Comparative Study of the Mechanical Properties of Al6061 with Graphite undergoing Equal Channel Angular Pressing

[1]Varadaraj K R [2]Ravishankar M K, [3] H R Vitala,[4] Lakshminarasimha N

[1] Assistant Professor, School of Mechanical Engineering,REVA University,Bengaluru

[2]Associate Professor, Department of Mechanical Engineering, MVJ College of Engineering, Bengaluru

[3]Professor, Department of Mechanical Engineering SJB Institute of Technology, Bengaluru

[4]Assistant Professor, Department of Mechanical Engineering, New Horizon college of Engineering, Bengaluru.

Abstract-

Continual interest, recent research and development in the field of Composite Materials motivated to entitle "Comparative Study of the Mechanical Properties of Al6061 with Graphite undergoing Equal Channel Angular pressing". The title introduces Equal channel angular pressing process in comparative study. The present work incorporates a stir casting technique in preparation of Al6061 with varying percentage of graphite and further (Al6061 with varying percentage graphite) undergoing Equal channel Angular pressing process to compare hardness and corrosion properties between them. Also the study comprises of comparative micro structural study. The comparative study results found that the Al6061 with graphite undergone Equal channel angular pressing process has increased strength, increased hardness, increased weight of material and fine microstructure.

1. INTRODUCTION

Equal channel angular pressing is one of the techniques in metal forming processes in which an ultra-large plastic strain is imposed on a bulk material in order to make ultra-fine grained and nano-crystalline metals and alloys. The technique is a viable forming procedure to extrude materials by use of specially designed channel dies without substantially changing the geometry by imposing severe plastic deformation. This technique has the potential for high strain rate super plasticity by effective grain refinement to the level of the submicron scale or nano-scale.

The Equal channel angular pressing die is composed of two channels with identical rectangular cross sections connected through the intersection at a specific angle; usually 90°.The cross section can also be circular or square. The work piece is machined to fit within the channel and extruded through two intersecting channels with the same cross section using a plunger.

During the Equal channel angular pressing process, adequate lubrication is essential because of frictional influences, tool wear and the loads necessary for plastic deformation. One important advantage of the Equal channel angular pressing process is that it can be repeated several times without changing the dimensions of the work piece, and the applied strain can be increased to any level; these advantages mean that the severe strains that can be applied and a simple shear deformation mode contribute to the strong and unusual properties of the material produced.

2. LITERATURE SURVEY

The literature survey is carried out to understand art of present work and current progress in research and developments in field of composite materials.

Michael OluwatosinBodunrin., et.al [1], [2015], Paper deals with major fabricating techniques in the design of aluminium hybrid composites.

Niranjan K N., et.al [2], [2017], title introduces stir casting method. Paper comprises study on hybrid composite. Process involves cutting of Al6061 bars into small ingots and melted. 6wt% of SiC is added into the melt and stirred; Gr of 3wt%, 6wt%, 9wt% at suitable intervals of 3wt% in steps of 3 is then added to the mixture of Al 6061 and SiC. Metal mould is meant for solidification and mould is removed and casted specimen machined as per ASTM standards for testing

Kazeem O Sanusi., et.al [3], [2012], Study reveals Equal channel angular pressing for the significant grain refinement of ultra-fine grained materials and concludes on speed and temperature of pressing influence the grain refinement and the homogeneity of the microstructures and textures of the pressed material.

Though there are several literatures survey articles are available only few articles are discussed in this section, others are addressed in reference section. These articles motivated to frame a title and carry out the present work.

3. MATERIAL SELECTION

Brief descriptions of the raw material as well as reinforcement materials used in synthesis of composites are as follows:

a. **Aluminium 6061 alloy**

   6061 is a precipitation-hardened aluminium alloy, containing magnesium and silicon as their major alloying element which belongs in the 6000 series. Their compositions are as in Table 1.

