear morphology

5. References

- [1] Fogagnolo JB, Velasco F, Robert MH and Torralba JM 2003 *Materials Science and Engineering: A* 342(1):131-43.
- [2] Torralba J, Da Costa C and Velasco F 2003 *Journal of Materials Processing Technology* 133(1):203-06.
- [3] Min KH, Kang SP, Kim D-G and Do Kim Y 2005 *Journal of alloys and compounds* 400(1):150-53.
- [4] El-Kady O and Fathy A 2014 *Materials & Design* (1980-2015) 54:348-53.
- [5] Taleghani MJ, Navas ER and Torralba JM 2014 *Materials & Design* 55:674-82.
- [6] Adamiak M, Fogagnolo JB, Ruiz-Navas EM, Dobrzański LA and Torralba JM 2004 *Journal of Materials Processing Technology* 155-156(Supplement C):2002-06.
- [7] Abdollahi A, Alizadeh A and Baharvandi HR 2014 *Materials & Design* 55:471-81.
- [8] Ravindran P, Manisekar K, Narayanasamy P, Selvakumar N and Narayanasamy R 2012 *Materials & Design* 39:42-54.
- [9] Ravindran P, Manisekar K, Narayanasamy R and Narayanasamy P 2013 *Ceramics International* 39(2):1169-82.
- [10] Baradeswaran A and Perumal AE 2014 *Composites Part B: Engineering* 56:472-76.
- [11] Yigezu BS, Jha PK and Mahapatra MM 2013 *Materials and Manufacturing Processes* 28(9):969-79.
- [12] Bykov YV, Rybakov K and Semenov V 2001 *Journal of Physics D: Applied Physics* 34(13):R55.
- [13] Prasad VB, Bhat B, Mahajan Y and Ramakrishnan P 2001
- [14] Padmavathi C, Upadhyaya A and Agrawal D 2011 *Materials chemistry and physics* 130(1):449-57.