

Mechanical and Machining Properties Analysis of Al6061-Cu-Reinforced SiC_p Metal Matrix Composite

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ABSTRACT

The metal matrix composite (MMC), despite of its high stiffness, strength, corrosion resistance, wear resistance, non-react with chemicals and so many other tailored qualities which are never obtained in alloy of metals, has limited utilization due to the high cost of fabrication. 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. The addition of 4% Cu in Al6061 is more or less comparable to the composition duralumin, which are widely used in aerospace applications. SiC_p is hard and has linear thermal expansion at high temperature. With reinforcement of SiC_p in Al6061-Cu alloy, it can be postulated that hardness of MMC retains at high temperature applications. An analysis of Variance (ANOVA) and linear regression was used for analysis of data with the help of SPSS (Version-17.0). Independent parameters are five levels of pouring rates (1.5 cm/s, 2.0 cm/s, 2.5 cm/s, 3.0 cm/s and 3.5 cm/s), and material type (Al6061 + 4% Cu alloy and Al6061 + 4% Cu, reinforced 5% SiC_p MMC processed using stir casting technique) and dependent parameters are hardness and impact strength material removal rates of workpiece. It is found that at different pouring rates material hardness and impact strength of workpiece are highly significant but the material removal rate of workpiece is having no significance value. At pouring rate of 2.5 cm/s and 700°C ± 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, 2.0 cm/s, 3.0 cm/s and 3.5 cm/s). Material Removal rate for work pieces of Al6061 + 4% Cu alloy is less as compared to MMC. So it can be concluded that MMC has better machining ability compared to Al6061 + 4% Cu alloy. Material removal rate of Al6061 + 4% Cu, reinforced 5% SiC_p MMC has maximum values at 1.5 cm/s pouring rate compared to 2.0 cm/s, 2.5 cm/s, 3.0 cm/s and 3.5 cm/s pouring rates. With reinforcement of 5% SiC trend of mechanical properties is same, but the 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.

KEYWORDS

MMC; Al6061 + 4% Cu Alloy; SiC Particulate; Stir Casting Technique; Mechanical Properties; Scanning Electron Microscopy (SEM); Machining Property of MMC

1. 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 [1]. Al-SiC_p metal matrix composites possess many excellent properties such as high specific strength, high specific stiffness, small coefficient of thermal expansion (CTE) and good wear resistance, etc. [2-5], and these qualities make it appropriate for demanding application in aerospace and automobile industries.

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Reinforcement of ceramics (Al_2O_3 or SiC) in Al MMC, mechanical properties is improved. However mechanical properties and homogeneity depend on the reinforced particulate size, weight percentage and processing methods [5,6]. 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 [7]. Christy *et al.* studied the effect of particulate silicon carbide on the mechanical behavior of Al 6061 MMC [8].

In the 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 the literature concern to MMCs.

2. Design of Experiment

2.1. Process Parameters

The material selection criteria involve the requirement of high strength and good corrosion resistant aluminium alloys for the matrix materials. Present work emphasizes 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, impact strength and material removal rate. It is postulated in null hypothesis that input variables (pouring rate and material type) have no significant effect on mechanical properties (Hardness, Impact strength and material removal rate or say wear resistance capacity). Five levels of pouring rate: 1.5 cm/s, 2.0 cm/s, 2.5 cm/s, 3.0 cm/s and 3.5 cm/s two levels of material type (Al6061 + 4% Cu alloy and Al + 4% Cu, reinforced 5% SiC_p MMC) and a constant pouring temperature 700°C (approx) were considered (Table 1).

2.2. Methodology

A stirring system has been developed by the motor with regulator and a cast stirrer (Figure 1). 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°C for 40 minutes before melting and the SiC particles were preheated at 1100°C 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 semisolid state. At this stage the preheated SiC particles were added and mixed manually. Manual mixing was done because difficulty in mixing by using an 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°C and the composite slurry was poured in a sand mould designed to get standard specimens as shown in Figure 2.

