CHAPTER 5

EFFECT OF STIRRING SPEED AND POURING TEMPERATURE ON MECHANICAL PROPERTIES AND MACHINING PROPERTIES

5.1 INTRODUCTION

The ceramic metal matrix composites are material that contains ceramic in discrete phases which provide it additional strength [Chennakesava et al., (2011)]. The previous researches advocated that ceramic metal matrix composites have better mechanical properties compared with its base alloy of metal especially hardness [Haque et al., (2014), Kunieda et al., (2005), Anil et al., (2011)] which make it difficult to machine through conventional machining processes. Ultrasonic machining destroys the finish of edge of workpiece through the repetitive generation of micro cracks [J Kumar et al., (2009)]. Laser machining has a high cost of production, it may cause thermal stresses and heat effected zone on workpiece [Tsai et al., (2007)].

Electric Discharge Machining (EDM) commercially utilized to machine complex geometrical shape and difficult material which are unfeasible to machine through conventional machining process while negligible machining force and low cost of machining [Rajurkar et al., (2000), Zhao et al., (2002), J Kumar et al., (2009)] make it most suitable for unconventional machining processes. Casting parameters of ceramic metal matrix composite effect on metal removal rate through EDM is not sufficiently argued in the literature, so in present research, it is tried to find out the optimal casting process parameter at which best machining through EDM is achieved. Ranieria et al., (2012) concluded that the particle size and stirring speed are the most predominant factors in stir casting technique. Puneet et al., (2013) concluded that with increase in stirring speed from 180, 250, 400 and 1400 rpm the mechanical properties like hardness and impact strength are enhanced for Al alloy MMCs and he postulated that it could be because of the additional power implemented by the stirrer at higher rpm. But this research is contradicted by the findings of Aqida et al., (2003) in which authors stated that Stirring speed at 500 rpm produced almost twice the porosity content of 100 and 200 rpm stirring speeds in Al-SiCp MMCs. Moreover Naher et al., (2004) stated that stirring speed from 200 to 500 rpm of slurry in semi-solid state produced uniform distribution in matrix without addition of any wetting agent.

Sozhamannan et al., (2012) experimental work focused the influence of processing temperature and stirring time on Al-11Si-Mg alloy reinforced with SiC_p. The specimen was prepared at 700^0C, 750^0C, 800^0C, 850^0C and 900^0C.In the specimens prepared at 850^0C and 900^0C having pores and particles clustering were observed. Strengths are enhanced up to 800^0C and then start declining. Abdizadeh et al., (2013) researched the effect of ZrO_2 ceramic and pouring temperature on the mechanical properties and fracture performance of A356 Al/ZrO_2 composites. The paramount mechanical properties were obtained for the specimen prepared at 750°C.

Hence the emphasis of present work is to find out the optimal range of stirring speed and pouring temperature where better mechanical and machining properties of Al-SiC_p MMCs are achieved. Through optimal range of stirring speed and pouring temperature, one can accomplish the economy in stir casting method

5.2 DESIGN OF EXPERIMENT

5.2.1 Process parameters

In this experimentation, the effort was to explore the effect of pouring temperature and stirring speed on mechanical properties (viz. hardness, impact strength) and machining property(Material Removal Rate) of metal matrix composite (MMC). Independent process parameters are five levels of pouring temperature 675˚C, 700˚C, 725˚C, 750˚C and 775˚C and five levels of stirring speed 50 rpm, 200 rpm, 400 rpm, 600 rpm and 800 rpm. The dependent parameters are hardness, impact strength and material removal rate. The null hypothesis postulation is 'the independent (input) parameters pouring temperature and stirring speed have not affected on dependent parameters, i.e., hardness, impact strength and material removal rate through EDM'. The full factorial design (5^2) with three replicates are adopted for observation plan as shown in Appendix II, Table II.

Input Variables

Material Type	Unit	Al 6061-4% Cu-5% SiC_p Metal Matrix Composite				
Pouring Temperature	^{0}C	675	700	725	750	775
Stirring Speed	rpm	50	200	400	600	800

Outputs variables

1. Mechanical Properties

    a) Hardness

    b) Impact Strength

    c) Ultimate Tensile Strength

2. Material Removal Rate/Machining ability through EDM of Metal Matrix Composite

5.2.2 Production of MMC

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. Billets of aluminium and copper were preheated at 450^0C for 40 minutes before melting and the SiC particles of 63 µm 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 into a sand mold designed to get standard specimens as per design matrix is shown in Appendix-II.