Table 1: Composition of Al6061

COMPONENT	AMOUNT (WEIGHT %)
Aluminium	95.8 - 98.6
Silicon	0.4 – 0.8
Magnesium	0.8 – 1.2
Iron	Max. 0.7
Copper	0.15 - 0.40
Zinc	Max. 0.25
Titanium	Max. 0.15
Manganese	Max. 0.15
Chromium	0.04 - 0.35
Others	0.05

b. Reinforcement- Graphite (Gr)

The key properties of Graphite selected are as shown in Table 2.

Table 2: Key properties of Graphite

PROPERTY	COMMERCIAL GRAPHITE
Bulk Density (gm/cm^3)	1.3 - 1.95
Porosity (%)	0.7 - 53
Modulus of Elasticity (GPa)	8 - 15
Compressive strength (MPa)	20-200
Flexural Strength (MPa)	6.9-100
Coefficient of Thermal Expansion (x10-6 °C)	1.2-8.2
Thermal conductivity (W/m.K)	25-470
Specific heat capacity (J/kg.K)	710-830
Electrical resistivity (Ω.m)	$5x10^{-6}$-$30x10^{-6}$

4. PREPARATION OF THE COMPOSITES

In stir casting method, the raw materials are collected i.e. Al6061 and graphite and make the initial preparation by cutting Al6061 in small pieces around 250 grams. Weigh the alumina for different compositions.

The casting reinforcements, stirrer, permanent mould preheated to 200ºC to remove moisture and gases from the surface of the reinforcements, and equipment's before casting. Now the required amount of Al6061 is weighed and placed in the crucible and heated to 700ºC using resistance furnace then the degassing tablet is added to minimize the coating film defects by expelling the volatile components present in the melt during casting. The tablet helps in the removal of entrapped air in the melt and thus prevents casting defects like porosity and blow holes. Then the matrix Al6061 is reinforced with graphite of different compositions, with a weighed 3%, 6% and 9%. The micro particle of Gr was added at the temperature of 750ºC and a constant rigorous stirring was done for 15mins until a clear vortex is formed.

At the pouring temperature of 850^{0}C the molten mixture was poured into the cast iron mould and allowed to solidify for few minutes. After complete solidification and then it is withdrawn from the mould and machined according to ASTM standards.

Now the produced composite is subjected to equal channel angular pressing by passing it through a die which is cylinder in shape having a passage of 90-degrees and further subjected to various tests. Now the tests are conducted on both the set of specimens i.e. the casted material and the casted material undergoing 90^0 Equal channel angular pressing.

The top, middle, and the bottom portion of the material were taken for Micro structural characterization to note the distribution of second phase particulates. Then specimens for various mechanical property tests are prepared as per ASTM standards. The mechanical property will be evaluated using results of various tests to note the extent of improvement of matrix behavior after Equal channel angular pressing. Finally, the improvements in the properties are obtained which are studied.

5. EQUIPMENT DETAILS

The Equipments used in the project process are as shown in Table 3.

Figure 1 shows the front view and side view of the die used for the Equal Channel angular pressing which consist of a passage through which the casted material is forced out. As it is seen that there is a hole present at the top and side of the cylinder which is connected to form the 90^0 for the materials to pass by it and improves its various properties and reducing burrs and residual stresses present in the material due to the casting.

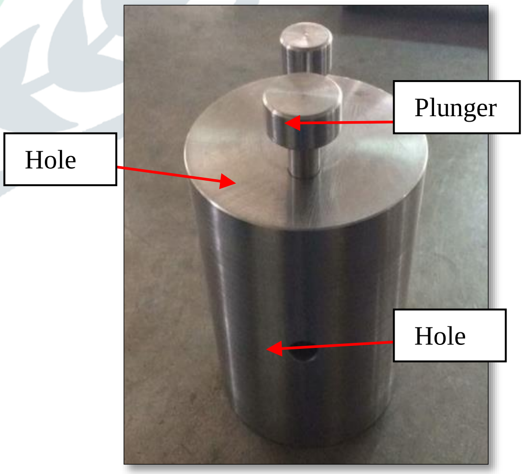

Figure 1: Die for Equal channel angular pressing

The material details of die and plunger is as below and Figure 2 shows the draft model of die and plunger with dimensions.