2.3. Testing of Materials

2.3.1. Hardness Test

Hardness test provides 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. The diameter of the impression made by indenter has been measured by Brinell microscope. The corresponding values of hard-

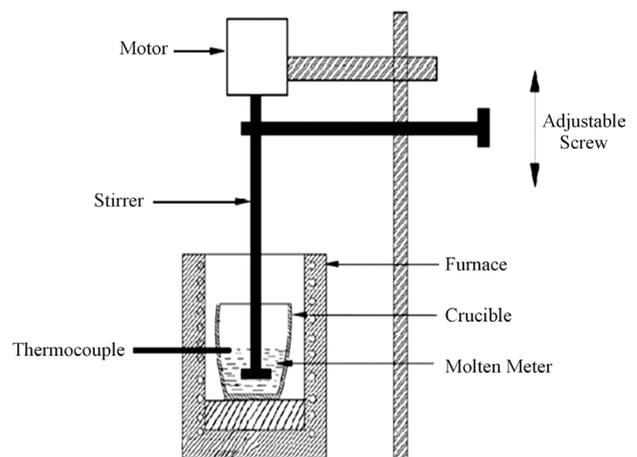


Figure 1. Schematic view of experimental setup and stirrer.

Table 1. Chemical compositions of Al (6061) alloy (weight percentage).

Mg	Si	Fe	Cu	Ti	Cr	Zn	Mn	Al
0.90	0.60	0.25	0.22	0.06	0.10	0.05	0.04	Bal

ness (BHN) were calculated from the standard formula.

2.3.2. 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. The Izod impact test was conducted on notched sample. Standard square impact test specimen of dimension 75 mm × 10 mm × 10 mm



Figure 2. Standard specimen for Brinell hardness and impact strength.

with notch depth of 2 mm and a notch of an angle of 45° were prepared by casting. The machine could provide a range of impact energies from 0 to 164 J. The mass of the hammer was 22 kg.

3. Results

From the 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 (**Figure 3(a)**), at pouring rate 2.5 cm/s having homogenous mixing is achieved (**Figure 3(b)**) and at pouring rate 3.5 cm/s shows the segregation of SiC from matrix alloy (**Figure 3(c)**).

Statistical analysis was 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, impact strength and material removal rate. It is obtained from MANOVA (**Table 2**), the effect of pouring rate and material type are highly significant for the output variables (hardness and impact strength) but for output variable material removal is not found significant for pouring rate. But for material type material removal rate is found significant. 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 multiple regression analysis of observed data was done by the of SPSS software for establishing mathematical relationship between independent variables on the dependent variables. From **Table 3** coefficient for independent variable pouring rate is [-0.600] and constant value is 63.967. Hence the dependent variable hardness of Al6061 + 4% Cu can be mathematically modelled as:

$$\text{Hardness} = 63.967 - 0.600 \times \text{Pouring rate} \quad (1)$$

Coefficient for independent variable pouring rate is [-0.733] and constant value is 37.167 (**Table 4**). Hence the dependent variable Impact strength (**Table 4**) and material removal rate (**Table 5**) are modelled mathematically

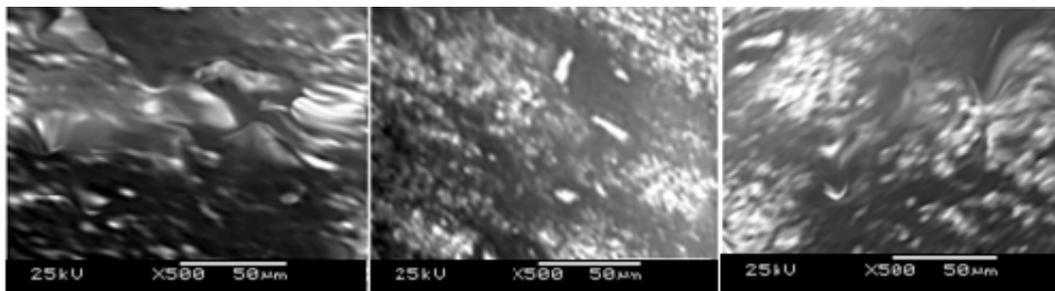


Figure 3. Micrograph of Al6061 + 4% Cu and 5% SiC composite at different pouring rate. (a) At pouring rate 1.5 cm/s; (b) At pouring rate 2.5 cm/s; (c) At pouring rate 3.5 cm/s.

Table 2. Summary of result analyzed by MANOVA.

