# Optimization of Machining Parameters & Surface roughness in LM6-SiC MMCs by Taguchi Approach

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***Abstract:*** Superior properties of metal matrix composites over traditional material created great interest for researchers in the recent years. For manufacturing industries, machinability of the composites become very important. Hence need to study the influence of machining parameters like Cutting speed, feed and depth of cut on cutting force. In this experimental investigation, influence of reinforcement of 0, 4, 8, & 12 wt% of SiC on machinability was examined. It was observed that increase in the wt% of reinforcement result in increase in hardness of the composite. Flank wear was induced to the Carbide tool by artificially grounding. The results shows the decrease in the cutting forces with increase in the wt% of reinforcement component may be due to thermal mismatch between the matrix and reinforcement. L16 Taguchi orthogonal array technique is considered with four factors i.e. material, tool wear, cutting speed and feed at 4 different levels has been employed. Cutting speed is the most influencing factor in the machining of composites followed by composite material reinforced with SiC particle

***Keywords* –Taguchi technique, ANOVA, MMCs, Cutting Force and Tool wear.**

## I. Introduction

Metal matrix composites are extensively used because of their superior properties over conventional materials. The properties like hardness, flexural strength, stiffness, high strength and wear resistant are very important parameters in the automobile and aerospace industries to increase the strength to weight ratio. S. Naher et al. [1] studied the uniform distribution of reinforcement partials in the composite casting. Results indicated that decrease in the particulate dispersion time with lower velocity and high blade angle of stirrer. Distribution of the SiC in the matrix material is also influenced by the height of the stirrer. Ali Kalkanli et al. [2] studied the influence of SiC particles on the 7075 matrix. Composites are fabricated by using the pressure casting technique. Experimental analysis is carried out for both as cast and heated samples. 3 point bending test reveals that, there is a increase in the flexural strength for as cast and the heat treated samples. The hardness values are increased with the increase in the reinforcement contents.

A Manna et al. [3] studied the influence of machining parameters like cutting speed, feed, depth of cut on the Cutting force and surface roughness of the SiC reinforced aluminium metal matrix material composites. Turing of composites is carried out using the rhombic tools. Effect of cutting parameters on the tool wear and the build-up edge (BUEs) analysis shows that, BUE were formed during the high speed and low depth of cut. This study gives the guidelines to use the fixed rhombic tool for the machinging of the composites. Tamer Ozben et al. [4] Studied and investigated the effect of SiC reinforcement particle on the machinability and mechanical properties of aluminium metal matrix composites. Results shows the increasing trend in the hardness and impact toughness with respect to increase in the reinforcement ratio, but tensile strength will increase only up to 10 Wt% & decreases at 15wt%. Cutting tool will tend to wear with increase in the reinforcement addition. Feed rate and cutting speed will affects the surface roughness of the material. Increase in the reinforcement partial ratio affect the surface roughness negatively. Srinivasan A et al. [5] studied the machinability of the composite material through the surface methodology approach. This paper discusses the combined effect of machining parameters on the surface roughness, tool wear and cutting force is reported. Optimized cutting condition were reported. Surface roughness increases with the speed and decreases with the feed rate. Cutting speed will cause more effect on the tool wear as compared to other machining parameters. Cutting force in the machining of composites varies linearly with the feed rate. A Pramanik et al.[6] have studied the effect of the reinforcement particles on the machining of MMCs. Aluminium 6061 alloy and SiC is used as a matrix and reinforcement material. According to this paper results shows surface residual stress are compressive in nature, feed controls the surface roughness, and reinforcement particle facilitates the chip breakage.

S. Kannan et al. [7] this study reported the effect of cutting forces and the change in the microstructure of matrix material as a result of cutting operation in the AA6061, AA7075 as a matrix material and alumina as reinforcement. Increase in the cutting forces is due to the increase in the particle size and volume fraction can be correlated to the increase in the average dislocation density. Cutting force component is dominant in all the samples used in the investigation.

D. Sai Chaitanya Kishore et al.[8] studied the Cutting force, surface roughness and tool flank wear on the composite material. Composite material of Al6061 as a matrix and the TiC reinforcement material is used in this study. Hardness performed on the Vickers hardness tester shoes increase in the hardness with increase in the reinforcement content of TiC. L25 Taguchi design technique is used for experimentation design. Results shows that at all levels of the experiment with the increase in the reinforcement content TiC increases the surface roughness and flank wear but reduces the cutting force. The results shows the increase in the feed, depth of cut and flank wear will increase the surface roughness and the cutting force.