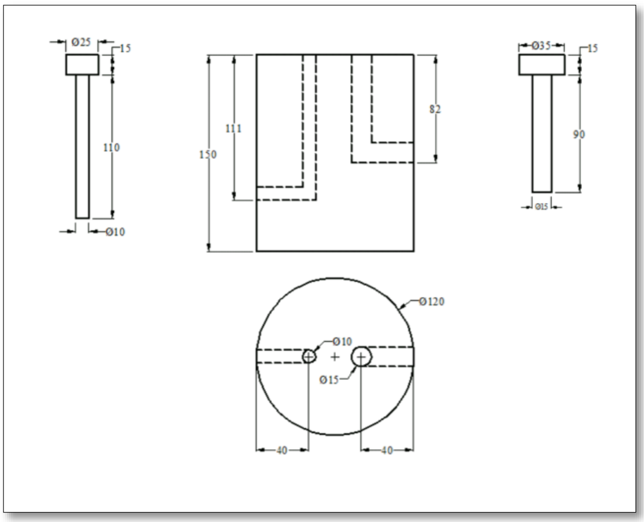

Figure 2: Dimension of die and plunger

Table 3: Equipments used

Sl. No	Instrument/ Equipment	Specification	Use in the present investigation
1	Resistance Furnace	Capacity-5kg, Operating temp-1000^{o}c Power rating-7.5kw Heating element-Sic	To melt the Aluminium 6061
2	Electric Oven	Volts-2.30 A.C Power rating-3.5kw Max Temp-300^{0}C	Preheating the reinforcement, degassing tablet, Die, and stirrer
3	Two disk Polishing Machine	RPM - 0 to 1000 Coolant nozzle and Table top type	To carry out the mirror image to get microstructure
4	Computerized optical microscope	Digital camera for microscope with 3.3 M pixel CCD system	For viewing the microstructure in different optical lens magnification
5	Brinell's hardness machine	Max force-10 to 500grams, Resolution - 0.0001 to 0.1micron Max testing height - 380mm, Depth of throat - 200mm	Testing hardness for materials in microns
6	Die	Cast Iron	To prepare the specimens
7	Universal Testing Machine	Loading Accuracy as high as + 1%.	The universal testing machine is used to push the material out of the die by transmitting a constant increasing force on the plunger of the die which in turn forces the material to pass through the 90^{0} passages.
8	Salt spray Chamber	ASTM B 117-2007	For the corrosion test on the casted material
9	Electronic Weighing Machine	Capacity-2.2 Kg Accuracy- 0.02gms	Weighing of different materials like matrix (Al-4.5% Cu), reinforcement, wear test specimen. etc.
10	Crucible	Graphite crucible	For melting purpose

11	Stirrer	Stainless steel coated with zirconia	Used for getting uniform distribution reinforcement in matrix phase.
12	Die	ES 31	For the equal channel angular pressing process
13	Plunger of the equal channel angular pressing die	High carbon chromium steel	For the equal channel angular pressing process

The complete dimension details of equal channel angular pressing die is as below:

- Die diameter – 120 mm
- Height of the die – 150 mm
- Diameter of the 1st passage – 10 mm
- Diameter of the 2nd passage – 15 mm
- Height of the 1st passage –111 mm
- Height of the 2nd passage – 82 mm
- Diameter of the plunger head for the 1st passage – 25 mm
- Height of the plunger head for the 1st passage – 15 mm
- Height of the plunger for the 1st passage – 110 mm
- Diameter of the plunger for 1st passage – 10 mm
- Diameter of the plunger head for the 2nd passage – 35 mm
- Height of the plunger head for the 2nd passage – 15 mm
- Height of the plunger for the 2nd passage – 90 mm
- Diameter of the plunger for 2nd passage – 15 mm

6. TEST RESULTS AND DISCUSSION

The results obtained from the following tests conducted are as discussed below.

