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CHARACTERISATION OF AL6061-Fe_2O_3 METAL MATRIX COMPOSITES SUBJECTED TO SEVERE PLASTIC DEFORMATION FOR MULTIPLE PASSES THROUGH EQUAL CHANNEL ANGULAR PRESSING

Phanibhushana M. V
Department of Mechanical Engineering Amrita School of Engineering, Bengaluru, Amrita Vishwa Vidyapeetham, India

C.N. Chandrappa
Department of Mechanical Engineering, Acharya Institute of Technology, Bengaluru, India

H.B. Niranjan
Department of Mechanical Engineering, Sambhram Institute of Technology, Bengaluru, India

ABSTRACT

Aluminum Metal Matrix Composites are being used widely since 3 decades in Engineering and non-Engineering applications due to their versatile properties. The properties of the composites can be enhanced by subjecting them to Severe Plastic Deformation (SPD). Equal Channel Angular Pressing (ECAP) is one of the most commonly used methods of SPD, which produces ultra-fine grains in the structure. In this work AMCs have been fabricated using Al6061 alloy as matrix material and Hematite (Fe_2O_3) as reinforcement. Stir casting technique has been used for the fabrication of composites by varying the composition from 0% to 4% in steps of 1%. The specimens are subjected to two passes of ECAP. The load for the deformation of the specimen has increased as the % reinforcement increased and also from first pass to the second pass. Performance of the composites before and after SPD is studied by evaluating different properties and an enhancement in the properties is observed.

Key words: Metal Matrix Composites, Hematite, Severe Plastic Deformation, Equal Channel Angular Pressing, Ultra-fine grains, Scanning Electron Microscope.

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1. INTRODUCTION

Composite materials are fabricated by the combination of matrix and reinforcement materials (1). In MMCs the matrix material is a metal of iron, copper, aluminum or magnesium and reinforcement may be ceramic or metal added in the form of particles, whiskers or fibers (2-3). Composite materials exhibit better mechanical properties such as high strength to weight ratio, higher stiffness & wear resistance, improved resistance to thermal expansion & corrosion, etc. as compared to monolithic materials (4-5). The properties of MMCs are enhanced by adding specific type of reinforcement Composite materials have wider applications in military, aerospace, automotive and sports sectors (6-7). When reinforcements are added to the matrix material, one property enhances at the cost of the other, for example, harder material increases hardness by decreasing the ductility (4-7).

2. SEVERE PLASTIC DEFORMATION

The properties of MMCs can be improved by subjecting them to secondary operations such as Extrusion, Drawing, Forging, Rolling and Heat Treatment Ductility and Yielding strength of a material are influenced by the grain size. Ultra-fine grain sizes can be obtained by imposing large plastic deformation through Severe Plastic Deformation (SPD) techniques (8-9). Ultra grain structures of the order of 100 nm can be produced by SPD techniques (10). The structural parameters such as grain size and shape, density of dislocations in grains and grain boundaries, micro structural homogeneity, changes of phase composition etc. can be refined by SPD. The yield strength is influenced by the grain size and is given by the Hall-Petch formula (8-10).

$$\sigma_f = \sigma_o + \lambda d^{-1/2}$$

Where, σ_f = flow stress of material, d = average grain size and σ_o & λ are material parameters which are strain & temperature dependent.

2.1. Grain Refinement Mechanism

In SPD technique, grain refinement is a multi-step process. Initially, the dislocations in the grains rearrange & form into dislocation cells. As the deformation continues, the dislocation cells form into sub grains and there by the size of the grains is further reduced (11).

2.2. Equal Channel Angular Processing

The particulate composites when subjected to severe plastic deformation, have exhibited enhanced strength and hardness and may likely to show increased ductility. Various techniques of SPD are Equal Channel Angular Pressing (ECAP), High Pressure Torsion (HPT), Twist extrusion (TE), Simple Shear Extrusion (SSE) and Repetitive Corrugation & Straightening (RCS) (8-12). Equal Angular channel processing [ECAP] technique is the most commonly used one & is accomplished by cold working without any reduction in the cross sectional area of the deformed sample. The ECAP die is as shown in the figure1. and the angle 'Φ' between the intersecting channels normally varies from 90°-135° (13-14). Friction has a major effect on the deformation behavior. For corner angles close to zero, the friction in the die during deformation process increases and the material under strain hardening sticks to the outer channel surface. This forms a dead metal zone and the strain distribution becomes inhomogeneous. The effect of friction can be minimised by increasing the corner angle and there by the strain distribution becomes homogenous. The flow of the material can be increased by providing a fillet at the inner channel surface junction (10).