5.2.3 Testing of MMC Specimens

5.2.3.1 Hardness test

Hardness test has been conducted on each specimen (Figure 5.1) using a load of 250 N and a steel ball indenter of diameter 5 mm as an indenter. The diameter of the impression made by indenter has been observed by the front display of Brinell hardness machine. The corresponding values of hardness (BHN) were calculated from the standard formula mentioned in Appendix-II also final values of hardness at all pouring temperature and stirring speeds are tabulated in Appendix-II.

Figure 5.1 Specimen for Brinell Hardness Test

5.2.3.2 Impact Strength Test

The Izod impact test was conducted on the notched sample. The Standard square impact test specimen (Figure 5.2) measured 75mm x 10mm x 10mm with a notch depth of 2mm and a notch of an angle of 45^0. The machine could provide a range of impact energies from 0 to 164J. The mass of the hammer was 22 kg. The energy required is calculated by standard formula as mentioned in Appendix-II.

Figure 5.2 Specimen of Impact Test

5.2.3.3 Tensile Strength Test

Tensile strength (TS), often know as Ultimate Tensile strength (UTS), is the maximum stress that a material can resist while being stretched or pulled before breaking. Tensile strength is defined as a stress, which is measured as force per unit area. The maximum capacity of Universal testing machine is 400KN. The standard tensile strength test specimen (Figure 5.3) measured 150mm x 20mm x 6mm. The specimen is prepared as per ASTM standard as shown in Figure 5.3. Final values of UTS at all pouring temperature and stirring speeds are tabulated in Appendix-II.

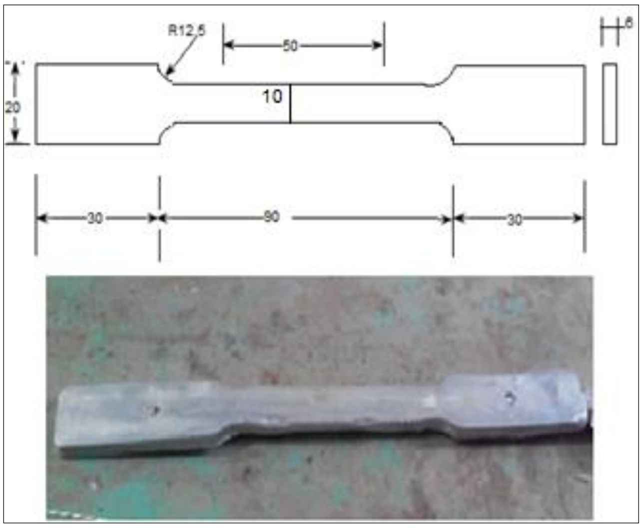

Figure 5.3 Specimen of Tensile Test

Figure 5.4 Electro discharge Machining.

5.2.3.3 Material Removal Rate of workpiece through EDM

A series of experiments were conducted using die-sinking EDM machine. A tool made of copper with diameter 10 mm was used as an electrode. The other electrode was Al6061 +4% Cu composites reinforced with 5wt. %SiC particles. The size of the workpiece is 10 mm diameter and 25 mm length. The commercial EDM oil (flash point = 130°C, density = 0.85) was used as a dielectric fluid and the side injection of dielectric fluid was adopted. Electro discharge machining operation shown in Figure 5.4. The process parameters (current 9A, pulse on time 300µs and 50 V) were being set in the EDM machine and the experiments were conducted as per the design matrix as shown in Appendix-II. After each experiment, the weights of specimens are measured with an electronic weighing machine.

5.3 RESULTS

5.3.1 Scanning Electron Micrograph (SEM)

It is observed from the surface micrographs (SEM) that with the increase in stirring speed up to certain limit increases the homogeneity of SiCp ceramic in matrix alloy. Further increase in stirring speed causes SiCp separation from the metal matrix. At stirring speeds of 50 rpm and 200 rpm, there is insufficient mixing of SiCp in the alloy metal [Figure 5.5 (a) and Figure 5.5 (b)]. The ceramic (SiCp) in MMCs is homogenous at stirring speed of 400 rpm [Figure 5.5 (c)]. SiC segregates at stirring speeds of 600 rpm and 800 rpm [Figure 5.5 (d) and Figure 5.5 (e)].

