Study of the Effect of Process Parameters on Mechanical Properties and Microstructure of Al-Cu and SiC_p Reinforced Metal Matrix Composite

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ABSTRACT: The high cost of fabrication hindered the actual application of metal matrix composite (MMC) despite of their high stiffness, strength, corrosion resistance, wear resistance, non-reactivity with chemicals and so many other tailored quality which are never obtained in alloy of metals. In this study, a modest attempt has been made to find out the process parameters at which best mechanical properties of Al6061, 4%Cu and reinforced 5% SiC_p ceramic MMC can be obtained. Addition of 4% Cu in Al6061 is more or less comparable to the composition of duralumin, which is widely used in aerospace applications. SiC_p is hard and having linear thermal expansion at high temperature. With reinforcement of SiC_p in Al-Cu alloy, it can be postulated that hardness of MMC retains at high temperature applications.

An analysis of Variance (ANOVA) was used for analysis of data with the help of SPSS (Version-17.0) software. Independent parameters are three levels of pouring rates (1.5cm/s, 2.5 cm/s and 3.5 cm/s), material type (Al6061+4%Cu alloy and Al+4%Cu, reinforced 5%SiC_p MMC processed using stir casting technique) and dependent parameters are hardness and impact strength, which is found that at different pouring rates material hardness and impact strength are highly significant. At pouring rate of 2.5 cm/s and 700±5˚C pouring temperature, optimum values of hardness and impact strength are observed as compared to other values of pouring rates (1.5 cm/s and 3.5 cm/s). With reinforcement of 5% SiC trend of mechanical properties is same, but hardness and impact strength of MMCs are increased by 25% and 20% respectively. Also it is observed from scanning electron microscopy (SEM) that at pouring rate 2.5 cm/s a better homogeneity can be obtained.

Key Words:MMC, Al6061+4%Cu alloy, SiC particulate reinforcement, Stir Casting Technique, Mechanical Properties, scanning electron microscopy (SEM).

I. INTRODUCTION

MMCs of aluminium are used for space shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs and a variety of other applications due to its light weight [9]. The major complication in processing MMCs is achieving a homogeneous distribution of reinforcement in the matrix as it has a strong impact on the properties and the quality of the material [10].

Reinforcement of ceramics (Al_2O_3 or SiC) in Al MMC, mechanical properties is improved. However mechanical properties and homogeneity are depends on reinforced particulate size, weight percentage and processing methods [5,3]. Chennakesava and Essa, in their rigorous experimentation, investigated the mechanical properties for different metal matrix composites produced from Al 6061, Al 6063 and Al 7072 matrix alloys reinforced with silicon carbide particulates [6].

Virgil, emphasized his work on the range of duralumin alloys and determined the fact that alloying is enlarging the possibilities of precipitation hardening [4]. Behera et.al, reported the solidification behavior and forgeability of aluminum alloy (LM-6)-SiC_p at different section of three stepped composite castings [1]. A new stir casting technique were developed in which all substances are placed in a graphite crucible and heated in an inert atmosphere until the matrix alloy is melted and then followed by a two-step stirring action before pouring into a mould has advantages in terms of promoting wet ability and mechanical properties enhancement of aluminum alloy MMC casting [7]. The effect of particulate silicon carbide on the mechanical behaviour of Al 6061 MMC has been studied previously [2, 8].

However in present study an attempt is made to find out the effect of pouring rate on mechanical properties and homogeneity of MMC (Al6061+4%Cu, 5%SiC_p reinforced) which is not appreciably found in literature concern to MMCs.

II. DESIGN OF EXPERIMENT

A. Process Parameters

The material selection criteria involve the requirement of high strength and good corrosion resistant aluminium alloys for the matrix materials. Present work emphasize on mechanical properties of Aluminium-Copper-Silicon Carbide (Al-Cu-SiC) metal matrix composite casting. ANOVA were used for analysis of data. Input variables are: pouring rate and material type and the output variables are: hardness and impact strength. It is postulated in null hypothesis that input variables (pouring rate and material type) have no significant effect on mechanical properties (Hardness and Impact strength). Three levels of pouring rate: 1.5cm/s, 2.5cm/s, 3.5cm/s two levels of material type (Al6061+4%Cu alloy and Al6061+4%Cu, reinforced 5%SiC_p MMC) and a constant pouring temperature 700^0C (approx) were considered.