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Material removal rate	0.001 ^a	9	0.000	0.930	0.521
	Impact strength	485.633 ^b	9	53.959	80.939	0.000
	Hardness	2098.533 ^c	9	233.170	112.824	0.000
Material Type	Material removal rate	0.001	1	0.001	6.836	0.0017
	Impact strength	396.033	1	396.033	594.050	0.000
	Hardness	1825.200	1	1825.200	883.161	0.000
Pouring Rate	Material removal rate	7.180E-5	4	1.795E-5	0.159	0.956
	Impact strength	87.133	4	21.783	32.675	0.000
	Hardness	264.533	4	66.133	32.000	0.000
Material Type * Pouring Rate	Material removal rate	0.000	4	2.538E-5	0.225	0.921
	Impact strength	2.467	4	0.617	0.925	0.469
	Hardness	8.800	4	2.200	1.065	0.400

^aR Squared = 0.295 (Adjusted R Squared = -0.022); ^bR Squared = 0.973 (Adjusted R Squared = 0.961); ^cR Squared = 0.981 (Adjusted R Squared = 0.972).

Table 3. Summary of linear regression coefficients for hardness of material-1 coefficient^a.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	63.967	2.942		21.742	0.000
	Pouring Rate	-0.600	1.132	-0.145	-0.530	0.605

^aDependent Variable: Hardness.

Table 4. Linear regression coefficients for impact strength of material-1 coefficients^b.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	37.167	1.921		19.348	0.000
	Pouring Rate	-0.733	0.739	-0.265	-0.992	0.339

^bDependent Variable: Impact Strength.

Table 5. Linear regression coefficient for material removal rate of material-1 coefficients^c.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.259	0.013		20.647	0.000
	Pouring Rate	0.001	0.005	0.061	0.221	0.829

^cDependent Variable: Material Removal Rate.

by Equation (2) and Equation (3) respectively as below:

$$\text{Impact Strength} = 37.167 - 0.733 \times \text{Pouring rate} \quad (2)$$

$$\text{Material Removal Rate} = 0.259 + 0.001 \times \text{Pouring rate} \quad (3)$$

Similarly for linear regression of material-2 (Al6061 + 4% Cu, reinforced 5% SiC_p MMC),

$$\text{Hardness} = 63.967 - 0.600 \times \text{Pouring rate} \quad (4)$$

$$\text{Impact Strength} = 37.167 - 0.733 \times \text{Pouring rate} \quad (5)$$

$$\text{Material Removal Rate} = 0.279 - 0.003 \times \text{Pouring rate} \quad (6)$$

The graphical analysis of the effect of the input variables on output characteristics is shown in **Figure 4**, **Figures 5** and **6** (for, Hardness, impact strength and metal removal rate). The hardness value initially increases with pouring rate up to 2.0 cm/s, thereafter it falls sharply with increase in pouring rate from 3.0 cm/s and 3.5 cm/s. For the pouring rate range of 2.5 cm/s to 3.0 cm/s the optimum value of hardness was obtained keeping pouring temperature constant at $700^{\circ}\text{C} \pm 5^{\circ}\text{C}$ for material-1 and pouring rate range of 2.0 cm/s to 3.0 cm/s hardness values are maximum. Similarly **Figure 5** indicates that at

the pouring rates ranges from 2.5 cm/s to 3.0 cm/s having impact strength values are optimum. Al6061 + 4% Cu, reinforced 5% SiC_p MMC has better response than Al6061 + 4% Cu alloy for the output characteristics hardness and impact strength.

From graph of **Figure 6** the material removal rate material-2 (MMC) is high compared to material-1 but not dependent on pouring rate.

4. 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.