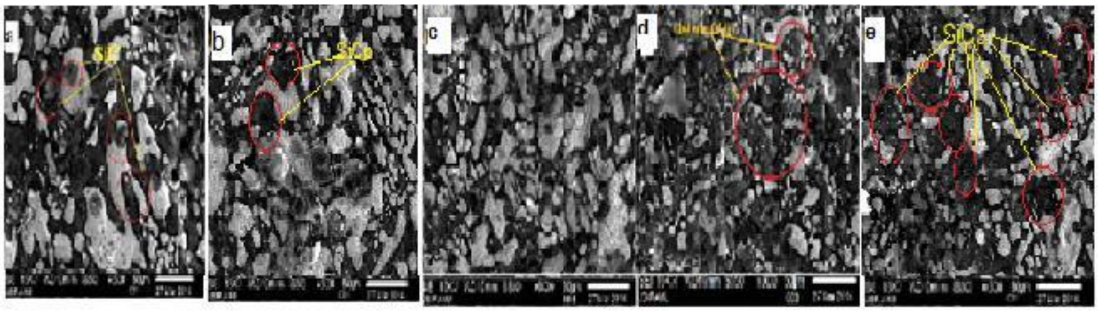

Figure 5.5 SEM of MMC at (a) 50 rpm (b) 200 rpm (c) 400 rpm (d) 600 rpm (e) 800 rpm at constant Pouring Temperature of 725˚C

The Figure 5.6(c) shows the scanning electron micrograph of Al6061/Cu/SiCp MMC at 725°C pouring temperature and 400 rpm stirring speed. It is clear from micrograph that size of particles are finer compared to 750°C and 775°C as shown in Figure 5.6 (d) and Figure 5.6 (e). At pouring temperatures of 675°C and 700°C, particles of SiC are observed at different locations [Figure 5.6 (a) and Figure 5.6 (b)]. The Figure 5.6 (e) exhibits that the homogeneity is ruined and clustering of SiC has occurred.

The homogeneity of mixing of SiCp are achieved at stirring speed 400 rpm at each level of pouring temperature respectively and at pouring temperature 725°C superior amalgamation compared among all levels of stirring speed; hence it can be postulated easily as an indication of better mechanical (viz. harness and impact strength) and machining properties of present MMCs. This fact is further supported by characteristic graphs which are discussed in section 5.3.3 of this chapter.

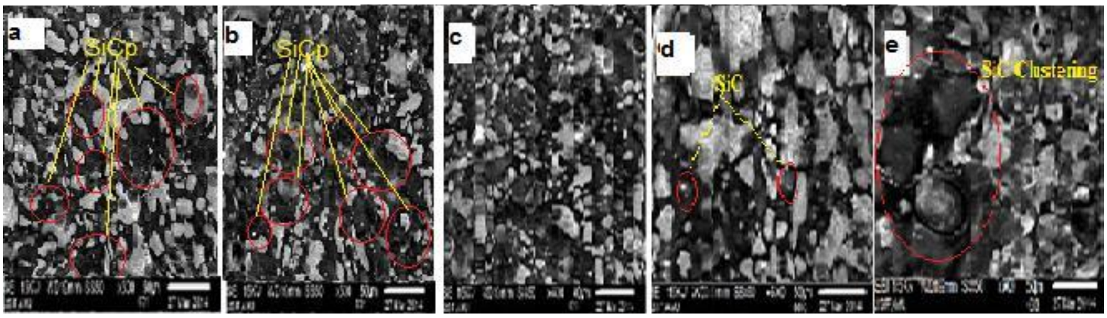

Figure 5.6 SEM at Pouring Temperature (a) 675˚C (b) 700˚C (c) 725˚C (d) 750˚C and (e) 775˚C at constant Stirring Speed of 400 rpm

5.3.2 Data Analysis

Multivariate Analysis of Variance (MANOVA) is used for the analysis of data with the help of SPSS-17 software, as shown in Table 5.1. The stirring speed is highly significant for hardness, impact strength and material removal rate ($p<<0.005$ i.e, confidence level=95%) but found insignificant for ultimate tensile strength. Similarly pouring temperature is a highly significant for hardness, impact strength and material removal rates ($p<<0.005$) but except ultimate tensile strength. The interaction affect of stirring speed and pouring temperature is also significant for hardness, impact strength and material removal rate ($p=0.001<<0.005$) but again ultimate tensile strength is not significant ($p=0.212 >>0.01$).

