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Effect of Process Parameters on Wear Rate of Al 6061-Cu reinforced SiC_p Metal Matrix Composites

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Abstract
The excellent mechanical properties of Aluminium Metal Matrix Composites (MMC), together with weight saving make them very attractive for a variety of engineering applications in the automotive, aerospace and heavy machinery industries. Including this other properties like their high stiffness, strength, corrosion resistance, wear resistance, non-react with chemicals and so many other tailored quality which never obtainable in alloy of metal can be easily achieved in MMCs attract researchers in the last few decades. The major challenges in the fabrication of MMC are the difficulties of achieving uniform distribution of reinforce material and possible chemical reaction s between reinforcement material and matrix. Therefore, the present research was conducted to investigate the effect of stirring speed and pouring temperature on wear rate and microstructure of Al6061-Cu reinforced SiC MMC by stir casting technique. The dependent variable is wear rate by pin on disc wear method while the independent parameters are five level of stirring speed and five level of pouring temperature. The optimal values of wear rate are observed between ranges of 200 to 600 rpm stirring speed, at high speed (800 rpm) the wear rate increases drastically. The wear rates are stable in range of 700˚C to 750˚C of pouring temperature, except at 800 rpm stirring speed.

Keywords: MMC, Stir casting technique, stirring speed, pouring temperature, wearing rate.

1. Introduction
SiC particle reinforced aluminium composites have received more commercial attention than other kinds of MMCs due to their high performance viz. high mechanical properties, wear resistance, low coefficient of thermal expansion and high thermal conductivity. They are remeltable and that can be produced by large quantities by the process analogue to that used for commercial aluminium alloys at cheap cost. Therefore they are more competitive on the MMC market and find wider application in industries [1–3].Despite of the variety of processing techniques available for particulate or discontinuous reinforced metal matrix composites; stir casting is one of the methods accepted for the production of large quantity commercially practised. It is attractive because of simplicity, flexibility and most economical for large sized components to be fabricated [3]. The abrasive wear resistance of MMC has increased with increase in SiC content but wear has increased with increase in sliding velocity and normal load [4]. Stirring speed and stirring time influence the distribution of SiC in metal matrix and hardness of MMC [5]. Effect of process parameters on mechanical and machining properties of Al 6061-Cu- reinforced SiC are previously investigated [6, 7].

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 focuses on comparative investigation of wear property of base

metal Al 6061, Al6061-Cu and (Al6061-Cu-SiC) metal matrix composite (MMC) casting. ANOVA were used for analysis of data. Input variables are: pouring temperature and stirring speed, the output variable is wear rate. It is postulated in null hypothesis that input variables (pouring temperature and stirring speed) have no significant effect on wear rate of MMC. Five levels of pouring temperature: 675^0C, 700^0C, 725^0C, 750^0C and 775^0C and 50 rpm, 200 rpm, 400 rpm, 600rpm and 800 rpm and a constant pouring speed 2.5 cm/s were considered.

2.2 Methodology

A stirring system has been developed by the motor with regulator and a cast 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 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 five different stirring speeds. In the final mixing process, the furnace temperature was within 800^0C and the composite slurry was poured in a sand mould designed to get standard specimens.

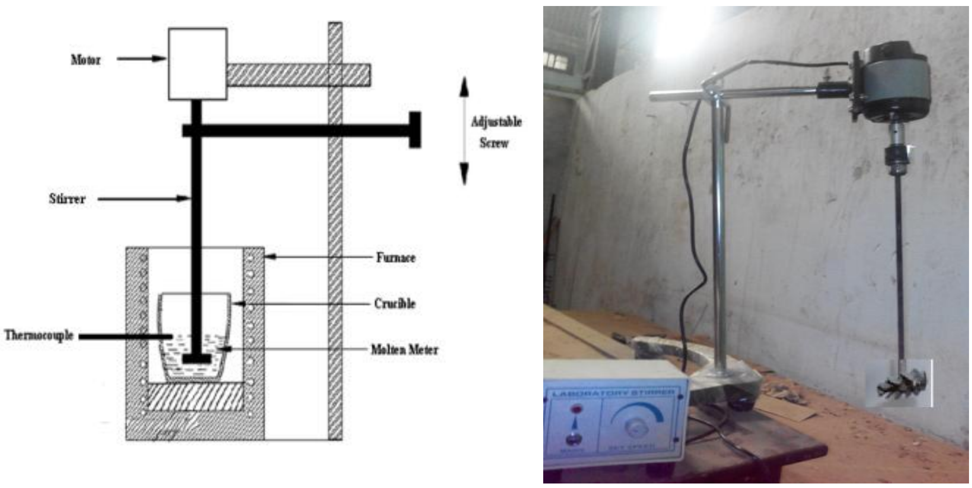

Figure1: Experimental setup and with stirring speed controller.