Ravi Sekhar et al.[9] this review paper discusses the mechanisms that make the composite material superior to the conventional materials. In the turning of the composite material mainly focused on the particle fracture, particle pullout, deboning, dislocation phenomena, thermal softening, wear modes, surface generation, cutting forces, chip formation, strains and stresses are discussed. This paper also reported the different phenomena such as effects of tool coatings, adhesion, friction, microstructures and strain hardening are also presented.

Ashvin j. Makadia et al.[10] in his experimental study on the AISI 410 steel, mathematical and surface roughness model has been developed for the different turning parameters. This study uses the response surface methodology (RSM) to investigate the different machining parameters on the surface roughness of the material. Results shows that, feed, cutting speed and tool noose radius have a significant effect on the surface roughness as compared to the depth of cut.

The objective of the present paper is to study the machinability & surface roughness of LM6 /SiC composite at different cutting conditions like cutting speed, feed and artificially induced tool wear. Design of experiment is done by Taguchi L16 orthogonal array technique with four factors i.e. material, tool wear, cutting speed and feed at 4 different levels.

## II. EXPERIMENTATION

In the present study, LM6 as per BS1490 aluminium alloy was used as a matrix material and SiC is used as a reinforcement material with the particle size of 400mesh (37µm). The chemical composition of the LM6 are presented in the table 1.

Table 1: Chemical Composition of matrix material LM6

| Elements | Copper | Lead | Magnesium | Silicon | Iron | Manganese | Nickel | Zinc | Tin | Titanium | Aluminium |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentage | 0.1 max | 0.1 max | 0.1 max | 10-13 max | 0.6 max | 0.5 max | 0.1 max | 0.1 max | 0.05 | 0.2 | Remainder |

The fabrication of the composites are carried out by stir casting technique. Matrix material aluminium is heated in the graphite crucible to a temperature of about 750$^0$C in the electric furnace. Then the stirrer is immersed inside the molten bath, stirring is carried out at a speed of 500rpm to create a vertex. Preheated SiC is added to molten metal, stirring is continued for few more seconds. Then the molten metal is poured into the mould. Composites are made up of 4, 8, and 12 Wt% of SiC are fabricated in the form of cylindrical rod of 180mm length and 25mm diameter. The specimen were turned in the lathe machine with carbide insert with cutting condition is given in the table 2. Carbide tool inserts are used in machining process. These carbide tool inserts are grounded artificially to induce artificial tool wear in the tool inserts. For each condition feed force ($F_f$), cutting force ($F_C$) and radial force ($F_d$) are measured using the lathe tool dynamometer. The setup is as shown in the fig1.

Table 2: Cutting condition

| | |
|---|---|
| Work material | Aluminium MMC |
| Tool material | Carbide |
| Tool geometry | 800 Diamond |
| Cutting speed | 250,500,750,1000 rpm |
| Feed rate | 0.1, 0.2, 0.3 and 0.4 mm/rev |
| Depth of cut | 1mm |
| Value of tool wear | 0.0, 0.1, 0.2 and 0.3mm |
| Lubrication | Dry |

Fig1: Lathe with lathe tool dynamometer

After machining of each workpiece, surface roughness values is measured using the Mitutoyo SJ-210 surface roughness tester. The surface roughness values of each specimen is noted in terms of Ra.

Taguchi design of experiments method is used to determine the best combination of input. In this experiment we have 4 different control parameters with 4 different levels is as shown in the table 3. Taguchi L16 orthogonal array of the experiment layout is used. The minitab statistical software package has been used to develop response equation and evaluate the coefficient values. This software is also used to perform the data analysis. Analysis of variance (ANOVA) is used to verify the adequacy of the experimental design.

Tables 4 shows the Taguchi L16 orthogonal array of the experiment layout, obtained & predicted results of feed force ($F_f$), cutting force ($F_C$), radial force ($F_d$) and surface roughness for all the experimental condition is summarized. Analysis regarding the influence of each control factor on feed force ($F_f$), cutting force ($F_C$), radial force ($F_d$) and surface roughness is performed by Minitab software package. 'lower the better' type of a quality characteristic is adopted. The S/N ratio for 'lower the better' type of response was used which is given by the following equation: $S/N = -10\log\left[\sum_{i=0}^{n}\frac{y_i^2}{n}\right]$

Where, n is the number of observations, y is result of the experiments. Regardless of the category of the quality characteristics, the desired value of S/N ratio is always intended to be the lower one.