5.3.3 Characteristic Graphs:

Figure 5.7 shows that higher values of hardness lies between the stirring speed of 200 to 600 rpm at all pouring temperatures. However, the maximum hardness is at 400 rpm. Figure 5.8 indicates that at high stirring speed i.e, 800 rpm the hardness of material is degrades drastically for all pouring temperatures viz. 675˚C, 700˚C, 725˚C, 750˚C and 750˚C. The higher values of hardness are achieved between the pouring temperature ranging from 700˚C to 750˚C and stirring speed ranging from 200 rpm to 400 rpm. The maximum value of hardness is depicted at pouring temperature of 725˚C and stirring speed of 400 rpm. At very low stirring speed i.e., 50 rpm and at high stir speed, 800 rpm hardness values are very low as compared to other stirring speeds.

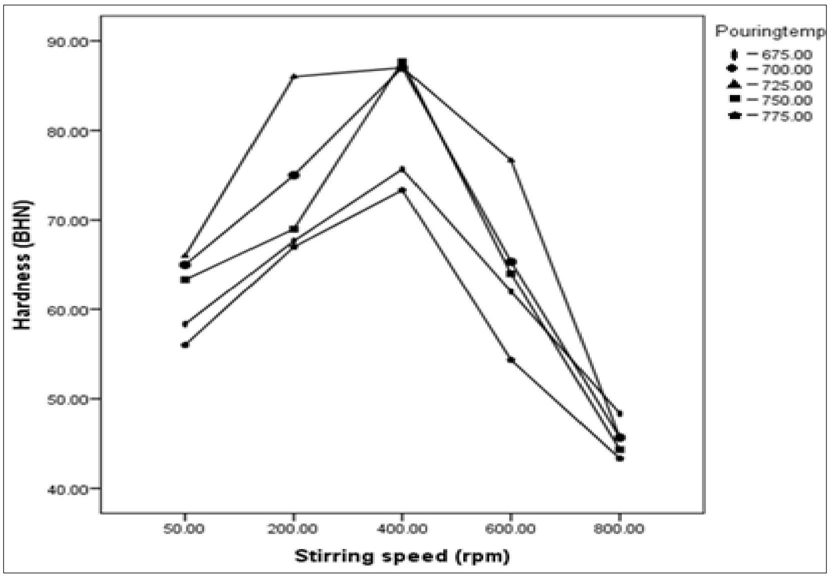

Figure 5.7 String Speed Vs Hardness Graph

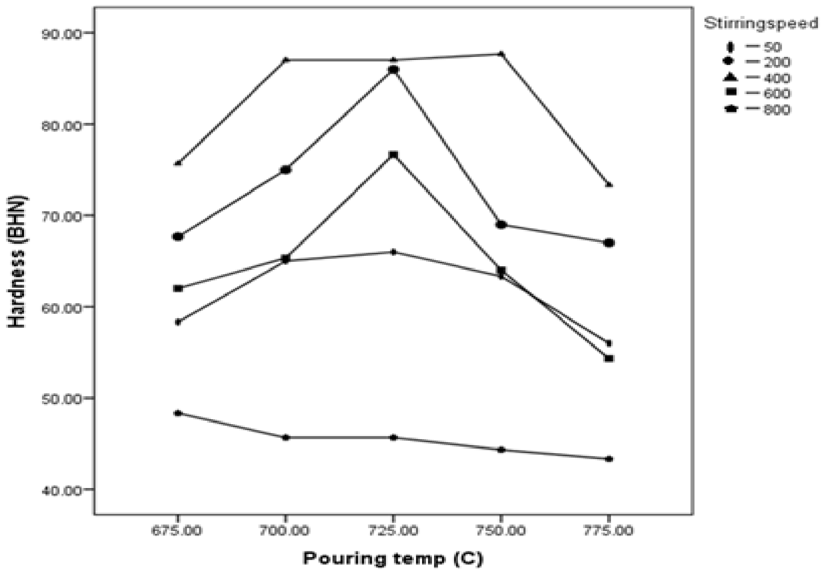

Figure 5.8 Pouring Temperature Vs Hardness Graph

Table 5.1

Summary of Result Analyzed by MANOVA

SOURCE	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
