Some Investigations on Drilling of Aluminium Based Metal Matrix Composites

Vinodkumar M. Chandankar[1], Aarti A. Dyade[2]

[1]Head of the Department, Department of Mechanical Engineering, Jayawantrao Sawant Polytechnic, (Second shift)Hadapsar, Pune-28 MS, India

[2]Lecturer, Department of Mechanical Engineering, TSSM'S Bhivarabai Sawant College of Engineering & Research, (Second shift Polytechnic) Haveli-Pune, MS, India

Abstract: ***In this study, Drilling is a metal removal process and is important for the final fabrication stage prior to application. This paper discusses the influence of cutting parameters on drilling characteristics of metal matrix composites (MMCs)-Al6061/SiC320grit. The composites are fabricated using stir casting method. In order to determine the mechanical properties of the produced composites, hardness and tensile tests were performed. Moreover, the effects of the machining parameters such as cutting speed, feed rate, particle fraction and cutting-tool material, and of their interactions on the thrust force and cutting torque were determined by means of Taguchi experimental design. In addition the drilling parameters were optimized in terms of cutting forces (thrust force and torque). Furthermore, an analysis of variance (ANOVA) was conducted to obtain the degree of the effect of the parameters. Therefore, the most influential control factor for the cutting forces was found to be the particle fraction and feed rate. According to the experimental results, the thrust force and cutting torque increased significantly with increasing the feed rate or the particle content. On the other hand, the influence of the drill-bit material and the interactions of the factors for the cutting forces were quite low.***

Keywords: MMC, Stir casting, drilling

1. Introduction

There are various routes which are employed to fabricate metal matrix composites. This includes solidification processing, deformation processing and powder metallurgy. Among them, the stir casting method is the cheapest one in which the reinforcing particles are stirred into the molten alloy and the resultant melt is used to obtain cast ingots of composites.

AL 6061 is widely used aluminum alloy in commercial industries due to its low density, electrical conductivity and corrosion resistance properties. The **Hashim** et al, [7] Fabricated the aluminum based MMCs by using the low cost stir casting method. The technical difficulties associated with attaining a uniform distribution of reinforcement, good wettability between substances, and a low porosity material are presented and discussed. In preparing the metal matrix composites by the stir casting method, there are several factors that need considerable attention, including1. The difficulty of achieving a uniform distribution of the reinforcement material; 2. Wettability between the two main substances.3. Porosity in the cast metal matrix composites.4. Chemical reactions between the reinforcement material and the matrix alloy. It conclude that the vortex method is one of the better known approaches used to create and maintain a good distribution of the reinforcement material in the matrix alloy. There are many other methods which have been developed to improve wettability. These includes (a) various processes of fibre treatment by molten sodium for the infiltration of carbon or alumina fiber by aluminum, (b) the TiB process involving the deposition of TiB on carbon fiber before infiltration in an oxygen free atmosphere by aluminum or magnesium, (c) pre-treatment of silicon carbide dehydrated sodium tetra borate for infiltration by molten aluminum. Their experimental work showed that there is a decrease in the porosity level with an increase in the holding temperature. **Pradeepkumar and Packiaraj [5]** used thetaguchi method to investigate the effects of drilling parameters such as cutting speed (5, 6.5, 8 m/min), feed (0.15, 0.20, 0.25mm/rev) and drill tool diameter (10, 12, 15mm) on surface roughness, tool wear by weight, material removal rate and hole diameter error in drilling of OHNS material using HSS spiral drill. **Kokhas [6] studied** the machinability of 2024Al/Al_2O_3 particle composite in terms of tool wear, tool life and surface roughness by turning specimens with TiN (K10) coated and HX uncoated carbide tools in different cutting conditions.He found that the tool life of the Tin coated K10 tool was significantly longer than that of the HX tool. However, in the machining of the matrix alloy the tool life difference between cutting tools was larger than that in the machining of the composite.

2. Experimental work

2.1 Fabrication of MMC

The work material selected for the investigation is Al6061 aluminum alloy shown in fig 2.1.1 andthe reinforced particle was SiC 320grit for fabrication of metal matrix composite .The work material isprepared in square plate form with uniform thickness shown in fig 2.2.2. The Chemical composition of Al 6061 is shown in table 2.1.The physical properties of the Al 6061 and SiC are also shown in table 2.2.