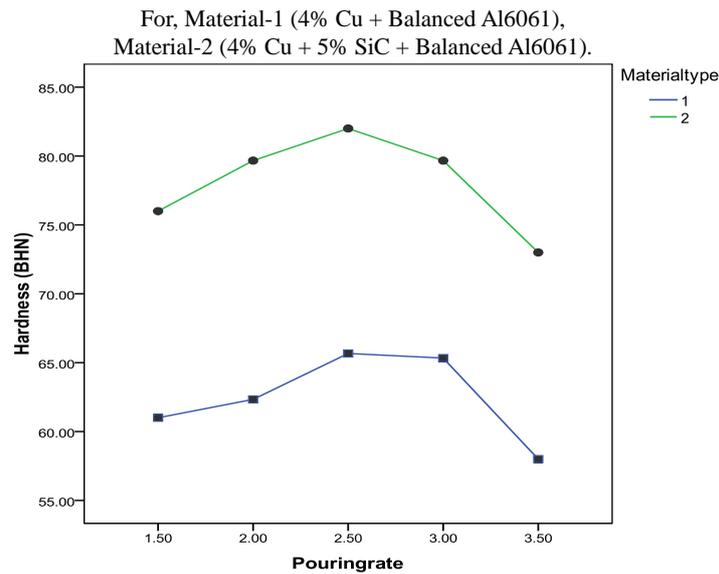


Figure 4. Pouring rate vs hardness.

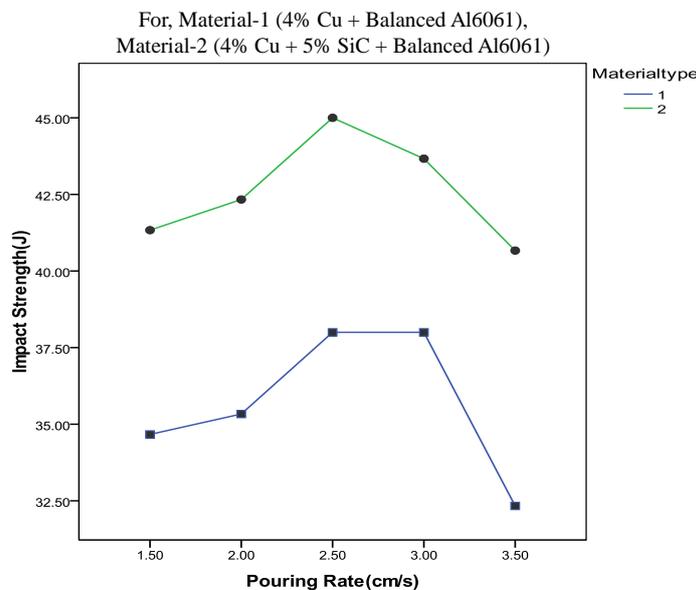


Figure 5. Pouring rate vs impact strength.

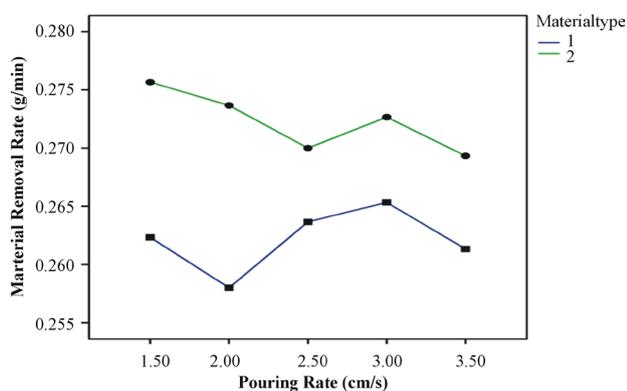


Figure 6. Pouring rate vs material removal rate of work pieces.

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 **Figures 4** and **5**, it is clear that the pouring rate ranges from 2.5 - 3.0 cm/s gives the optimum value of hardness and impact strength for both materials, when the pouring temperature were kept constant at 700°C. Material-2 (Al6061 + 4% Cu + reinforced 5% SiC particulate MMC) has high values of hardness and impact strength than material-1 (Al6061 + 4% Cu alloy) 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 [9]. 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 *et al.*, study, who found that the pouring range of rate 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 [10].

5. Conclusions

1) Reinforcement of SiC_p increases the impact strength, hardness and also material removal rate.

2) Increased material removal rate due to addition of SiC particulates is concluded as better machinability of MMC as compared to base alloy.

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

4) The optimal value of hardness and impact strength

for matrix alloy and MMC is obtained at pouring rate 2.5 cm/s.

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

6) 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.

7) Material removal rate is high in MMC compared to matrix alloy means better machining property is obtained if up to 5% SiC is reinforced in matrix alloy.

8) Pouring rate does not significantly affect the material removal rate for both matrix alloy and MMC.

9) The postulation of null hypothesis was failed so the alternative hypothesis is “the input variables pouring rate and material type have significant effect on hardness and impact strength and material removal rate is not affected by pouring speed”.

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