6.1 Micro structural study

Microstructure was visualized with the help of optical microscope. For the specimen preparation, first of all specimens, were cut into small cylindrical shape and then the different samples were grinded on different grit size papers sequentially i.e. 220, 400, 600, 800 and 1000. After grinding, the specimens were rubbed mechanically by alumina paste and then etched by Keller's reagent to obtain better contrast. The specimens were visualized on different magnifications (100X, 200X) to show the presence of reinforcement and its distribution on the metal matrix. The microstructures of all the samples i.e. as cast and with different combination of reinforcement of Graphite are shown in Figures 3&4. In the current work, an attempt has been made to prepare Al6061-Gr aluminium alloy matrix composites with micro size Graphite particles by stir casting method combined with preheating of the reinforcing particles. The optical micrographs of as cast Al6061-Gr alloy reinforced with 6 wt. % and Al6061-Gr alloy reinforced with 6 wt. % undergoing Equal channel angular pressing, are shown in Figure 3 and Figure 4 respectively. Optical micrographs of Al6061-Gr with 6 wt.% after Equal channel angular pressing, composites revealed the uniform distribution of Graphite particulates in the matrix, and no void and discontinuities were observed. Common casting defects such as porosity and shrinkages were not found in the micrographs. There was a good interfacial bonding between the Graphite particles and Al6061 alloy matrix.

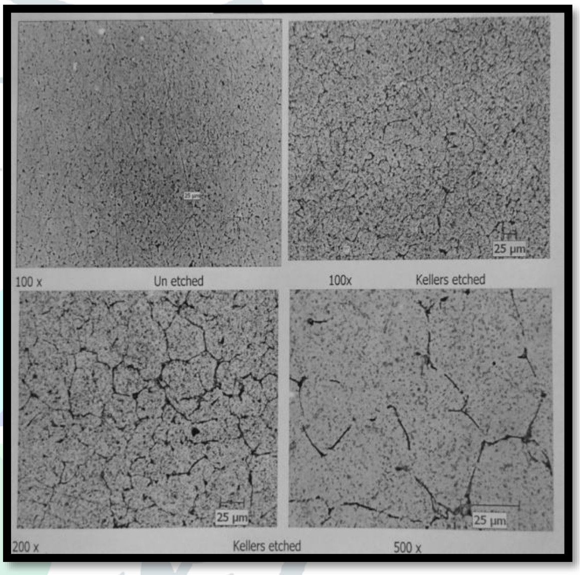

Figure 3: Micrographs of Al6061-Gr with 6 wt. % of graphite before Equal channel angular pressing
[Clockwise from top left] ***100X, 100X etched with Keller's reagent, 200X, 500X.***

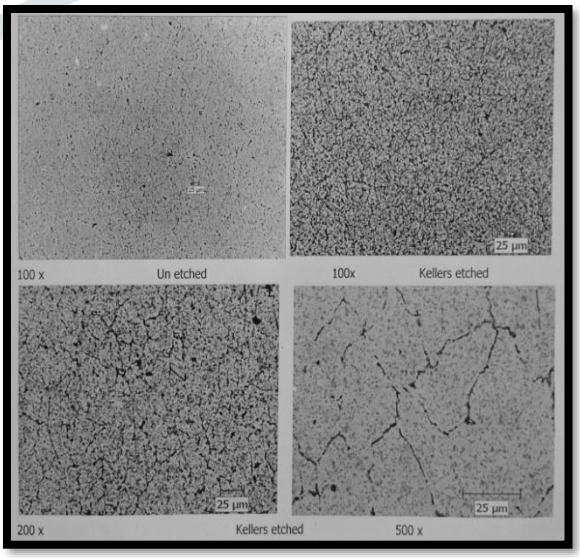

Figure 4: Microstructure of Al6061-Gr with 6 wt. % of graphite after Equal channel angular pressing