Table 2.1: Chemical composition of Al 6061

Component	Wt %	Component	Wt%	Component	Wt%
Al	95.8-98.6	Mg	.8-1.2	Zn	Max 0.25
Cr	0.04-0.35	Mn	Max 0.15	Other each	Max 0.05
Cu	0.15-0.4	Si	0.4 -0.8	Other, total	Max 0.15
Fe	Max 0.7	Ti	Max 0.15		

Figure 2.1.1: Al 6061

Figure 2.2.2: SiC Particle

Table 2.2: Physical Properties of Al 6061and SiC

Properties	Density (g/cc)	Melting Temperature (^{0}C)	Coefficient of thermal expansion(10^{-6}xC^{-1})	Modulus of elasticity (GPa)	Ultimate tensile Strength (GPa)
Al 6061	2.8	582-652	234	70	0.31
SiC	3.2	2220	218	480	3

A stir casting method is used for the fabrication of cast metal matrix composite. The aluminum alloy (Al 6061) was heated in a furnace upto 750ºC and held for 1 hr until it melts completely. The melting was carried out in a clay-graphite crucible placed inside the resistance furnace. An induction resistance furnace with temperature regulator cum indicator is utilized for melting of Al/SiC-MMCs. The aluminium dross floating over the surface of the molten metal at the furnace was completely removed. After that the preheated of SiC at 450ºC particles were added constantly to the molten metal over the side of vortex created by mechanical stirring set up. Al 6061 molten metal with SiC reinforcement was poured into the mould for the preparation of specimens after stirring. Figure shows the stirrer & fabrication set up.

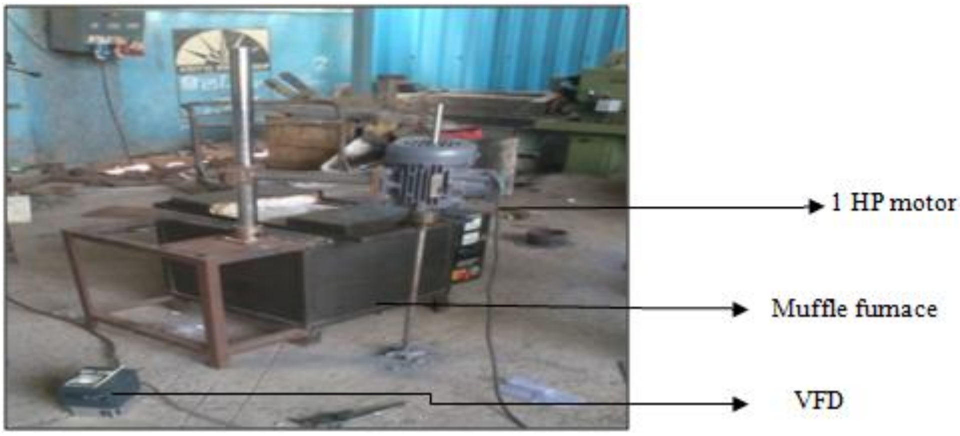


Fig. 2.1.3 Schematic of MMC fabrication

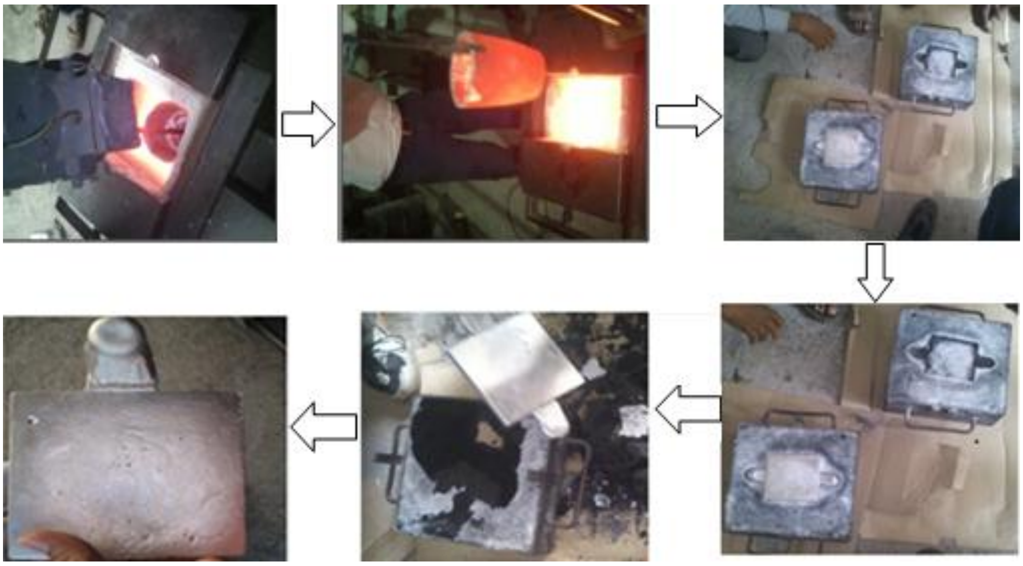


Figure 2.1.4: Preheating of Sic in Furnace

Fig: Process of fabrication of cast metal matrix composite

Figure 2.1.8: Test Specimen: a) Rectangular Plate for drillingb) Circular Bar for tensile test