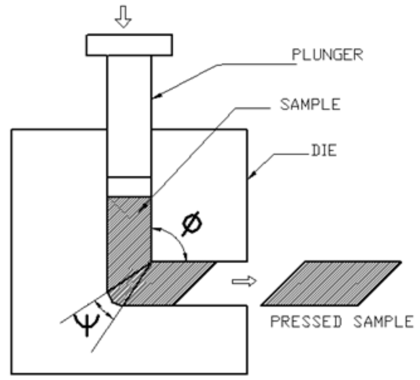

Figure 1 Equal Channel Angular Pressing Die

2.3. Strain Path for different Routes

At the intersection of these channels, the sample is subjected to deformation due to simple shear [11]. The approximate shear strain to which the material is subjected is given by the equation $\varepsilon=2/\sqrt{3}\cot(\Phi/2)$. A maximum strain rate of 1.15 per pass can be achieved for $\Phi=90°$ [15].

$$\varepsilon_{eq} = 1/\sqrt{3}[2\cot(\psi/2 + \varphi/2) + \psi \operatorname{cosec}(\psi/2 + \varphi/2)].$$

Ψ = corner radius angle, ε_{eq}= equivalent strain, Φ = angle of intersection of two channels.

Higher strains can be achieved by subjecting the sample for multiple passes by changing the Strain path between subsequent passes. The path is changed by rotating the sample around its longitudinal axis to an angle of 0° for route A, 90° for route B and 180° for the route C.

3. FABRICATION OF ALUMINUM-HEMATITE METAL MATRIX COMPOSITE MATERIAL

For the experimental study, Hematite is used as the reinforcement with matrix material Al 6061 as is the most widely used commercial form of aluminum (12, 14-15, 16-19). The chemical composition of Al6061 is shown in the table 1. & mechanical properties in table 2. Magnesium and Silicon added as constituents in Al6061 series, increases the fluidity and flowability of the metal in casting processes (17). The Hematite (iron oxide) is naturally available in powder form and is harder & brittle in nature (20). The properties of Hematite are shown in the table 3. In this study, Hematite (Fe_2O_3) of 40-45 microns of LR grade in different weight percentages is reinforced with Aluminum 6061 to fabricate a good wear resisting composite.

Table 1 Chemical composition of Al6061

Constituent	Si	Fe	Cu	Mn	Mg	Ni	Ti	Zn	Sn	Cr	Pb	Al
% by weight	0.43	0.43	0.24	0.139	0.802	0.05	0.022	0.006	0.001	0.184	0.204	Bal

Table 2 Properties of Al & Al6061

Material	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Hardness (BHN)	Density (gm/cc)
Aluminum	40 – 50	15 – 20	15	2.6
Al 6061	110-115	45-55	30	2.7

Table 3 Properties of Hematite

Tensile Strength (MPa)	Elastic Modulus (GPa)	Poisson's ratio	Melting point	Density (gm/cc)
350	211	0.35	1595 ^{o}C	5.26

Aluminum-Hematite composite was fabricated by standard stir casting technique, which ensures uniform mixing of the reinforcement with matrix material (21, 22). The different proportions of Al6061and Hematite composite are given in table 4. The specimens are fabricated successfully and subjected to various mechanical characterizations.

Table 4 Compositions of Al6061 and Hematite for different specimens

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Weight of Al6061 Added	2000 grams	1980 grams	1960 grams	1940 grams	1820 grams
% of Hematite	0%	1%	2%	3%	4%
Weight of Hematite added	0.0 grams	20 grams	40 grams	60 grams	80 grams

3.1. ECAP Process

The ECAP die and punch shown in fig. 2 are prepared by EN-31 material and hardened. EN-31 is a high carbon alloy steel with high compressive strength and abrasion resistance. The required load for the deformation process is applied by using Universal Testing Machine TUE-CN-400l and is as shown in the fig.3. The specimens obtained through ECAP Process are shown in the fig.4.

