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Improvement In Tribological And Mechanical Properties Of Al6061-Sic

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Abstract- In present scenario, there has been heavy surge in the utilization of the aluminium matrix composites. AMCs have gained relative importance in various fields of engineering such as aeronautical, bio-medical, defence system etc. A 6061 Aluminium alloy with Silicon carbide as the reinforcing agent is implemented as composite constituent. The reinforcement content is diversified in terms of weight percentage. Further, the casted specimens are made to experience high strain through means of "Equal channel angular extrusion*"* wherein grain enhancement takes place leading to improvement in its tribiological and mechanical characteristics with no alteration in the cross section.

Index Terms – ECAP, Aluminium, SiC.

1. INTRODUCTION

Composite material overtakes the homogenous materials because of their enhanced properties specially designed for the suitable purposes. Since conventional metals and their alloys are getting limited/ restricted usage due to the limitations such as achievement of desirable toughness, high temperature performance, combined strength, wear, corrosion inhibition etc. Thus metal scholars have averted their attention from monolithic to amalgamated materials [1]. There are various applications of composites in the field of aerospace, marine, defence, medical purposes, nanotechnology, construction, bio- engineering and the list goes on.

In this research, work has been conducted to create metal matrix composite which is manufactured by a suitable manufacturing technology selected after reviewing from several sources of information. The selection of the matrix and the reinforcement is done considering its suitability for particular application. Later the fabricated materials are made to undergo a severe deformation with a view of enhancing their properties so that its range of applications can be widened.

1.1 Selection of Al6061 And Silicon Carbide

- Selection Criteria for Aluminium 6061

In manufacturing industry, the requirement to produce lightly weighed, strong and most importantly economical material has led to intense research and growth of AMC's. The main objective involved in the production of MMC is to fuse the desirable properties of ceramics and the metals, which will widen its level of applicability. Equally we know aluminium is the third most available in plenty element after silicon and oxygen, making up of 8% of earth's solid surface by weight. Aluminium has superior characteristics than titanium and magnesium in terms of wet ability, flexibility and strong bondage, although density of magnesium is 35% lower than that of aluminium but inferior properties of magnesium such as attraction towards oxygen leading to corrosion makes it lag behind.

Table 1 - Aluminium series

Al series	Types available	Alloying element
1xxx	1050,1060 ,1199, 1100	99% aluminium(pure)
2xxx	2014, 2024, 2219	Copper
3xxx	3003, 3004, 3102	Manganese
4xxx	4041,4043	Silicon
5xxx	5005 , 5052, 5059	Magnesium
6xxx	6005 (6005A) , 6066, 6060, 6061, 6063	Magnesium and silicon
7xxx	7005 , 7072, 7020 , 7022, 7046, 7075	Zinc
8xxx	8000, 8090	n/a

The first digit in the designation gives key information regarding the principal elements. The 2,6 and 7 series are included in as heat treatable alloys which are strength improved by precipitation hardening during the alloying process and 1,3,5 series are specified as non-heat treatable alloys which are strengthened through means of work hardening. Al-Mg-Si alloys (6xxx series) have broadly found its application in building and automobile industry because of its low cost and medium strength. Daryoush et al.[1] stated the applicability of aluminium alloys for applications such as diesel engine under high temperature and pressure. Elastic modulus of the pure aluminium was improved through addition of 60% by volume continuous aluminium fibre varying from 70 to 240GPa, but this addition also led to decrement in coefficient of expansion of the alloy.

- Selection of Silicon Carbide

Hard ceramic particulates like Alumina (Al_2O_3), Silicon carbide, Zirconia, TiC, TiB, ZrB_2, AlN, Si_3N_4 are introduced into the metal matrix to enhance the corrosion and wear resistance, stiffness, strength, fatigue withstand and temperature stability. Amongst these hard ceramics, SiC has a high level of compatibility with aluminium alloys causing enhancement in the wear resistance of alloy, reduction in thermal expansion coefficient, superior modulus of elasticity hence exhibiting remarkable strength to cost and strength- weight ratio in comparison to traditional base alloys. In addition it is found that composites with SiC as reinforcement and aluminium as matrix exhibited improved wear resistance, light weight and thermal stability.