2.2 Drilling Experiments

For the drilling tests of the produced MMCs, a computer numerically controlled (CNC) vertical machining center (CNC HAAS Milling Machine) having the capacity of 7.5 kW and 3 500 r/min was used.

Table 2.2.1: Machining conditions used during the experiments

Machine tool	Hass CNC TM-2 Controlled vertical machining center	
Drills	HSS:	10 mm, 135° tool tip angle, spiral, 30° helical angle
	Uncoated carbide:	10 mm, 140° tool tip angle, spiral, 45° helical angle
	Coated carbide:	10 mm, 140° tool tip angle, spiral, 30° helical angle
Work Piece materials	Mass fractions: 10 % Sic/Al, 15 % Sic/Al and 25 % Sic/Al composite	
Cutting parameters	Spindle speeds (n): 1000 r/min, 1500 r/min, 2000 r/min, 2500 r/min Feed rates (f) : 0.1 mm/r, 0.2 mm/r, 0.3 mm/r	

Each test was repeated twice to reduced the experimental data error. The experiments were conducted as per L27 taguchi orthogonal array. The drilling forces were measured during the experiments using KISTLER 9272 cutting force Dynamometer. After measuring the thrust forces and drilling torques, the results were recorded into a computer environment using the KISTLER Dynoware software.

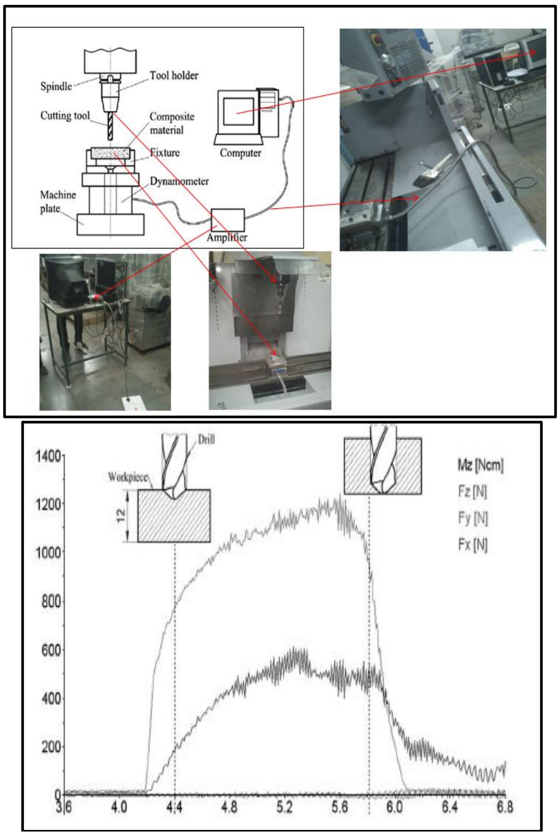


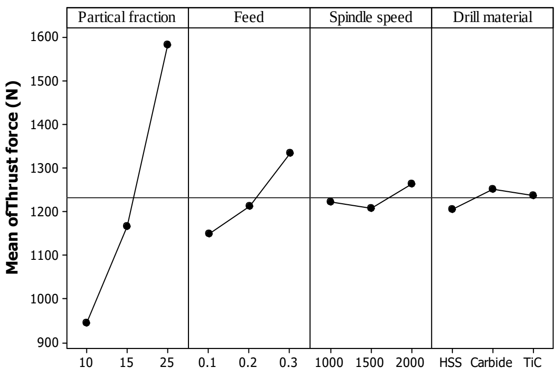
Figure 2.2.1: Schematic presentation of the measuring setup