## 3. Result and Discussion

Figure2 shows the micrograph of 8wt% reinforced composite taken from Inverted metallurgical microscope. From the microstructure, a uniform distribution of SiC particulate has been observed. Figure 3 shows the Hardness value (BHN) of the composite will increase with the increase in reinforcement i.e. SiC wt%

Table 3 Levels for various control factors

| Code | Control Factors | Level | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| A | Material (Al+ SiC) (%) | 0 | 4 | 8 | 12 |
| B | Cutting speed (rpm) | 250 | 500 | 750 | 1000 |
| C | Feed rate (mm/rev) | 0.1 | 0.2 | 0.3 | 0.4 |
| D | Tool wear ( Flank wear)(mm) | 0 | 0.1 | 0.2 | 0.3 |

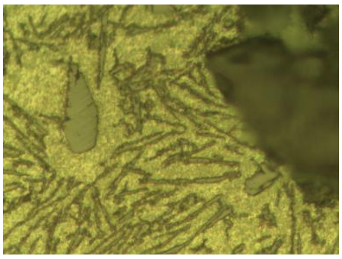

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Figure 2. Micrograph of LM6/8 wt%SiC

Following Taguchi $L_{16}$ orthogonal array of the experimental layout and the obtained results of feed force ($F_f$), cutting force ($F_C$), radial force ($F_d$) and surface roughness are presented in the table 4. Analysis regarding the influence of each control factor on the feed force ($F_f$), cutting force ($F_C$), radial force ($F_d$) and surface roughness is performed by Minitab software package.

Mathematical model is developed through regression analysis using the minitab software. In this approach, least square estimation was used model the relation between the different machining parameters on the cutting force and the surface roughness of the material. The model for feed force ($F_f$), cutting force ($F_C$), radial force ($F_d$) and surface roughness derived from the experimental data and as given in below equation.

Feed force ($F_f$) = 180.12+ 79.2 Material (%) - 10.73 Tool wear (mm) - 0.07445 Speed (rpm) + 18.36 Feed (mm/rev) (1)

Cutting force (FC) = 332.20 + 385.2 Material (%) - 110.78 Tool wear(mm) - 0.11801 Speed(rpm) - 106.78 Feed(mm/rev) (2)

Radial force (Fd) = 74.59 + 91.8 Material (%) - 24.20 Tool wear(mm) - 0.02490 Speed(rpm) - 17.10 Feed(mm/rev) (3)

Surface roughness (Ra)= 10.651 + 9.19 Material(%) - 0.98 Tool wear(mm) + 0.002830 Speed(rpm) - 2.17 Feed(mm/rev) (4)

S/N response values for cutting forces and surface roughness are presented in the table 5 & 6 . Delta refers to the difference between maximum and minimum S/N ratio for a particular control factor. The higher the value of the delta, the more significant will be the control factor. The result form the table shows that the cutting speed is the most dominant control factor followed by Materials for the cutting force. Tool wear and the material are the most dominant control factor for the surface roughness.

Table 4 Design matrix with measured values of cutting force and surface roughness.