B. Methodology

A stirring system has been developed by motor with regulator and a casted stirrer. To ensure the proper mixing of melts, all the melting was carried out in a graphite crucible in an open hearth furnace. Billet of aluminium and copper were preheated at 450^0C for 40 minutes before melting and the SiC particles were preheated at 1100^0C for 2 hours to make their surfaces oxidized. The furnace temperature was first raised above the liquidus to melt the feed stock completely and was then cooled down just below the liquidus to keep the slurry in a semi-solid state. At this stage the preheated SiC particles were added and mixed manually. Manual mixing was done because difficulty in mixing by using automatic device when the alloy was in a semi-solid state. After sufficient manual mixing, the composite slurry was reheated to a fully liquid state and then automatic mechanical mixing was carried out for about 10 minutes at a normal stirring rate of 600 rpm. In the final mixing process, the furnace temperature was within 760^0C and the composite slurry was poured in a sand mould prepared as per the standard specimen specifications.

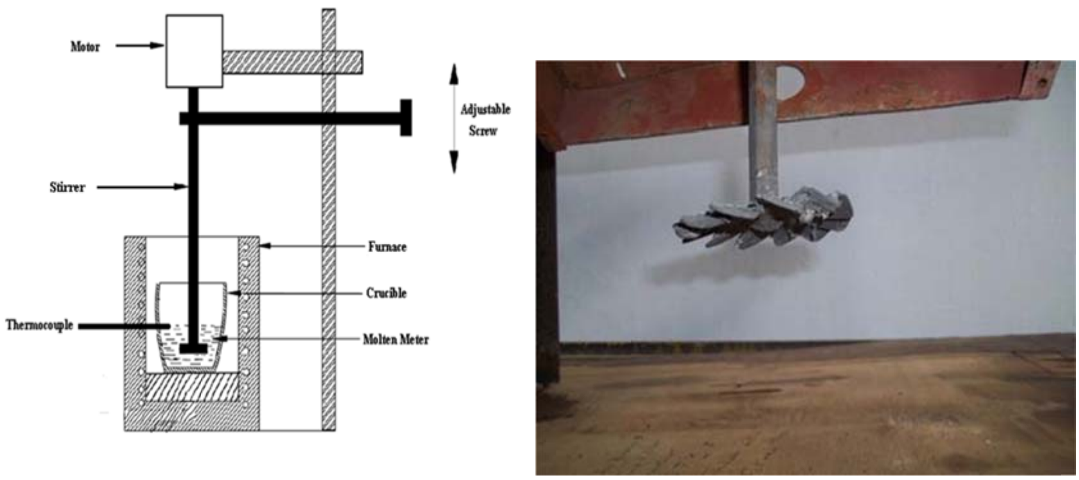


Fig.1-Schematic view of Experimental setup and strirer

C. Testing of materials:

i) Hardness test:

Hardness test provide an accurate, rapid and economical way to determine the material deformation. The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece. Hardness and impact strength were recorded and tabulated. Hardness test has been conducted on each specimen using a load of 250 N and a steel ball indenter of diameter 5 mm as indenter. Diameter of impression made by indenter has been measured by Brinnell microscope. The corresponding values of hardness (BHN) were calculated from the standard formula.

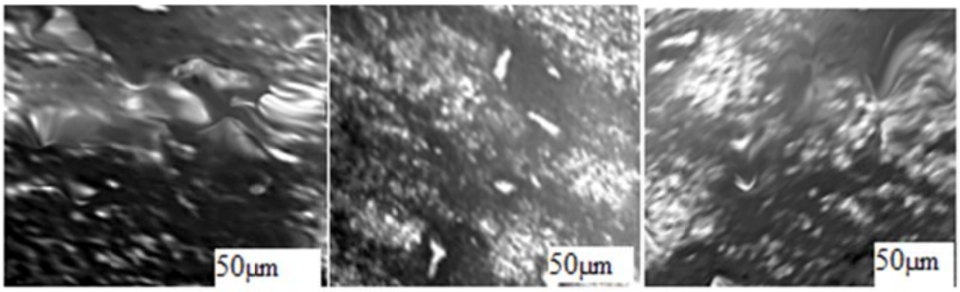
Fig. 2- Brinell hardness and Impact strength Tested Specimen.

ii) Impact Strength Test

An impact test signifies toughness of the material that is the ability of a material to absorb energy during plastic deformation. Impact strength is generally lower as compared to strength achieved under slowly applied load. Therefore the impact test measures the energy necessary to fracture a standard notch bar by applying an input load. Izod impact strength testing is a standard method of determining impact strength. Izod impact test were conducted on notched sample. Standard square impact test specimen of dimension 75mm x 10mm x 10mm with notch depth of 2mm and a notch of angle of 45^0 were prepared by casting. The machine could provide a range of impact energies from 0 to 164J. The mass of the hammer was 22 kg.