2. LITERATURE SUREVY

Claudio et al.[2] fabricated/prepared a metal medium with Al6061 as the matrix with 60% by volume Al2O3 spherical particles as the reinforcement. Gas pressure infiltration process, because of its advantages to produce pore free, high reinforced, defect free and also ease of processing, was adopted for the fabrication of these composites and it was experimentally determined that spherical alumina particles don't react with the molten magnesium containing matrix during the process, making the Al6061 retain its ability of being strengthened by precipitation-heat treatment. Daljeet et al.[3] focused on changing the property of the aluminium by inclusion of reinforcements Al2O3 and SiC in terms of weight percentage and further investigations were carried out concluding that addition of described reinforcements led to enhancement in properties such as ultimate strength, hardness, yield strength but the same time it was found that ductile behaviour had been converted into brittle. Maninder Singh et al.[4] worked on determining the properties of Aluminium alloy matrix reinforced with SiO2 and TiO2. The composites were manufactured through liquid metallurgy and investigated for the microstructural and mechanical behaviour changes.
S. Mahadavi et al.[5] investigated the effect of variation in particle size of Silicon carbide particles during dry sliding wear of SiC-Graphite and SiC reinforced Al6061 composites. Three particle sizes 19, 93, 146μm were studied and the composites were fabricated through means of In-situ powder metallurgy approach and the outcomes determined that, with surge in the size of SiC particles, the level of porosity, wear rate, hardness of both the composites decreased. Horita et al.[6] determined the improvement in the characteristics of different series of aluminium alloys, 6 different commercial alloys were considered with varying grain sizes. The pressing process was conducted at room temperature and 90° angle die was employed for experiment. The extruded specimens were sliced for given dimensions and annealed followed by Vickers hardness testing and tensile testing. The test outputs revealed that 1100 and 3004 series alloy with stranded maximum load of 2 tonne and 4.5 tonne respectively.

Survey Conclusion

Thus after reviewing it is noticed that Al 6061 alloy is suitable for stir casting process as it can withstand high temperature and its combination various reinforcement tends to provide superior properties than the base alloy. Thus Al6061 is adopted for the stir casting process. Considering the properties of the SiC, the reinforcement of particle type with size of 400microns is used for the addition purpose. The review infers that ECAP can be consecutively implemented for aluminium alloys. The channel angle of 120° is considered for the extrusion purpose with a single passing of the specimen through the ECAP channel via Route A.

3. METHODOLOGY

3.1 Material Allocations

Table 2 - Aluminium elemental composition

Element	Ti	Zn	Sn	Cr	Cu	Mn	Si	Fe	Mg	AI
Weight %	0.007	0.0889	0.01	0.060	0.197	0.079	0.473	0.5	0.757	Remaining

Since this metal belongs to 6xxxx series, its can heat treated making it a suitable selection for stir casting process whereby severe heat is generated during melting and plastic deformation procedure.

Table 3 - Properties of Aluminium 6061 & SIC

	Density ρ (gm/cc)	Modulus of elasticity E (GPa)	Poisson's ratio γ	Coeff. of thermal expansion(K^{-1})
Al6061	2.7	68.3	0.345	23.5 x 10^{-6}
SiC	3.2	470	0.17	4.5 x 10^{-6}

Considering the above properties, the reaction during the casting process given as

$$4AI + 3SiC \rightarrow AI_4C_3 + 3Si \quad (1)$$

The above reaction signifies that reaction yield includes carbide of aluminium. Stir moulding is a type of the liquid metallurgy process which includes integration of liquefied alloy with the reinforcement particulates by constant stirring action.
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3.2 Moulding Cast Die Specifications

Material type**:** D2 steel tool material

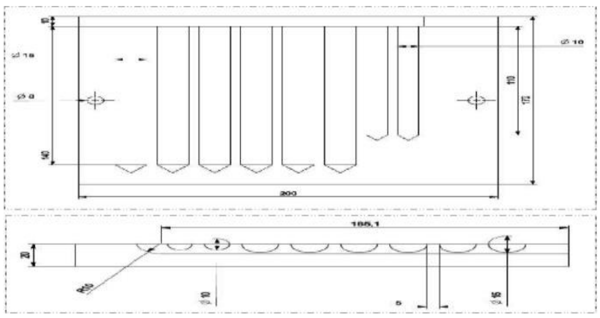

Fig. 1 - Schematic illustrations of the mould casting die

3.3 The Reinforcement Addition To The Molten Matrix

Weight of the 6061 aluminium ingots = 7.633Kg.
Since the casting mould die consists of cavity in the form of cylinder-shaped rod of varying diameter and

length.

Fig. 2 - Aluminium ingots

Table 4 - Reinforcement to be added

Percentage of SiC	Weight of 6061Al	Weight of SiC to be
0%	7.58Kg	0gms
2%	7.1Kg	142gms
4%	6.62Kg	131.4gms
6%	6.14Kg	120.76gms
8%	5.665Kg	110.3gms

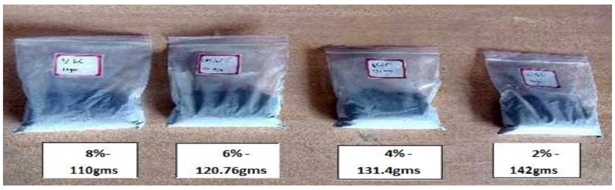

Fig. 3 - Weighed and sorted SiC particles as per the requirement

- The reinforcement used was SiC of fine mesh with particle size of 400µ.
- After weighing of the reinforcements as per the calculation, they were organised systematically as shown in the above figure 3.2.