[Clockwise from top left] ***100X, 100X etched with Keller's reagent, 200X, 500X.***

6.2 Hardness Test

The Brinell Hardness test on all compositions was conducted using steel ball indenter at an applied load of 60kgf at 50X with dwell time 10 seconds for each sample at different locations.It can be observed that the hardness of the composite with Equal channel angular pressing is greater than that of its cast matrix; the graphs also indicate that the hardness decreases with the increasing wt. % of graphite and increases with the wt. % of Gr. It is evident from the Figure 5 there is decrease in the hardness as the graphite reinforcement content is added. This drop in the hardness is due to softness of the graphite particles, it also noticed that hardness increases when the casted material undergoes Equal channel angular pressing.

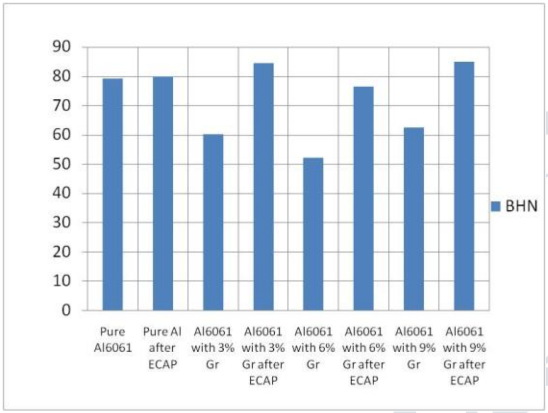

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Figure 5: The Brinell hardness number of different composites prepared under study

From Figure 5; ECAP- Equal channel angular pressing and BHN- Brinell Hardness number

The results obtained and the observations made are consistent with the results of other workers. Increased in the hardness of composites reinforced with hard particles has been reported by several workers.

6.3 Corrosion Test

The casted materials after undergoing the salt spray test are weighted and the results are obtained as shown in the Table 4 and the casted materials after Equal channel angular pressing are tested and the results are shown in the Table 5. It is seen that after the Equal channel angular pressing process the weight of the specimens has increased though in small fraction. The test method used is ASTM B 117-2007.

Table 4: Results of corrosion test before Equal channel angular pressing

Before Equal channel angular pressing					
		Weight In grams			
Date	**Total Hours**	**Pure Al**	**Al with 3% Gr**	**Al with 6% Gr**	**Al with 9% Gr**
21.06.2017-Initial		1.4117	1.4789	1.3123	1.4025
21.06.2017	12	1.3461	1.3617	1.2974	1.3317
22.06.2017-Final	24	1.2221	1.3717	1.1147	1.2716

Table 5: Results of corrosion test after Equal channel angular pressing

After Equal channel angular pressing					
		Weight In grams			
Date	**Total Hours**	**Pure Al**	**Al with 3% Gr**	**Al with 6% Gr**	**Al with 9% Gr**
21.06.2017-Initial		1.1471	1.5741	1.6002	1.5789
21.06.2017	12	0.9614	1.4476	1.4476	1.4964
22.06.2017-Final	24	0.7117	1.3717	1.3711	1.3141

7. CONCLUSION

The significant conclusions of the studies on Al6061 with graphite undergoing Equal channel angular pressing process are as follows:

1) Stir casting techniques were successfully adopted in the preparation of Al6061 with graphite varying from 0%, 3%, 6% and 9%.
2) It is seen that Equal channel angular pressing process has increased the strength, hardness and fine microstructure formation.
3) Equal channel angular pressing process is carried out in 90^0 which results in reducing the burrs and residual stresses present in the material after the process of casting.
4) The micro structural study revealed the uniform distribution of the particles in the matrix system.
5) The hardness of the casted materials before Equal channel angular pressing were lesser compared to that of the casted materials that's have undergone Equal channel angular pressing.
6) The corrosion test using salt spray mechanism which increase the weight of the casted material by small fraction.

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