III. RESULTS

From surface micrographs (SEM) study it is observed that with the increase in pouring rate up to certain limit increases the homogeneity in mixing of SiC_p ceramic in matrix alloy but after that SiC_p is separated from metal alloys. At pouring rate 1.5 cm/s insufficient mixing of alloy metal and SiC ceramic [fig.4(a)], at pouring rate 2.5 cm/s having homogenous mixing is achieved [fig.4(b)] and at pouring rate 3.5 cm/s shows the segregation of SiC from matrix alloy [fig.4(c)].



(a) At pouring rate 1.5 cm/s (b) At pouring rate 2.5 cm/s (c)At pouring rate 3.5 cm/s

Fig.4. Micrographs of Al (Al6061)-4% Cu and 5% SiC Composite at different pouring rate.

Statistical analysis were performed using SPSS (Version-17.0).The result of Multivariable Analysis of Variance (MANOVA) to see the effect of input variables such as pouring rate and material type on output properties such as hardness and impact strength. It is obtained from MANOVA (table-1), the effect of pouring rate and material type are highly significant for the output variables. However the interaction of Material Type and pouring rate on output variables are not found significant. The above analyses were done for 95% confidence level.

The graphical analysis of the effect of the input variables on output characteristics is shown in fig.-5 and fig.-6 (for, Hardness and impact strength). The hardness value initially increases with pouring rate, thereafter it falls sharply when the pouring rate is 3.5 cm/s. For the pouring rate of 2.5cm/s the optimum value of hardness were obtained keeping pouring temperature constant at 700±5˚C for both materials. Similarly fig.-5 indicates that at the pouring rate 2.5cm/s, impact strength is optimum. Material-2 has better response than material-1 for the output characteristics hardness and impact strength.

Table-1. Summary of Result Analyzed by MANOVA

Source	Dependent Variable	Type III Sum of Squares	Degree of freedom	Mean Square	F	Significance
Material	Hardness	1073.389	1	1073.389	483.025	.000
	Impact Strength	242.000	1	242.000	335.077	.000
Pouring Rate	Hardness	213.778	2	106.889	48.100	.000
	Impact Strength	79.000	2	39.500	54.692	.000
Material*Pouring Rate	Hardness	1.778	2	.889	.400	.679
	Impact Strength	2.333	2	1.167	1.615	.239

(1) HARDNESS:

For, Material-1 (4%Cu+ Balanced Al6061),

Material-2 (4%Cu+5%SiC+ Balanced Al6061).

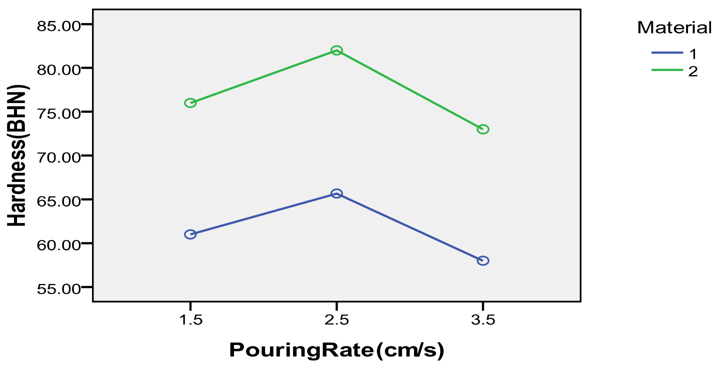


Fig. 5. Pouring rate Vs Hardness

(2) IMPACT STRENGTH:

For, Material-1 (4%Cu+ Balanced Al6061),

Material-2 (4%Cu+5%SiC+ Balanced Al6061)

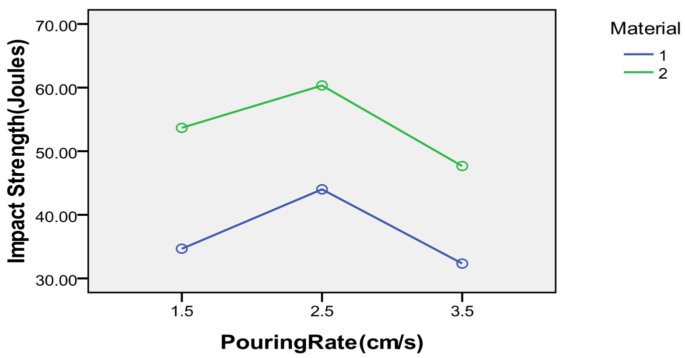


Fig. 6. Pouring rate Vs Impact strength

IV.DISCUSSION

No significant work has been found in literature survey on the effect of pouring rate on Al6061+4%Cu and Al6061+4%Cu + reinforced 5% SiC particulate MMC.