Figure 2.2.2: Kistler Dynamometer with computer system

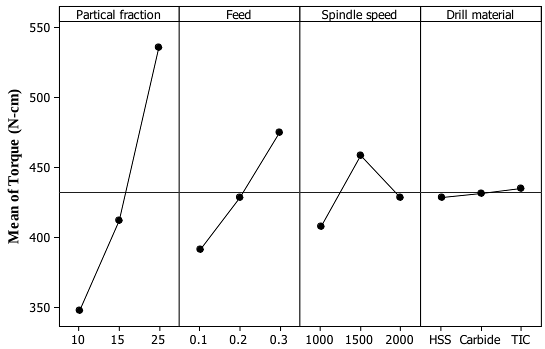
A good design can reduce the number of experiments and simultaneously the rapid change in the model error. In the present work, a four-factor, 27 row and three-level L27 orthogonal array was chosen since it has the ability to control the interactions among the factors. The experimental results are summarized in table.

Table 2.2.2: Experimental design with L27 orthogonal array

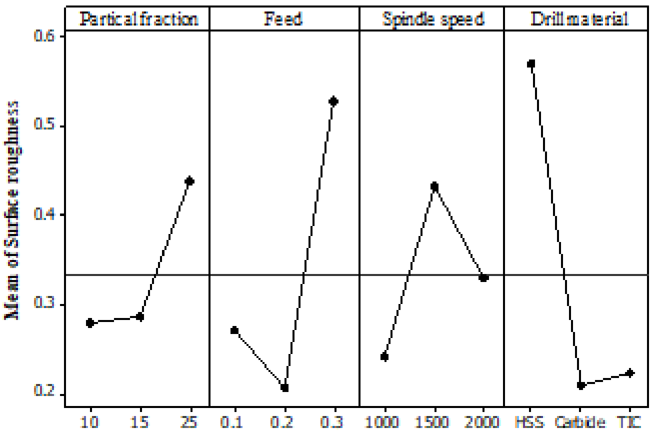
Test No.	Particle Fraction (A)	Feed rate (B)	Spindle Speed (C)	Drill Material (D)	Thrust Force (N)	Torque (N-Cm)	Surface Roughness (Ra)
1	10	0.1	1000	1	843.2	293	0.47
2	10	0.1	1500	2	834.3	300.9	0.56
3	10	0.1	2000	3	804.3	249.3	0.046
4	10	0.2	1000	2	966.8	478.4	0.063
5	10	0.2	1500	3	924.1	344	0.152
6	10	0.2	2000	1	880.7	294	0.156
7	10	0.3	1000	3	1113.3	434.7	0.44
8	10	0.3	1500	1	1048	446.6	0.41
9	10	0.3	2000	2	1096	291.3	0.22
10	15	0.1	1000	2	1168	500.3	0.091
11	15	0.1	1500	3	1062	398.5	0.32
12	15	0.1	2000	1	973.3	309.1	0.22
13	15	0.2	1000	3	1244	496.7	0.5
14	15	0.2	1500	1	1132	370.6	0.349
15	15	0.2	2000	2	1089	340	0.321
16	15	0.3	1000	1	1313	578.3	0.1824
17	15	0.3	2000	2	1310	328	0.557
18	15	0.3	2000	3	1218	388.5	0.045
19	25	0.1	1000	3	1631	627.1	0.022
20	25	0.1	1500	1	1655	434.1	0.158
21	25	0.1	2000	2	1374	415.4	0.55
22	25	0.2	1000	1	1826	496.2	0.205
23	25	0.2	2000	2	1477	492.8	0.1097
24	25	0.2	2000	3	1379	547.8	0
25	25	0.3	1000	2	1835	674.1	0.1956
26	25	0.3	1500	1	1629	641	2.07
27	25	0.3	2000	1	1441	492.2	0.633



a) Thrust force



b) Drilling Torque



c) Surface roughness

Figure 2.2.3: Mean effect graphs of responses: a) thrust force b) drilling Torque c) Surface roughness

Table 2.2.3: Average S/N ratios for each factor and level with regard to Thrust force and cutting torque

	Level	A	B	C	D
For Thrust Force	1	-59.4564	-60.8976	-62.1689	-61.5337
	2	-61.3091	-61.4479	-61.5665	-61.6429
	3	-63.941	-62.361	-60.9711	-61.53
	Difference	4.4846	1.4634	1.1978	0.1092
	Rank	1	2	3	4
For Torque	1	-50.6201	-51.5226	-53.9199	-52.0704
	2	-52.1194	-52.4621	-52.194	-52.2421
	3	-54.462	-53.2168	-51.0877	-52.8891
	Difference	3.8419	1.6942	2.8322	0.8187
	Rank	1	3	2	4