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	balance

2.3 Wear Testing of materials

Pin-on-disc test apparatus were used to investigate the dry sliding wear characteristics of the commercial aluminium Al 6061-4%Cu and Al6061-4%Cu- 5%SiC MMC specimens. Dry sliding wear tests, of sample size as per ASTM G99 standards, were conducted. Wear specimens of 10mm diameter and about 20mm length re-machined from cast samples and then polished by emery paper numbering in the sequence of 180,220, 320, 400, 600, 800 and 1200. Cleaned specimens were pressed against a rotating EN32 steel disc (hardness 65 HRC) of diameter 70mm and thickness 8mm by applying the constant encounter normal load of 5kg (at a room temperature about 25oC. The speed of the rotating disc was controlled at a constant speed of 620 rpm. The time

for each sample was set for 10 minutes. The wear testing machine was microprocessor controlled, in which height loss and frictional force can be monitored simultaneously by a PC-based data logging system. The weight losses were converted into volumetric loss by dividing density of test specimen. The wear rate was calculated by dividing volumetric loss with sliding distance and counter load applied. After each test the disc was cleaned.
The wear rates in terms of volume loss per unit sliding distance and per unit normal load were calculated by using the following formula:

$$\textbf{Wear rate} = \textbf{Volume loss during a given time (in mm3)/load per unit distance (in N/m)}$$

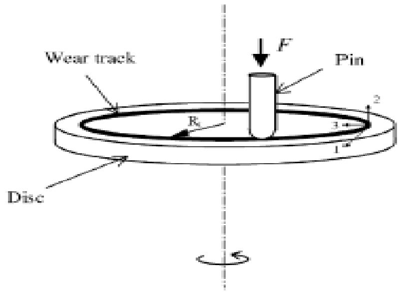

Figure 2 (a) : Pin on disc Wear Testing Machine **Figure 2 (b)** : Wear principle

3. Results:

3.1 Scanning Electron Micrograph (SEM): The SEM shown in figure 3(a), figure 3(b) and figure 3(c) are taken for specimens of constant pouring temperature of 725^0C and variable stirring speed of 200 rpm, 400 rpm and 600 rpm respectively. It is observed from the surface micrographs (SEM) study that with the increase in pouring speed up to certain limit increases the homogeneity in mixing of SiC_p ceramic in matrix alloy but after that metal alloy is separated from SiC_p. At pouring speed 200 rpm insufficient mixing of alloy metal and SiC ceramic [figure 3 (a)], at pouring speed of 400 rpm having homogenous mixing is achieved [figure 3 (b)] and at pouring rate 600 rpm the clouting of SiC are observed again [figure 3 (c)]. The figure 3(d) , figure 3(e) and figure 3(f) represents the surface micrographs of specimens produced at constant stirring speed of 400rpm and variable pouring temperatures of 725^0C, 750^0C and 775^0C respectively. It is reverted from figure 3(a) more homogeneous mixing of SiC_p in base alloy and also size of particles are small compared to figure 3(b) means 750^0C and figure(c) means 775^0C.

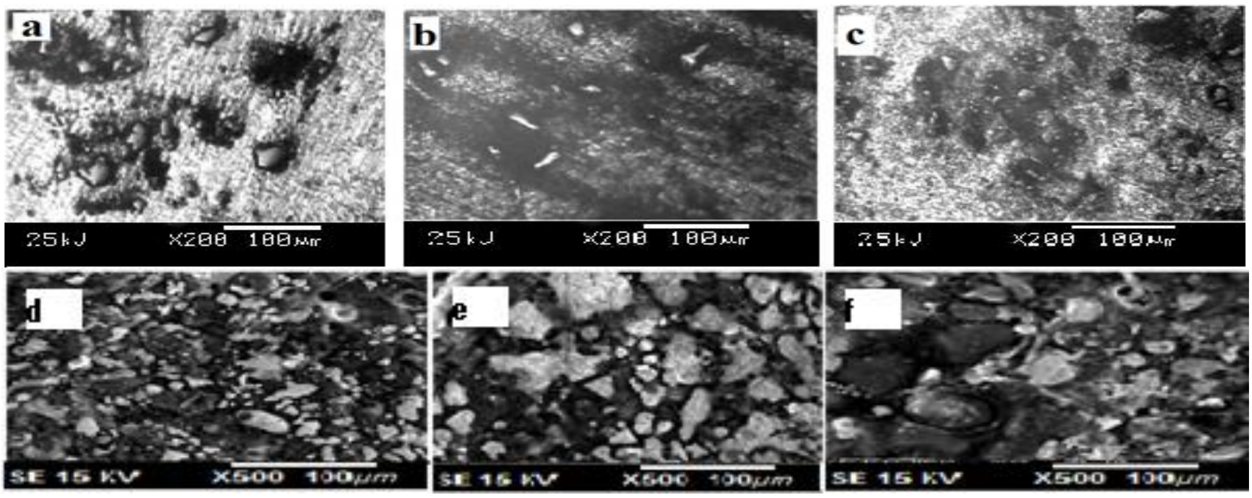

Figure 3: Micrograph of Al6061+4% Cu and 5% SiC_p Composite at different stirring speeds and pouring temperatures.