STIRING SPEED	HARDNESS	10963.120	4	2740.780	244.422	.000
	IMPACT STRENGTH	2158.347	4	539.587	178.278	.000
	ULTIMATE TENSILE STRENGTH	142.187	4	35.547	1.237	.307
	MRR	145236.720	4	36309.180	251.937	.000
POURING TEMP	HARDNESS	2273.253	4	568.313	50.682	.000
	IMPACT STRENGTH	1203.413	4	300.853	99.401	.000
	ULTIMATE TENSILE STRENGTH	142.187	4	35.547	1.237	0.307
	MRR	13799.920	4	3449.980	23.938	.000
STIRING SPEED * POURINGTEMP	HARDNESS	563.547	16	35.222	3.141	.001
	IMPACT STRENGTH	113.253	16	7.078	2.339	.011
	ULTIMATE TENSILE STRENGTH	615.547	16	38.472	1.339	.212
	MRR	4411.547	16	275.722	1.913	.041

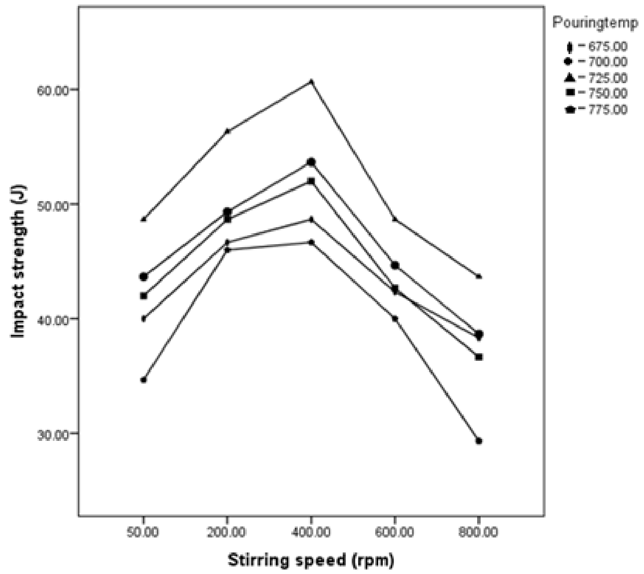

Figure 5.9 Stirring Speed Vs Impact Strength Graph

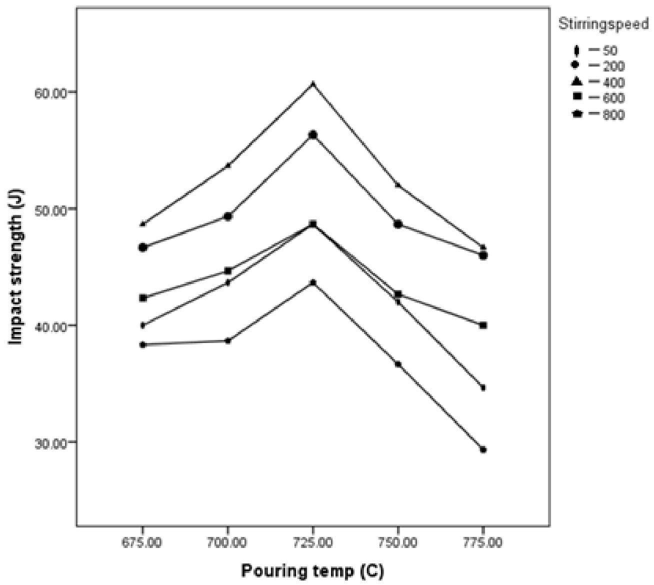

Figure 5.10 Pouring Temperature Vs Impact Strength Graph

It is clear from Figure 5.9 and Figure 5.10 that higher values of impact strength range between the stirring speeds of 200 rpm to 600 rpm. The maximum value of impact strength is obtained at pouring temperature of 725˚C and stirring speed of 400rpm.