Figure 2 ECAP Die

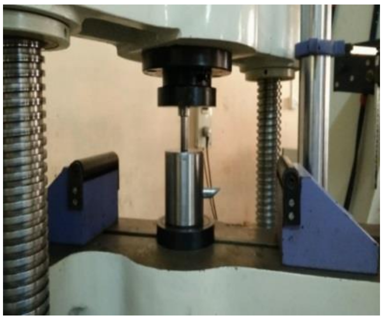

Figure 3 ECAP Process

Figure 4 Specimen after ECAP process

4. EXPERIMENTATION, RESULTS & DISCUSSION

4.1. Density Test

Theoretical density of the specimen was determined by rule of mixture and also the density was measured experimentally by direct method. The density of various samples is tabulated in the table 5. and by graphical representation in figure 5. It is observed from the results that, the density of the composites increase with increase in the percentage of reinforcement. As the reinforcement added was in smaller proportions, no much variation was found in the densities measured even though the density of the reinforcement is higher than the matrix material. There are some variations in the densities of the composites measured theoretically and experimentally, may be due to the defects in the castings.

Table 5 Density v/s % Reinforcement

Weight % of Reinforcement		**0%**	**1 %**	**2 %**	**3 %**	**4 %**
Theoretical Density in gm/cc		2.70	2.71	2.72	2.73	2.75
Experimental Density in gm/cc	Before ECAP	2.69	2.71	2.69	2.72	2.73
	After ECAP (2 Passes)	2.70	2.73	2.75	2.78	2.81

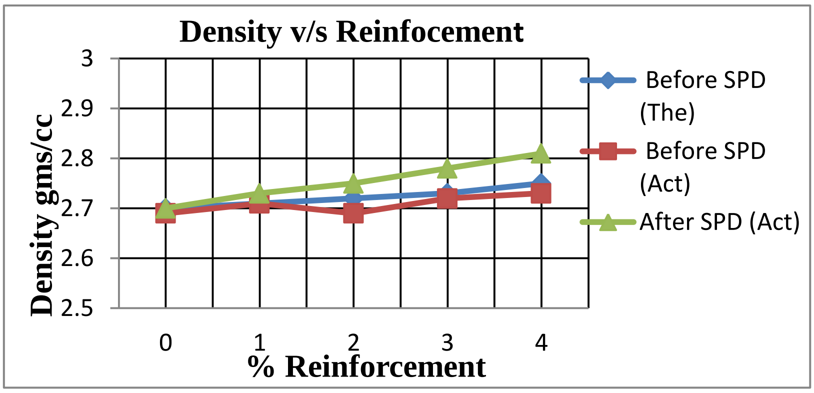

Figure 5 Density v/s % Reinforcement

4.2. Deformation Load

The deformation load for the ECAP process was applied using Universal Testing Machine of 40 ton capacity. For the deformation of the specimen, route 'B' technique was adopted. The specimens were subjected to two passes. The maximum load that was applied for the deformation process of each pass with different compositions is shown in table 6. and same is represented by graph in figure 6. From the above results, it is observed that the load has increased as the percentage of reinforcement increased from 0 to 4%. It is because of increase in hardness with increase in % reinforcement. And also there is an increase in deformation load by 2.5 times from 1st pass to the 2nd pass. It is due to the strain hardening of specimen. When the specimen was subjected to compressive load, the voids in the structure were minimised and the ultra-grains were formed due to the 90^{o} angle between the channels of the die.

Table 6 Deformation Load v/s % Reinforcement & Number of passes

% of Reinforcement	**0%**	**1 %**	**2 %**	**3 %**	**4 %**
First Pass (Load in kN)	40	55	63	72	80
Second Pass (Load in kN)	110	140	162	170	198

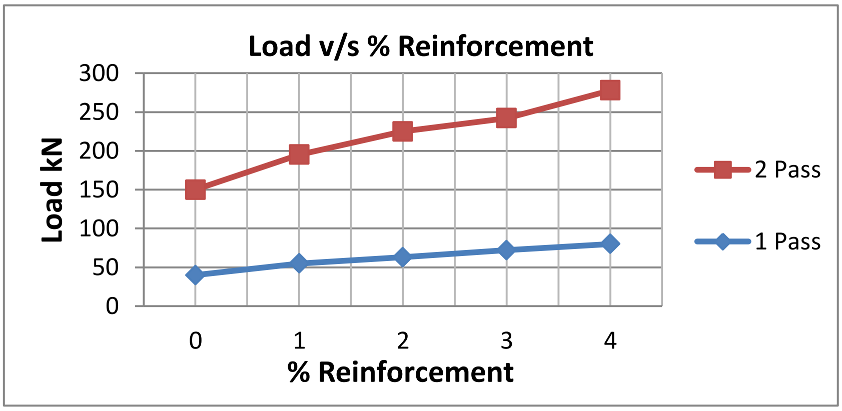

Figure 6 Deformation Load v/s % Reinforcement & Number of passes

4.3. Hardness Test

The grain size of the specimen influences the hardness. Brinnel Hardness Testing Machine TKB 3000 was used to determine the hardness. The test was performed by applying a load of 250 kg with a hardened steel ball indenter of 5 mm diameter. The hardness was calculated using the formula BHN $=2F/[\pi D*(D-\sqrt{(D^2-d^2)})]$.