| Run | A | B | C | D | $F_f$ (N) | Predicted | %Error | $F_C$ (N) | Predicted | %Error | $F_d$ (N) | Predicted | %Error | Ra | Predicted | %Error |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 163.48 | 163.34 | -0.09 | 290.77 | 292.01 | 0.43 | 68.46 | 66.65 | -2.71 | 10.5 | 11.15 | 5.83 |
| 2 | 1 | 2 | 2 | 2 | 145.2 | 145.49 | 0.21 | 240.85 | 240.76 | -0.04 | 52.81 | 56.3 | 6.2 | 11.2 | 11.54 | 2.95 |
| 3 | 1 | 3 | 3 | 3 | 130.4 | 127.64 | -2.16 | 185.9 | 189.50 | 1.91 | 45.15 | 45.94 | 1.74 | 11.6 | 11.93 | 2.77 |
| 4 | 1 | 4 | 4 | 4 | 108.55 | 109.79 | 1.14 | 140.3 | 138.24 | -1.49 | 38.5 | 35.59 | -8.18 | 12.4 | 12.32 | -0.65 |
| 5 | 2 | 1 | 2 | 3 | 152.2 | 151.57 | -0.42 | 262.03 | 256.56 | -2.13 | 60.54 | 60.68 | 0.24 | 12.8 | 11.79 | -8.57 |
| 6 | 2 | 2 | 1 | 4 | 170.5 | 170.94 | 0.27 | 263.95 | 264.31 | 0.14 | 63.93 | 62.77 | -1.84 | 11.4 | 10.77 | -5.85 |
| 7 | 2 | 3 | 4 | 1 | 105.2 | 108.52 | 3.07 | 194.78 | 196.76 | 1.01 | 45.07 | 46.81 | 3.73 | 13.8 | 13.44 | -2.68 |
| 8 | 2 | 4 | 3 | 2 | 130.46 | 127.90 | -2 | 208.7 | 204.51 | -2.05 | 47.46 | 48.90 | 2.96 | 12.6 | 12.42 | -1.45 |
| 9 | 3 | 1 | 3 | 4 | 138.4 | 137.96 | -0.32 | 230.18 | 231.79 | 0.7 | 57.82 | 56.41 | -2.49 | 12.3 | 12.65 | 2.77 |
| 10 | 3 | 2 | 4 | 3 | 115.2 | 116.44 | 1.07 | 200.06 | 201.89 | 0.91 | 48.59 | 49.48 | 1.81 | 13.2 | 13.47 | 2.01 |
| 11 | 3 | 3 | 1 | 2 | 165.96 | 169.36 | 2.02 | 288.63 | 290.00 | 0.48 | 66.45 | 67.44 | 1.49 | 11.4 | 11.47 | 0.62 |
| 12 | 3 | 4 | 2 | 1 | 149.09 | 147.84 | -0.85 | 258.51 | 260.09 | 0.62 | 64.22 | 60.51 | -6.13 | 12.2 | 12.3 | 0.82 |
| 13 | 4 | 1 | 4 | 2 | 118.94 | 118.84 | -0.08 | 238.04 | 239.05 | 0.43 | 57.74 | 57.28 | -0.8 | 14.2 | 14.15 | -0.36 |
| 14 | 4 | 2 | 3 | 1 | 136.47 | 134.54 | -1.43 | 271.76 | 268.16 | -1.35 | 63.55 | 62.80 | -1.2 | 13.8 | 13.57 | -1.7 |
| 15 | 4 | 3 | 2 | 4 | 157.76 | 157.59 | -0.11 | 253.89 | 254.55 | 0.26 | 59.53 | 61.47 | 3.17 | 11.3 | 12.11 | 6.69 |
| 16 | 4 | 4 | 1 | 3 | 173.29 | 173.30 | 0.01 | 283.61 | 283.65 | 0.02 | 66.34 | 66.99 | 0.98 | 11.8 | 11.52 | -2.44 |

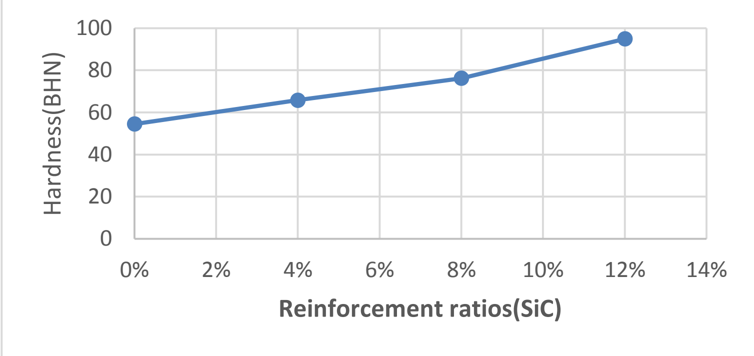


Figure 3. Hardness (BHN) vs. Reinforcement ratios ( wt%SiC)

Table 5 Response Table for Signal to Noise Ratios Cutting force

| Feed force ($F_f$) | | | | | Cutting force ($F_C$), | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Level | Material | Tool wear | Speed | Feed | Level | Material | Tool wear | Speed | Feed |
| 1 | -42.63 | -43.06 | -44.52 | -42.72 | 1 | -46.31 | -48.10 | -48.99 | -48.00 |
| 2 | -42.76 | -42.95 | -43.58 | -42.86 | 2 | -47.24 | -47.69 | -48.09 | -47.69 |
| 3 | -42.98 | -42.78 | -42.53 | -42.99 | 3 | -47.68 | -47.12 | -46.93 | -47.21 |
| 4 | -43.24 | -42.82 | -40.97 | -43.03 | 4 | -48.34 | -46.66 | -45.57 | -46.68 |
| Delta | 0.60 | 0.29 | 3.55 | 0.31 | Delta | 2.03 | 1.44 | 3.42 | 1.32 |
| Rank | 2 | 4 | 1 | 3 | Rank | 2 | 3 | 1 | 4 |