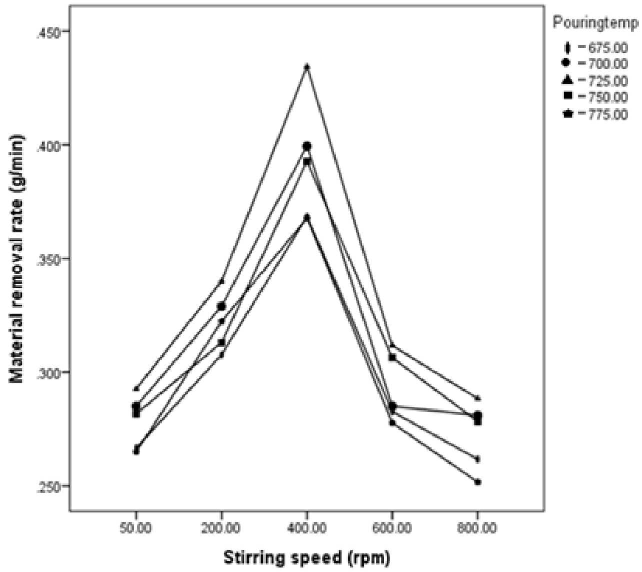

Figure 5.11 Stirring Speed Vs Material Removal Rate Graph

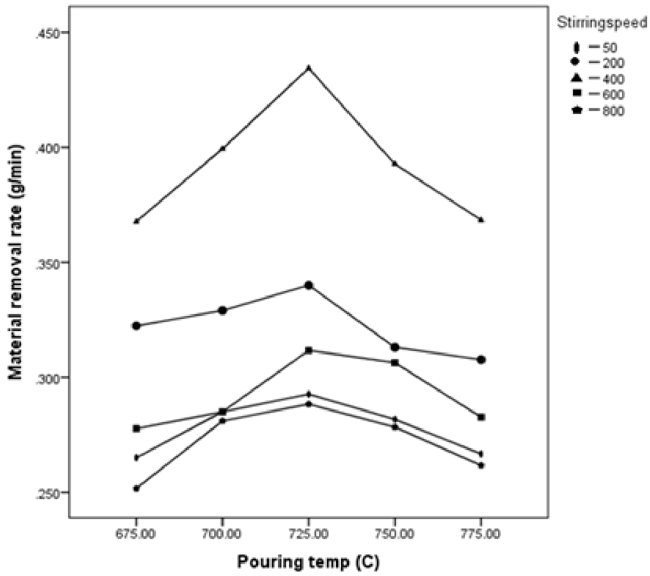

Figure 5.12 Pouring Temperature Vs Material Removal Rate Graph

The graph of Figure 5.11 and Figure 5.12 depicts that material removal rate (MRR) of MMCs have little variation for the pouring temperature ranging from

675˚C to 775˚C for all stirring speed, except stirring speed of 400 rpm. At 400 rpm the material removal rate is high. It is due to better mixing of SiC_p in MMCs. The better homogeneity is also revealed by SEM Figure 5.5 (b).

The characteristic graphs between pouring temperature vs. ultimate tensile strength and stirring speed vs. ultimate tensile strength are not considered, as ultimate tensile strength is not found statistically significant for pouring temperature or stirring speed. Moreover, the combined effect of pouring temperature and stirring speed also statistically insignificant factor for ultimate tensile strength properties of MMCs.

5.3.4 Regression analysis and validation:

Regression analysis shows that there is polynomial relationship between pouring temperature (PT), stirring speed (SS) and hardness (H). The R-square value computed as 90.4% which indicates that there is a good polynomial relationship between predictors pouring temperature, stirring speed and hardness. The hardness can be modeled as:

$$H= -1341+2.906 (PT) + 0.168 (SS) - 0.00000005326 (SS)^2 * (PT) + 0.0000000045 (PT)^2 *(SS) + 0.000000101 (SS)^3 - 0.000001857 (PT)^3 \quad \ldots\ldots\ldots\ 5.1$$

Similar trend of polynomial relationship is observed by impact strength. The R-square value for impact strength is 91%. The impact strength (I) can be modeled in terms of stirring speed and pouring temperature as:

$$I= (-1094.11) + 0.019 (SS) + 2.375 (PT) + 0.0000147 (SS)^2 - 0.00000037 (SS)^2 * (PT) + 0.00000018 (PT)^2*(SS) + 0.000000133 (SS)^3 - 0.000001818 (PT)^3 \quad \ldots\ldots 5.2$$