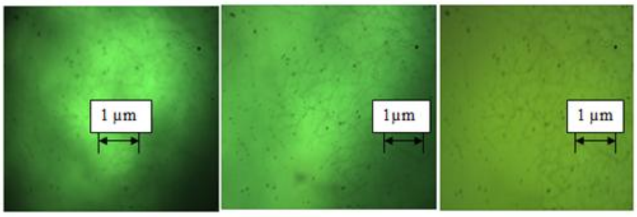
- Optimal level

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

3. Results and Discussion

a) Microstructure

Optical micrographs showed reasonably uniform distribution of Sic particles and this is good agreement with earlier work. Homogenous dispersion of Sic particles in the Al matrix shows an increasing trend in the samples prepared by applying stirring casting technique. From microstructure study we have observed that, homogenous mixing is in 15 % Sic particle sample.



b) Tensile Strength

From the result graphs it indicates that maximum tensile strength has been obtained at 15% Sic ratio. This indicates that the Aluminium silicon carbide composite material is having less weight and more strength; it is very much useful in practical aerospace. % Elongation and % Reduction in area decreases with the increase in reinforced particulate 10%, 15%, and 25% of Sic particles.

Table 2: Tensile Strength Vs Elongation

Sic particle mass fraction w/%	Yield strength Mpa	Tensile strength Mpa	Elongation %
10	491	527	22.2
15	532	599	6.9
25	328	408	4.8

c) Hardness (HRB)

Increases with the increase in reinforced particulate weight fraction 10%, 15%, and 25% of Sic particles. Maximum Hardness (HRB) = 83, has been obtained in 15% Sic.

Optimization with the Taguchi Method

In this section, optimization of drilling parameters was carried out in terms of drilling forces with theTaguchi analysis. The importance order of the effects of each control factor on drilling forces was identified. For this purpose, the factors selected in the Taguchiexperimental design and the levels of these factors are shown in Table 3.A four-factor, the arithmetic average of S/N ratios for the levels of each control factor was calculated with respect to the thrust force and the cutting torque (Table5). In addition, after arranging the difference between the maximum and minimum S/N ratios for each factor in a descending order, the degree of influence of each factor on the thrust force or cutting torque was found. Accordingly, the effective control factors for the thrust force were particle fraction, feed rate, spindle speed and drill-bit material (Table5).The optimum machining parameters for the thrust force and drilling torque are found at the level where each factor has the largest S/N ratio.14 Therefore, the optimal machining conditions for the thrust force Were found to be the particle fraction of 10 %, feed rate of 0.1 mm/r, spindle speed of 2000 r/min and drill Material of coated carbide. Similarly, the optimal Machining conditions for the drilling torque were found to be the particle fraction of 10 %, feed rate of 0.1mm/spindle speed of 2000 r/min and a HSS drill. The effect graph of each control factor for the thrust force and drilling torque, according to the mean responses, was given in Figures 8a and 8b, respectively. Both Figures 8a and 8b showed that the thrust force and drilling torque increased with an increase in the particle fraction and the feed rate, while the thrust force and cutting torque decreased with an increase in the spindle speed. However, the effect of the drill-bit material on the thrust force was very low.

Table 5: Average S/N ratios for each factor and level with regard to thrust force and cutting torque

	Level	A	B	C	D
For Thrust Force	1	-59.4564*	-60.8976*	-62.1689	-61.5337
	2	-61.3091	-61.4479	-61.5665	-61.6429
	3	-63.941	-62.361	-60.9711*	-61.53*
	Difference	4.4846	1.4634	1.1978	0.1092
	Rank	1	2	3	4
For Torque	1	-50.6201*	-51.5226*	-53.9199	-52.0704*
	2	-52.1194	-52.4621	-52.194	-52.2421
	3	-54.462	-53.2168	-51.0877*	-52.8891
	Difference	3.8419	1.6942	2.8322	0.8187
	Rank	1	2	3	4

*= Optimal Level

3.1 Analysis of Variance (ANOVA)

The purpose of the analysis of variance was to determine which parameter significantly affects the cutting forces.ANOVA was performed to find whether individual factors and their interactions that affect the cutting forces were meaningful. According to the ANOVA results presented in Table 6 the most influential factor for the thrust force was found to be the particle fraction of (80.23%). The other important factors were feed rate (6.72 %) and spindle speed (6.73%). Similarly, the most influential factor for the drilling torque was found to be the particle fraction of 45.99 %, followed by spindle speed (25.25%) and feed rate (8.75%) as seen in Table 7. In addition, the effect of the drill-bit material on the cutting forces was found to be small. Ftest values for the cutting forces, with regard to the factor interactions, were not meaningful since they were smaller than Ftable values.27 hence, the statistical significance of interactions was minimum and it could be neglected.