Fig. 4 - Manufactured Mould casting die

- Split type die configuration was used for casting purpose. The die was made up of tool material.
- The casting apparatus consisted of crucible made up of graphite. The reason for adopting graphite crucible included high temperature stability and non-reactive with the aluminium alloy, hence served the purpose.

Fig. 5 - Graphite crucible for molten alloy

Fig. 6 - Experimental setup of stir casting

- This graphite crucible was placed within the ceramic muffle with heating coil wounded around it. The chamber is closed to prevent oxidation of the aluminium at liquid stage as it is highly reactive at its molten stage.
- A continuous and constant feed rate is required during the stirring of the molten alloy. This is necessary in order to avoid thickening of the liquefied alloy. The stirring of the melted liquefied alloy was performed at the speed of 300-500rpm. After constant stirring, the molten was allowed to cool for 2mins at its semi molten state. Degasser was added to the liquefied metal during stirring process for the removal of unwanted dust and oxides. After the addition of the degasser, the impurities floated at the top layer of the molten metal, which were removed carefully and disposed off.
- After each addition of the reinforcement, constant stirring rate ensures satisfactory distribution of the particles added. Longer the stirring time, better the distribution and infusion of the reinforcement particulates.

Fig. 7 - Casted specimens kept for cooling

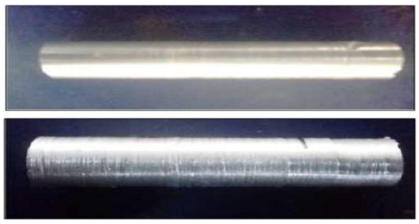

Fig. 8 - Comparison of surface finish achieved between 2% (top) and 6% (bottom).

- It was noted that with the increase in the percentage concentrations the ability to achieve smooth surface finish gets declined i.e. as the percentage of SiC increases surface roughness also increases hence restricting production of smooth surface.
- It was also observed that the time required to slice the cast specimen increased with a surge in reinforcement percentage, this is due to the

restriction to the cutting blade movement offered the SiC particles within the AMC.

- The latter specimens were needed to be polished by using emery paper which was the requirement for successful and smooth extrusion.

3.4 ECAP Working Method

- The specimen/billet were machined as per the channel specification i.e. Φ10.6mm and length 80mm.

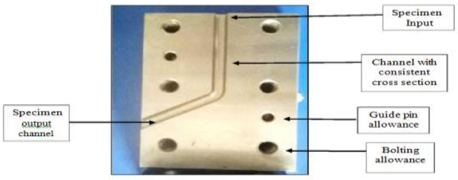

Fig. 9 - Illustration of the ECAP die with 120° channel angle

Fig. 10 - Extruded samples

- Specimen was coated with lubricant and introduced into the die. Pressing was carried on a universal testing machine with pressing speed of the 2~3mm / s. No heat treatment was given to the billet and the die.
- Route A was implemented during the pressing that is no rotation was given to the billet.
- Strain imposing was done on the billet by passing it for single time only.
- The extruded specimens were machined as per the testing requirements.

4. RESULTS AND DISCUSSION

4.1 Density Test

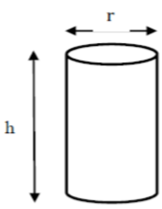

Fig. 11 - Cylinder volume

The theoretical density is calculated by making use of rule of mixture formula. It is known that the composite mass fraction is stated as

$$W_r + W_m = W_c \quad (2)$$

Thus expressing the above equation in terms of density

$$\rho_r V_r + \rho_m V_m = \rho_c V_c \quad (3)$$

Thus simplifying the equation in terms of mass fraction

$$\frac{1}{\rho_c} = \frac{W_r}{\rho_r} + \frac{W_m}{\rho_m} \quad (4)$$

Where Wm is the weight of the matrix. Wr is weight of the reinforcement. ρ_c is density of the composite. ρ_m is density of the matrix. ρ_r is density of the reinforcement.

Thus the densities for both type specimens are calculated and along with that experimental density are determined. The experimental measurements included weighing and measuring the dimensions of the specimen.