Likewise material removal rate also shows that polynomial is the best fitted regression. The R-square value is 75.6% which indicates the good relationship between predictors and material removal rate. Mathematically, material removal rate (MRR) is represented as:

$$MRR= (-4.06) + 0.001 (SS) + 0.009 (PT) + 0.0000024 (SS)^2 + 0.00000000036 (SS)^2 * (PT) - 0.00000000039(PT)^2*(SS) + 0.00000000115 (SS)^3 - 0.0000000056 (PT)^3 \quad \text{......5.3}$$

Table 5.2 Experimental validation of optimal set of process parameters

Response	Predicted	Experimental	Error (%)
Hardness (BHN)	92	87	5.7
Impact strength (J)	56	52	7.69
Material Removal Rate (g/min)	0.45	0.434	3.6

Table 5.2 shows the results of verification experiment and the amounts of relative errors at optimal process parameters.

The validity of the model is tested by normal regression standardized residual plot as shown in Figure 5.13, Figure 5.14 and Figure 5.15. It is computed from normal regression standardized residual plots for hardness, impact strength and material removal rate. The predicted values of the response variables are fairly close to the corresponding observed values of the response variables.

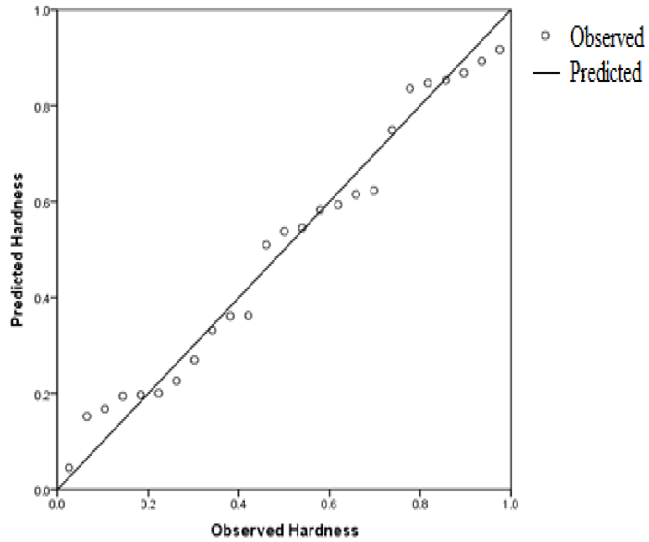

Figure 5.13 Normal plot of standardized residual for Hardness.

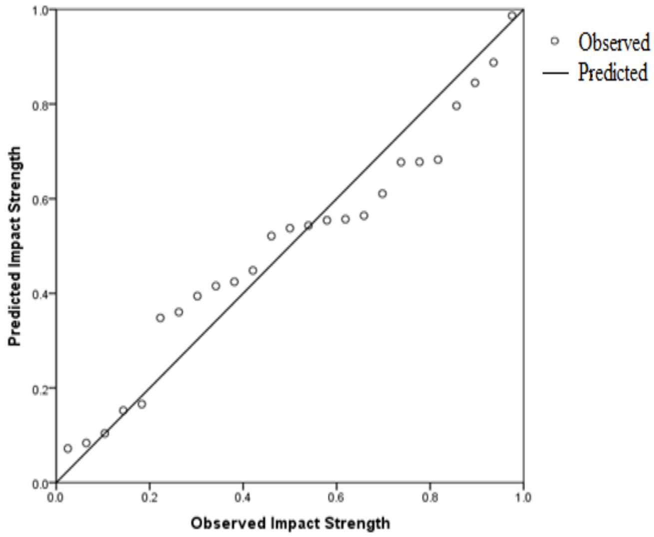

Figure 5.14 Normal plot of standardized residual for Impact strength.