Where, F = Load applied in kgf., D = Diameter of the indenter in mm, d = Diameter of the indentation in mm.

The hardness of the specimen for different compositions before & after ECAP process was tabulated in table 7 and same is represented by graph in figure 8. The results show that, there is an increase in hardness as the reinforcement percentage increased and is evident that the reinforcement of hematite particles are harder in nature. As observed, the hardness also increased as the number of passes have increased, it may be due to the higher strain hardening during the deformation process which minimises voids & cracks. It is evident that, as the voids are minimised, the ultra-grain structure increases the hardness.

Table 7 Hardness v/s % Reinforcement & Number of passes

% of Reinforcement	**0%**	**1 %**	**2 %**	**3 %**	**4 %**
0 Pass (Hardness)	35	39	42	40	44
1 Pass (Hardness)	44	49	52	59	61
2 Pass (Hardness)	68	70	67	72	76

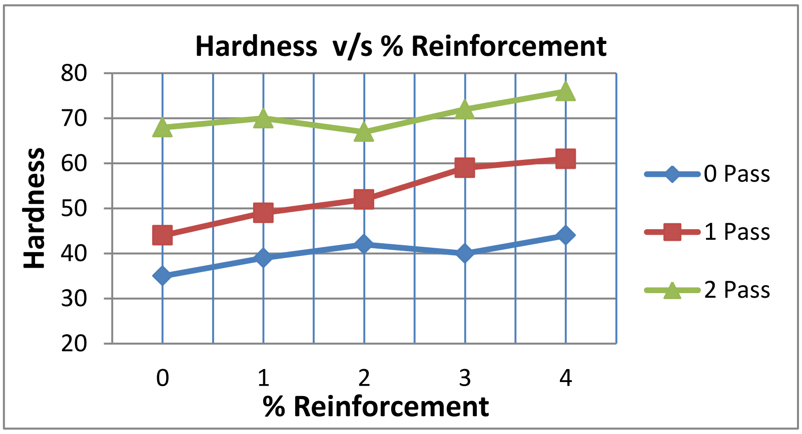

Figure 8 Hardness v/s % Reinforcement & Number of passes

5. CONCLUSIONS

The following conclusions are drawn from the study made on severe plastic deformed Al6061-Fe_2O_3 composites of different composition.

- The Density of Al6061-Fe_2O_3 composite has increased slightly with increase in the reinforcement. A maximum variation of only 4% was observed in actual density of the composite.
- In the fabrication, uniform distribution of reinforcement particles is achieved by **s**tir casting technique.
- It is observed from the results that, the load taken for the deformation has increased considerably from 0% reinforcement to 4% reinforcement of Hematite.

- It is also evident from the results that, the deformation load for 2nd pass has increased almost 2.5 times the load consumed for the 1st pass. It is due to the higher strain hardening by larger plastic deformation in the ECAP method.
- The increase in the deformation load is evident for ultra grain refinement in the composite due to larger plastic deformation and it indicates an increase in strength of the composite.
- The hardness value has increased from 20 -30 % with increase in % reinforcement. It is also seen from the results that, there is an appreciable increase in hardness (60-70 %) as the number of passes increased.

REFERENCES

[1] Autar K. Kaw, Taylor & Francis Mechanics of Composite Materials II edition, 2004.

[2] Metal Matrix Composites and Metal Foams, Eds. T. W. Clyne and F. Simanick (Wiley-VCH, Weinheim, Wiley-Veft, (2000),1-48.

[3] K.G.Satyanarayana, R.M.Pillai, B.C.Pai and P.K.Rohatgi. In: 2006 TMS Annual Meeting & Exhibition- Solidification Processing of Metal Matrix Composites-Rohatgi Honorary Symposium, March 12-16, 2006, San Antonio, Texas, USA.(Nikhil Gupta & W.W. Hunt), v.1., (2006), p.15 – 25.

[4] Surappa. M.K., Rohatgi. P.K., "Preparation and Properties of Cast Aluminum-Ceramics Particle Composites", Jounral of Materials Science, Volume 16, pp. 983-993,(1981).

[5] J.U Ejiofor, J. Metals and Reddy. R.G., "Developments, Processing and Properties of Particulate AL- Si Composites", Journal of Materials, pp. 31-37, November, (1997).