It is inferred from experimental results that variables (pouring rate and material type) have a significant effect on output variables such as hardness and impact strength. From the fig-5& 6, it is clear that the pouring rate of 2.5cm/s gives the optimum value of hardness and impact strength for both materials, when the pouring temperature were kept constant at 700^{0}C. Material-2 has high values of hardness and impact strength than material-1 as above pouring rates.

The result is partially supported by the study of Manoj et al., Which suggest that with the increase in the composition of SiC, increases the hardness and impact strength, also the study suggest that homogenous dispersion of SiC particles in the Al matrix shows an increasing trend in mechanical properties[2]. The reason of better result in the context of higher values of hardness and impact strength of aluminium-copper and silicon carbide ceramic reinforced (Al-Cu-SiC) MMC compare to Aluminium-Copper alloy, may be the homogeneous dispersion of SiC particles due to stir casting technique.

Also the results match with Akpan result, who found that the pouring rate range which gave the best surface finish and optimum values of hardness, impact strength and ultimate tensile strength is between 2 cm/s and 2.8 cm/s for aluminium alloy casting[3].

V.CONCLUSION

1. Reinforcement of SiC_p increases the Impact strength and Hardness.

2. Increase in poring rate increases the impact strength and hardness of material up to a certain limit after that these properties decrease drastically.

3. The optimal value of hardness and impact strength for Matrix alloy and MMC is obtained at pouring rate 2.5cm/s.

4. It is observed from SEM study that at pouring rate 2.5cm/s better homogeneity can be obtained.

5. Reason of improved mechanical properties of the composites compare to matrix alloy may be the stir casting technique of production and reinforcement of $SiC_{p.}$,

References

[1] Rabindra Behera, Kayal,S and Sutradhar,G,(2011) Solidification behavior and detection of Hotspots in Aluminium Alloy castings: Computer Aided Analysis and experimental validation, Vol. 1, No. 4, pp 715-726.

[2] Manoj Singla, D. Deepak Dwivedi, Lakhvir Singh, Vikas .C.,(2009),Development of Aluminium Based Silicon Carbide ParticulateMetal Matrix Composite, Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No.6, pp 455-467.

[3] Mohammad.B.N,Akpan.P.P.,(2007), Behavior of Aluminium Alloys Casting under Different Pouring Temperature and Speeds, Leonardo Electronic journal of Practices and Technologies pp. 71-80.

[4] Virgil Geaman .,(2009) ,Applications of Isostatic Processing Technology in the field of Duralumin Alloys, Bulletin of the Transilvania University of Brasov , vol. 2, pp.130-134.

[5] Nrip.Jit Anand.K.Tyagi and Nirmal.S.,(2009), Al-Cu-Si-(Al_2O_3) composite using A 384.1 Al Alloys, Asian Journal of Chemistry ,Vol,21,No.10:066-077.

[6] A. Chennakesava .R, Essa Z.,(2010), Matrix Al-alloys for silicon carbide particle reinforced metal matrix composites, Indian Journal of Science and Technology, Vol. 3 No. 12 ,pp.1184-1187.

[7] Jasmi Hashim.,(2007), The Production of Cast Metal Matrix Composite by a Modified Stir Casting Method, University Technology Malaysia, Journal Technology, Vol. 35, pp. 9-20.

[8] Srivatsan T.S., Meslet Al-Hajai, B. Hotton and P. C. Larn.,(2002) Effect of Particulate Silicon Carbide on Cyclic Plastic Strain Response and Fracture Behaviour of 6061Aluminium alloy MMC, Applied Composite Materials,vol.9,pp. 131-153.

[9] Miracle DB. Metal matrix composites – from science to technological significance. Compos Sci Technol,(2005),Vol.65,pp.2526–2540.

[10] Naher S, Brabazon D, Looney L. Development and assessment of a new quick quench stir caster design for the production of metal matrix composites. Journal of Material Process Technology 2005,vol.166(3),pp.430–439.