3.2 Analysis of data Statistical analysis was performed using SPSS (version- 17.0). The result of Analysis of Variance (ANOVA) to see the effect of input variables stirring speed and pouring temperature on output property material abrasive wear rate. It is obtained from ANOVA (table-1), the effect of pouring temperature and stirring speed are highly significant for the material wear rate (p=0.00 for stirring speed and p= 0.004 for pouring temperature which are very less than 0.05). However the interaction effect of stirring speed and pouring temperature on wear rate not found significant (p=0.15 > > 0.005). The above analyses were done for 95% confidence level.

It is inferred from graph of figure 4(a) that at stirring speed 200 rpm to 600 rpm the wear rate are less compared to 50 rpm and 800 rpm. The wear rate is high at 800 rpm at all five pouring temperatures. The graph of figure 4(b) shows that wear rate are more or less stable trend between pouring temperature of 700˚C to 750˚C after that it increases drastically.

Table2: Summary of Result Analyzed by ANOVA Dependent Variable: Wear Rate

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Stirringspeed	125.059	4	31.265	16.610	.000
PouringTemp	32.642	4	8.161	4.335	.004
Stirringspeed * PouringTemp	44.223	16	2.764	1.468	.150
Error	94.115	50	1.882		
Total	16975.714	75			
Corrected Total	296.039	74			

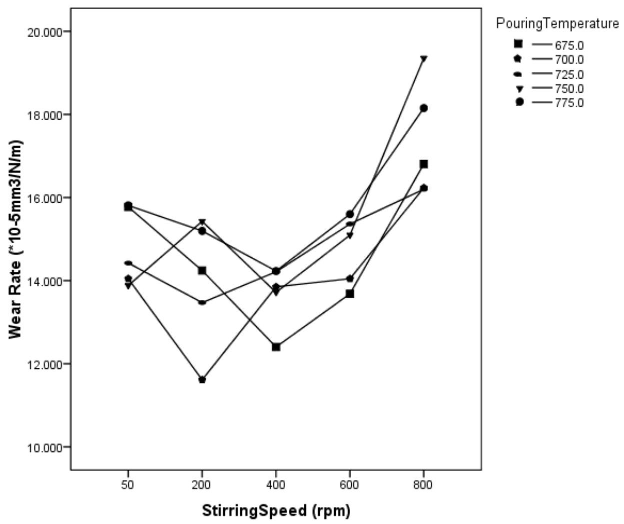

Figure4 (a) : Stirring Speed Vs Wear Rate

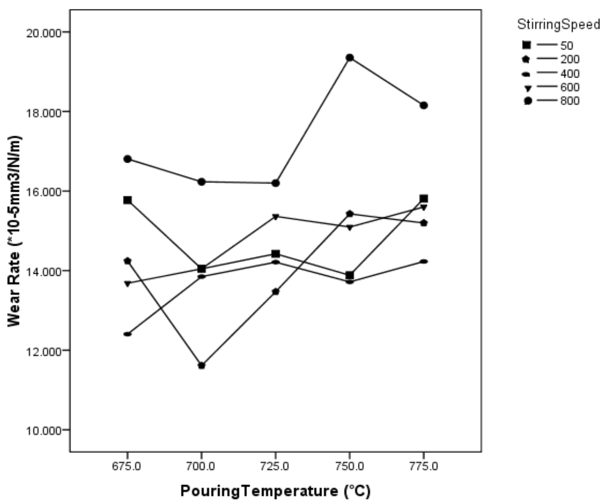

Figure4 (b) : Pouring Temperature Vs Wear Rate

Wear rate is high at 675 ˚C the reason may be the mechanical properties of the SiC reinforced composites are degraded due to the formation of Al_4C_3 at pouring temperature of 660 [8] also the reaction product Al_4C_3 is unstable in some environments such as water, methanol, and hydrochloric acid [9, 10] the composite can be susceptible to corrosive environments resulting in reduced mechanical properties of the composites. The high wear rates are observed at high stirring speed and low stirring speed these results are supported by the result of Aqida et.al. 2004, investigation in which it is concluded that at high speed porosity of MMC were increased drastically after certain limit of stirring speed also at low speed clustering of metal alloy and non homogenous micrographs are observed [11].

Conclusion

I. Wear rates are optimal at range of 200 rpm to 600 rpm for Al6061-4%Cu- 5%SiC MMC.
II. Optimum values of wear rates are obtained between ranges of 700˚C to 750˚C for Al6061-4%Cu- 5%SiC MMC.
III. At low pouring temperature 675˚C near melting point of metal matrix, wear rates are high for Al6061-4%Cu- 5%SiC MMC.
IV. Wear rates are also at high at high pouring temperature (775˚C) for Al6061-4%Cu- 5%SiC MMC.
V. Wear rates are high at high stirring speed above 600 rpm and also wear rates high when stirring speed is low i.e., 50 rpm.
VI. The MMC result may be valid for 2000 series of aluminium as with addition of 4% copper it is more or less comparable to 2000 series of commercial aluminium.

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