Table 6: ANOVA results for the thrust force

Factor	*DF*	*SS*	*V*	F_{test}	*PD*
Particle Fraction (A)	2	163615	81808	15.92	45.99
Feed rate (B)	2	31123	15562	3.029	8.749
Spindle Speed (C)	2	89834	44917	8.742	25.25
Drill material (D)	2	10230	5115	0.995	2.876
A x B	4	11959	2990	0.582	3.362
A x C	4	12466	3116	0.607	3.504
B x C	4	5689	1422	0.277	1.599
Error	6	30829	5138		8.666
Total	26	355745			100

DF: Degree of Freedom, SS: Sum of Squares, V: Variance, PD: Percentage
Distribution Ftable (0.05;2;6) = 5.14, Ftable (0.05;4;6) = 4.53

Table 7: ANOVA results for the drilling torque

Factor	*DF*	*SS*	*V*	F_{test}	*PD*
Particle Fraction (A)	2	163615	81808	15.92	45.99
Feed rate (B)	2	31123	15562	3.029	8.749
Spindle Speed (C)	2	89834	44917	8.742	25.25
Drill material (D)	2	10230	5115	0.995	2.876
A x B	4	11959	2990	0.582	3.362
A x C	4	12466	3116	0.607	3.504
B x C	4	5689	1422	0.277	1.599
Error	6	30829	5138		8.666
Total	26	355745			100

DF: Degree of Freedom, SS: Sum of Squares, V: Variance, PD: Percentage
Distribution Ftable(0.05;2;6) = 5.14, F table (0.05;4;6) = 4.53

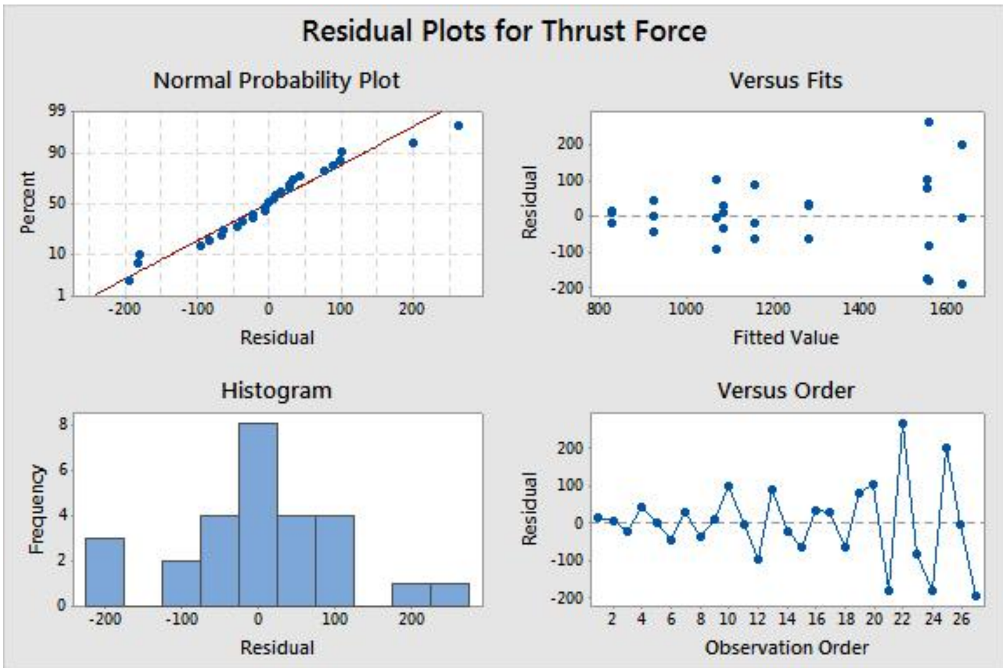
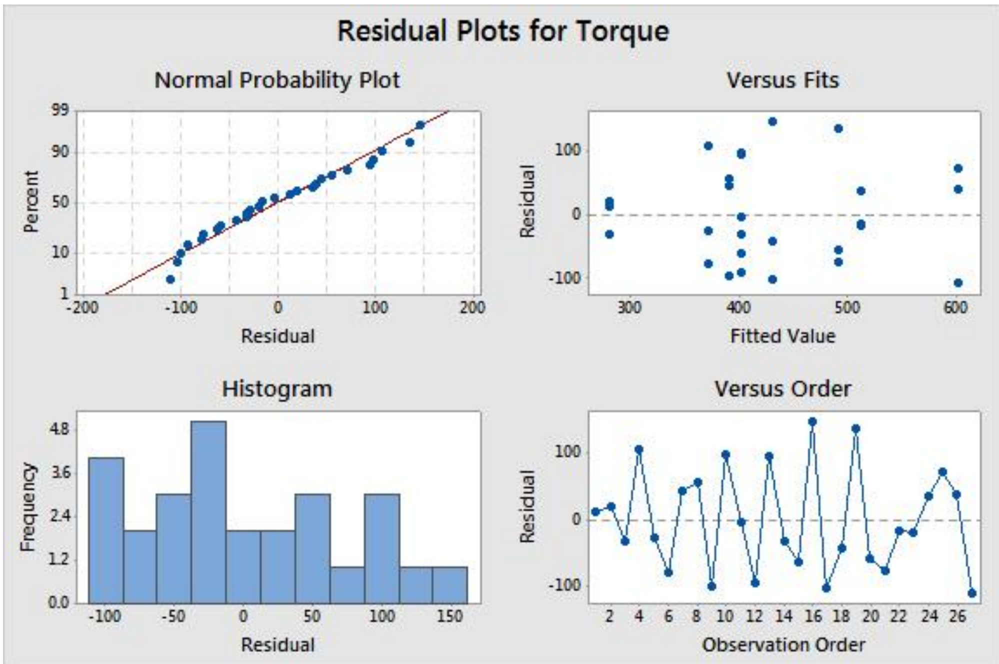