- For 2% of reinforcement addition:

$$\frac{1}{\rho_c} = \frac{0.02}{3.22} + \frac{0.98}{2.7}$$

$$\rho_c = 2.708\ gm/cc$$

Table 5 - Densities obtained of Non ECAPed specimen

Reinforcement %	Theoretical (gm/cc)	Non-ECAP (gm/cc)	ECAP (gm/cc)
0	2.7	2.573	2.594
2	2.708	2.6079	2.627
4	2.7175	2.609	2.692
6	2.7264	2.623	2.714
8	2.7353	2.695	2.967

The comparative of Non-ECAPed and ECAPed specimen infer that there has been significant improvement in the densities of the ECAPed specimens. This is due high shear strain enforced during the pressing process and also due to the back pressure acting on the specimen. Although the cross sections remain same after the extrusion but there is considerable improvement in the density. This ensures that there has been suitable effect on the grain refinement of the billet leading to significant improvement in the densities of the extruded part.

4.2 Hardness Test

Hardness is mechanical property of a material by virtue of which it provides resistance to indentation. The specimen's micro hardness were determined through means of Brinell hardness testing machine. Generally in Brinell hardness testing of metallic surface ASTM 10-7a standard is implemented. The testing equipment consists of steel ball indenter with diameter of 10mm whereby this steel ball is pressurised on the surface of the specimen in order to impinge the impression on it.

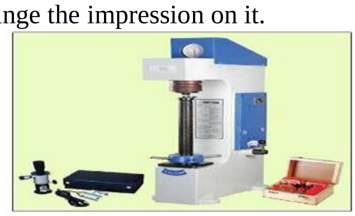

Fig. 12 - MRB 250 Brinell hardness tester

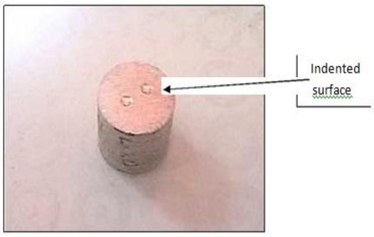

Fig. 13 - Specimen subjected to hardness test indentation

The equation for Brinell hardness number is given as:

$$B = \frac{W}{\left(\frac{\pi}{2}\right)\left(D - \sqrt{D^2 - d^2}\right)} = \frac{W}{\pi} \qquad (5)$$

Where D – diameter of steel ball.
d – Indentation diameter.
t - Impression depth, W- Load applied in kilograms

Table 6 - Brinell hardness value

% of reinforcement	Non ECAP	ECAP
0	62	68.4
2	64	68.4
4	65.7	84.3
6	67.7	95.4
8	66.2	87.6

4.3 SEM

Scanning electron microscope is a kind of electron microscope which creates images of the specimen by examining it with a concentrated ray of electrons. The electrons intermingle with the atoms in the material hence producing various signals containing data about surface topography. Resolution of 1nano meter can be achieved in SEM. The surface morphology of the specimen can be studied in low and high vacuum condition, elevated temperature and wet conditions.

Fig. 14 - SEM equipment & Mirror polished specimen ready for SEM analysis

The SEM analysis provide information regarding changes occurring at microstructural level such as particle size and distribution, identification of porosities, Crack propagation path etc. Suitable images were captured and analysed for variations within the matrix phase.
From the images captured, the differentiation of the reinforced particles is scarcely possible. This possibly might be due to smaller particle size of 400 micron mesh. There has been considerable decrease in the porosity level after the ECAP process and clustering of the particles has reduced.

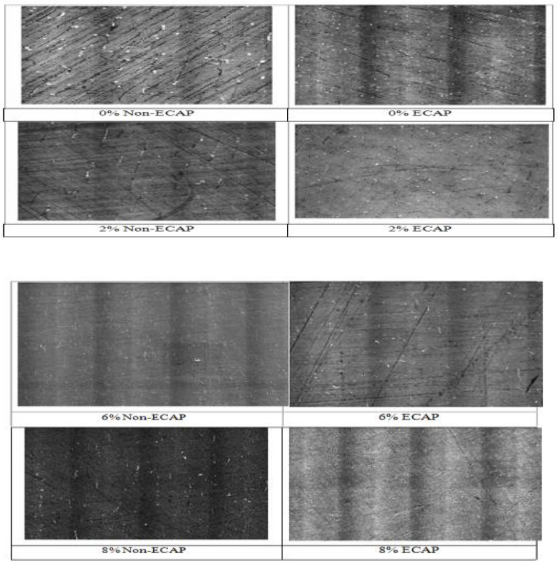

Fig. 15 - SEM imaging of the polished surfaces

5. CONCLUSION

Addition of the SiC particles to the Al6061 alloy leads to enhancement in both tribological and mechanical properties. Since Al6061 belonged to heat treatable series, it could be certainly implemented for stir casting and pressing technique. Thus this casting technique can be successfully adopted for the casting of AMC unless the process parameters are strictly followed. Stir casting technique is reliable and economical in comparison to other processing methods. The Equal channel angular pressing is successfully implemented, i.e. imposing of high strain when passed through the ECAP channel leading to grain refinement which in turn enhances the materials property.

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