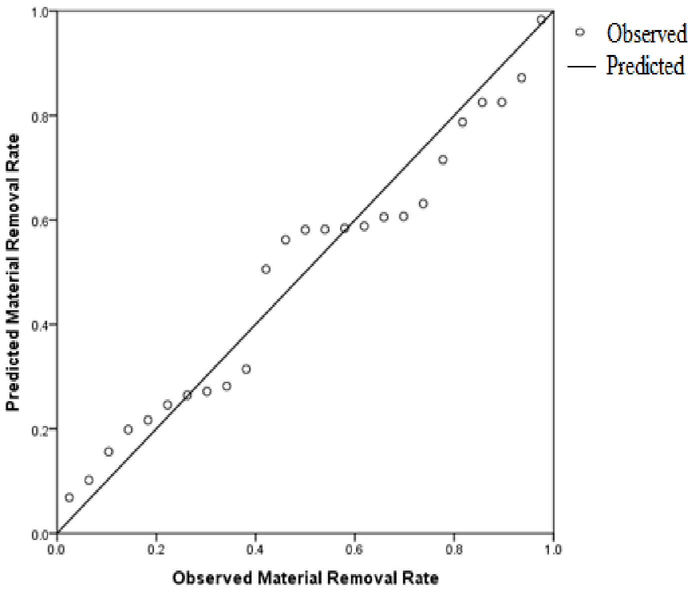

Figure 5.15 Normal plot of standardized residual for Material Removal Rate.

5.4 DISCUSSIONS

The optimal value of hardness, impact strength and material removal rate was obtained at pouring temperature of 725°C and stirring speed of 400 rpm. Ajay Singh et al., (2012) has also reported that the hardness value was maximum for Al6063-9% fly ash metal matrix composite at pouring temperature of 720°C and stirring speed of 400 rpm. The present study is close to the previous findings.

Ultimate tensile strength is not significant factor for stirring speed as well as for pouring temperature; reason may be the less weight percentage of SiC_p in MMCs.

The material removal rate is low at 675°C. The mechanical properties of the SiC reinforced composites are degraded due to the formation of Al4C3 at pouring temperature of 660˚C [Hull et al., (2001)]. Moreover, as the reaction product Al_4C_3 is unstable in some environments such as in water, methanol and hydrochloric acid [Ishikawa et al., (1982) and Chou,(1992)], in addition due to this the composite can be susceptible to corrosive environments resulting in reduced mechanical properties of the composites. Also, if the melt temperature of SiC-Al composite materials rises above a certain value from melting temperature, Al_4C_3 is formed. This increases the viscosity of the molten material, which can result in severe loss of corrosion resistance and degradation of mechanical properties in the cast composite. An excessive formation of Al_4C_3 renders the melt unsuitable for casting [Chou et al., (1985)].

The low material removal rates are observed at high stirring speeds and low stirring speeds. Aqida et al., (2003) reported that the porosity of MMCs is increased drastically after a certain limit of stirring speed. The effect of porosity on mechanical properties was discovered by Skolianos (1996). The research was concentrated on tensile and fatigue properties of aluminum MMC.

The homogeneous distribution of SiC particles in the MMC by increasing the stirring speed is also reported by previous researchers [Shasha et al., (2012) and Prabu et al., (2006)]. Furthermore, the increment in stirring speed causes to develop gas bubbles which are entrapped in composite melt to form porosity. Zhang et.al, observed that very high stirring speed resulted in the high porosity due to entrapment of gases in composites [Hamedan et al., (2012)].

Effect of pouring temperature and stirring speed on mechanical properties of Al MMC was also accomplished by so many researchers [Sozhamannan et al., (2012), Abdizadeh et al., (2013) and Ansary et al., (2009)].

5.5 CONCLUSIONS

i. There is an increase in hardness and impact strength in MMCs with an increase in stirring speed to a maximum. Further increase in stirring speed decreases the hardness and impact strength of MMC.

ii. Material removal rate increases with an increase in pouring temperature up to 725˚C and then decreases abnormally in all levels of pouring temperatures.

iii. The least rate of material removal of MMC is at a pouring temperature of 675˚C.

iv. The optimum mechanical properties of MMC (Al6160- 4% Cu-5%SiC) castings are obtained at the pouring temperature of 725˚C and stirring speed 400 rpm.

v. The optimum value of hardness (87 BHN), impact strength (52 J) and material removal rate (0.434 g/min) are at a stirring speed of 400 rpm and at pouring temperature 725°C.

vi. The sizes of the particles and matrix of alloy get refined at 725°C as compared to 750°C and 775°C at the constant stirring speed of 400 rpm. In other words, dispersion hardening phenomenon is obtained at 725°C pouring temperature and 400 rpm stirring speed.

vii. The ultimate tensile strength values are not found significant for pouring temperature, stirring speed and also interaction effect of pouring temperature and stirring speed is insignificant.

viii. The independent (input) variables, pouring temperature and stirring speed, significantly affects the dependent parameters, i.e., hardness, impact strength and material removal rate through EDM.