Figure 4.1: ANOVA results for the drilling torque: a) thrust force b) drilling Torque

According to the ANOVA results presented in Table 6, the most influential factor for the thrust force was found the particle fraction of 80.23 %. The other important factors were feed rate (6.72 %) and spindle speed (6.73 %).



According to the ANOVA results presented in Table 7 the most influential factor for the drilling torque was found the particle fraction of 45.99 %, followed by spindle speed (25.25 %) and feed rate (8.75%).

3.2 Result and Discussion of fabrication of MMCs

1) It is observed that both the matrix and the reinforcement materials be **Pre-heated** at a certain temperature before being mixed to release all the moisture and trapped air between the particles. It is also helpful for defect free casting.
2) **Stirring speed** is the important process parameter because of the following reason
   - Mechanical stirring is necessary to help in promoting wettability.
   - Stirring while the slurry (melt of matrix and reinforcement) is solidifying improves incorporation of the particles into the matrix alloy .However the slurry must then be re-melted to a fully liquid condition in order to enable pouring into a mould. A decrease in solidifying time during stirring increases the percentage wetting. The particles tend to float to the top of the molten alloy, regardless of the speed of stirring.
3) **Stirring temperature** is an important process parameter (it is related to the meltingTemperature of matrix). The processing temperature is mainly influencing the change in viscosity of Al matrix and it also accelerates the chemical reaction between matrix and reinforcement. The change of viscosity influences the particle distribution in the matrix. The viscosity of liquid decreased when increasing processing temperature with increasing holding time (stirring time)
4) The stirrer must be designed such that it avoids the agitation of the melt surface, and the formation of vortex must be avoided or minimized. The selection of **blade material** and design of **blade shape** is also important consideration for effective integration.

3.3 Conclusions and Future Scope

In this study, aluminum MMCs containing three different weight fractions of SiC particles were produced MMC'S by Stir Casting method and drilling experiments were carried out to study the effects of the machining parameters on the thrust force and cutting torque. Moreover, the optimum drilling parameters were obtained for the performance characteristics (thrust force and torque) using the Taguchi analysis. The obtained results can be summarized as follows:

1) An increase in the proportion of the SiC particle caused a decreased ductility of the material but an increased hardness of the composite. The highest tensile strength was obtained with the **15 % Sic particle fraction**.
2) According to the experimental results, the **cutting forces** significantly increased with an increase in the SiC fraction and the feed rate but decreased with an increase in the spindle speed.
3) **HSS tools** produced more thrust forces than the two carbide tools especially when drilling the composites with higher particle fractions. On the other hand, the coated and the solid carbide tools produced similar thrust forces. However, the coated tools produced somewhat higher drilling torques than the uncoated ones.
4) With the Taguchi and ANOVA analysis, the effective factors for the thrust force and drilling torque were found to be the **particle-weight fraction and feed rate**, respectively. Furthermore, the effects of the cutting tool material and the interactions of the factors on the thrust force and cutting torque were found to be very low.There is lot of scope carrying out the research in this field