[6] [6] Das. S., "Development of Aluminum Alloy Composite for Engineering Applications", Indian Institute of Materials, Volume 27, No. 4, pp. 325-334, August, 2004.

[7] Alexander Evans, Christopher SanMarchi, Andreas Mortensen, Metal matrix composites in industry and a survey, Pub: Kluwer Academic Press, 2003.

[8] Bert Verlinden, "Severe Plastic Deformation of Metals", Association of Metallurgical Engineers Serbia and Montenegro Scientific paper, AME, UDC:669.01:620.174/.175=20. The second and third Int. Conf. on Ultrafine Grained Materials, ed. Y.T. Zhu et. al., TMS (2002) and (2004).

[9] A. Azushima, R. Kopp, A. Korhonen, D.Y. Yang, F. Micari , G.D. Lahoti , P. Groche J.Yanagimoto, N. Tsuji, A. Rosochowski, A. Yanagida, "Severe plastic deformation (SPD) processes for metals" CIRP Annals - Manufacturing Technology 57 (2008) 716–735, Elsevier Publications

[10] Nakashima K, Horita Z, Nemoto M, Langdon TG, Influence of Channel Angle on the Development of Ultrafine Grains in Equal-channel Angular Pressing. Acta Materialia 46(5): (1998), 1589–1599.

[11] Segal, V.M.; Reznikov, V.I.; Drobyshevskiy, A.E.; Kopylov V.I, Plastic working of metals by simple shear (Russian translation). *Russ. Metall. (*1981), *1*, 99–105.

[12] Cherukuri B, Nedkova TS, Srinivasan RA, Comparison of the Properties of SPD-processed AA-6061 by Equal-channel Angular Pressing, Multi-axial Compressions/forgings and Accumulative Roll Bonding. Materials Science and Engineering A 410–411 (2005), 394–397.

[13] I. Balasundar, M. Sudhakara Rao, T. Raghu, Equal channel angular pressing die to extrude a variety of materials, Materials and Design30 (2009)1050–1059, Elsevier Publications.

[14] Yong Li¤, Terence G. Langdon, Equal-Channel Angular Pressing Of An Al-6061 Metal Matrix Composite, Journal Of Materials Science 35 (2000), 1201 – 1204.

[15] Kim JK, Kim HK, Park JW, Kim WJ, Large Enhancement in Mechanical Properties of the 6061 Al Alloys after a Single Pressing by ECAP. Scripta Materialia 53(10) (2005), 1207–1211

[16] Phanibhushana M.V, C.N.Chandrappa, H.B.Niranjan, Evaluation of Mechanical Properties of Al6061 Reinforced with Hematite, Journal of Multidisciplinary Engineering Science and Technology (JMEST) ISSN: 3159-0040 Vol. 2 Issue 1, January – (2015), 255-260.

[17] S.C. Sharma, B.M. Girish, R. Kamath, and B.M. Satish, Fractography, Fluidity and Tensile Properties of Aluminum/Hematite Particulate Composites, "International Journal of Materials Engineering and Performance", Volume 8, p 309-314, June (1999).

[18] G.B. Veeresh Kumar, C.S.P. Rao, N. Selvaraj, "Studies on mechanical and dry sliding wear of Al6061–SiC composites", Composites: Part B 43 (2012) 1185–1191.

[19] V. Ravi Kumar, B. P. Dileep, S. Mohan Kumar, M. V. Phanibhushana, Effect of Metal Coatings on Mechanical Properties of Aluminium Alloy, International Conference on Functional Materials, Characterization, Solid State Physics, Power, Thermal and Combustion Energy AIP Conf. Proc. 1859, 020037-1–020037-6, 2017.

[20] Industrial Minerals. Minerals Zone. Retrieved 2008-04-29.

[21] Phanibhushana M.V, C.N. Chandrappa, H.B.Niranjan, Study of Wear Characteristics of Hematite Reinforced Aluminum Metal Matrix Composites, 5th International Conference of Materials Processing and Characterization (ICMPC 2016), Materials Today: Proceedings 4 (2017), 3484–3493, Elsevier Publications.

[22] Muhammad Hayat Jokhio, Muhammad Ibrahim , Panhwar and Mukhtiar Ali Unar, Manufacturing of Aluminum Composite Material Using Stir Casting Process, Mehran University, Research Journal of Engineering & Technology, Volume 30, No. 1, January, (2011) , p53-64, [ISSN 0254-7821].