- The effect of different size of stirrer and stirring speeds It may be feasible to reduce particle fracture, further improve wetting, and minimize porosity through improved understanding of the process of mechanical stirring.
- The microstructure and phase composition of the composite produced variations in stirring and casting temperature can influence chemical reactions, and solidification
- The effective method of fabrication of MMCs will be possible.
- Based on the analysis, feed rate has highest influence on thrust force and surface roughness as compared to cutting speed. The optimum cutting speed and feed suggested for further statistical analysis are
  Feed Rate= 25 to 125 mm/min.
  Cutting Speed= 1000 to 1500rpm.
- Based on microstructure analysis and drilling output parameter, it is concluded that these are optimum parameters for further statistical analysis.
  Stirring speed = 450 RPM
  Stirring time = 6 min.
  Melting temp. = 600
  Wt. % of Sic = 15

References

[1] "**Introduction to composite material**" by Nicholas J Pagano (Author), J N Reddy (Editor)

[2] "**The production of cast metal matrix composites by a modified stir casting method**" - JASMI HASHIM* JurnalTeknologi, 35(A) Dis. 2001: 9–20, University Teknologi Malaysia.

[3] "**Defects in Composite Material caused by Drilling in Manufacturing Process"** by Marilena Colt-Stoica, Dorel Anania, Cristina Mohora, Daniel Stoica, University Politehnica from Bucharest.

[4] "**An optimise drilling process for an aircraft composite structure using design of experiments"** by M. K. A Mohd Ariffin1*, M. I. Mohd Ali2, S. M. Sapuan3 and N. Ismail4, Faculty of Engineering, Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang Selangor, Malaysia. Accepted 21 July, 2009.

[5] "**Effect of drilling parameters on surface roughness, tool wear, material removal rate and hole diameter error in drilling of OHNS**" by j.pradeep kumar1*, p.packiaraj2, PSG College of Technology Coimbatore, INDIA, E-ISSN2249–8974.

[6] "**A Study on The Machinability of Al2o3 Particle Reinforced Aluminium Alloy Composite"** by MetinKok, KahramanmarasSutcu Imam University, Karacasu Campus, 46100 Kahramanmaras, Turkey.

[7] **"Metal matrix composites: production by the stir casting method**" byJ. Hashim, L. Looney*, M.S.J. Hashmi, School of Mechanical and Manufacturing Engineering, Dublin City University, Dublin 9, Ireland, Journal of Materials Processing Technology 92±93 (1999) 1±7.

[8] **“Some studies on drilling of hybrid metal matrix compositesbased on Taguchi techniques”**by S. Basavarajappaa, ∗, G. Chandramohanb, J. Paulo Davimc,

[9] **“Statistical analysis of process parameters in drilling of AL/SICP metal matrix composite”by**S. Basavarajappaa, ∗, G. Chandramohanb, J. Paulo Davimc.

[10] “**Surface Roughness Optimization in a Drilling Operation Using the Taguchi Design Method”** byJulie Z. Zhang a & Joseph C. Chen.

[11] **“Drilling of hybrid metal matrix composites—Workpiece surface integrity”** by S. Basavarajappaa,, G. Chandramohana, M. Prabub, K. Mukundb, M. Ashwinb.

[12] **“The drilling of Al/SiCp metal–matrix composites. Part II: work piece surface integrity**” by G€ulTosun *, MehtapMuratoglu.

[13] **“OPTIMIZATION OF THE DRILLING PARAMETERS FOR THE CUTTING FORCES IN B4C-REINFORCED Al-7XXX-SERIES ALLOYS BASED ON THE TAGUCHI METHOD”**by Ahmet Taþkesen1, Kenan Kütükde2.

[14] **“Tool wear in drilling of composite/titanium stacks using carbide and polycrystalline diamond tools”**by Kyung-Hee Park[a], AaronBeal[b], .

[15] **“Optimization of drilling parameters on surface roughness in drilling of AISI 1045 using response surface methodology and genetic algorithm”** by ErolKilickap, MesutHuseyinoglu, AhmetYardimeden