Table 6 Response Table for Signal to Noise Ratios Cutting force & Surface roughness

| Radial force (Fd) | | | | | surface roughness (Ra) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Level | Material | Tool wear | Speed | Feed | Level | Material | Tool wear | Speed | Feed |
| 1 | -33.99 | -35.71 | -36.43 | -35.50 | 1 | -21.97 | -22.06 | -21.76 | -21.65 |
| 2 | -34.59 | -35.09 | -35.44 | -34.92 | 2 | -21.57 | -21.71 | -21.69 | -21.42 |
| 3 | -35.39 | -34.53 | -34.48 | -34.73 | 3 | -21.04 | -21.06 | -21.12 | -21.35 |
| 4 | -35.81 | -34.46 | -33.44 | -34.64 | 4 | -20.87 | -20.62 | -20.88 | -21.02 |
| Delta | 1.81 | 1.25 | 2.99 | 0.86 | Delta | 1.10 | 1.44 | 0.88 | 0.63 |
| Rank | 2 | 3 | 1 | 4 | Rank | 2 | 1 | 3 | 4 |

**Analysis of Variance**

Individual statistical significance of the each control factor is determined by using the ANOVA. The ANOVA results are listed in table 7 and 8 for Cutting force and surface roughness. The extreme right hand column refers to the percentage contribution of each control factor on the cutting force and the surface roughness. Cutting speed contribution is 95.83%, 64.62% & 61.6% which is highest as compared to other factors. In general, cutting speed is most paramount factor on the cutting force and surface roughness.

Table 7 Analysis of variance for Cutting force

| Feed force ($F_f$) | | | | | | | Cutting force ($F_C$), | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | DF | Adj SS | Adj MS | F-Value | P-Value | Contribution % | DF | Adj SS | Adj MS | F-Value | P-Value | Contribution % |
| Material | 3 | 204.84 | 68.28 | 26.84 | 0.01 | 2.82 | 3 | 4775.1 | 1591.69 | 126.47 | 0.001 | 17.72 |
| Tool wear | 3 | 28.73 | 9.58 | 3.76 | 0.15 | 0.39 | 3 | 2475.4 | 825.15 | 65.56 | 0.003 | 9.18 |
| Speed | 3 | 6956.37 | 2318.79 | 911.33 | 0.00 | 95.83 | 3 | 17416.0 | 5805.32 | 461.26 | 0.000 | 64.62 |
| Feed | 3 | 69.13 | 23.04 | 9.06 | 0.05 | 0.95 | 3 | 2281.7 | 760.58 | 60.43 | 0.004 | 8.46 |
| Error | 3 | 7.63 | 2.54 | | | | 3 | 37.8 | 12.59 | | | |
| Total | 15 | 7266.7 | | | | | 15 | 26986.0 | | | | |

The degree of freedom (DF) for each of four control factor will be three. i.e. total number of levels minus one. Hence total DF for four control factors is fifteen (5 x 3). On the other hand, DF of a $L_{16}$ orthogonal design is 15 (Total number of test runs -1). The variance ratio or F value is 2.9 at 95% confidence level for DFs of 3 and 15.

The effect pf Wt% of SiC , speed on feed force, cutting force & radial force is as shown in the Figure 4. It can be seen from the graph that, with the increase in the wt% of silicon carbide particle there will be increase in cutting forces. Figure 5. Shows the Interaction plot for SiC Wt%, speed on Surface roughness Ra. Surface roughness increases with the cutting speed. This is due to the reinforcement material. Since harder material like SiC causes difficulty in machining proces. Lower the Wt% of the SiC combination then the cutting force and surface roughness is minimum.

Table 8 Analysis of variance for Cutting force & Surface roughness

| Radial force (Fd) | | | | | | | Surface roughness (Ra) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | DF | Adj SS | Adj MS | F-Value | P-Value | Contribution % | DF | Adj SS | Adj MS | F-Value | P-Value | Contribution |
| Material | 3 | 273.68 | 91.22 | 20.65 | 0.017 | 21.7 | 3 | 4.4519 | 1.4840 | 4.42 | 28.49 | 27.69 |
| Tool wear | 3 | 134.38 | 44.79 | 10.14 | 0.044 | 10.66 | 3 | 0.4369 | 0.1456 | 0.43 | 43.68 | 2.69 |
| Speed | 3 | 776.20 | 258.73 | 58.58 | 0.004 | 61.6 | 3 | 10.061 | 3.3540 | 9.99 | 20.99 | 62.59 |
| Feed | 3 | 75.73 | 25.24 | 5.72 | 0.093 | 6.01 | 3 | 1.1269 | 0.3756 | 1.12 | 6.82 | 7.01 |
| Error | 3 | 13.25 | 4.41 | | | | 3 | 1.0069 | 0.3356 | | | |
| Total | 15 | 1273.24 | | | | | 15 | 17.084 | | | | |

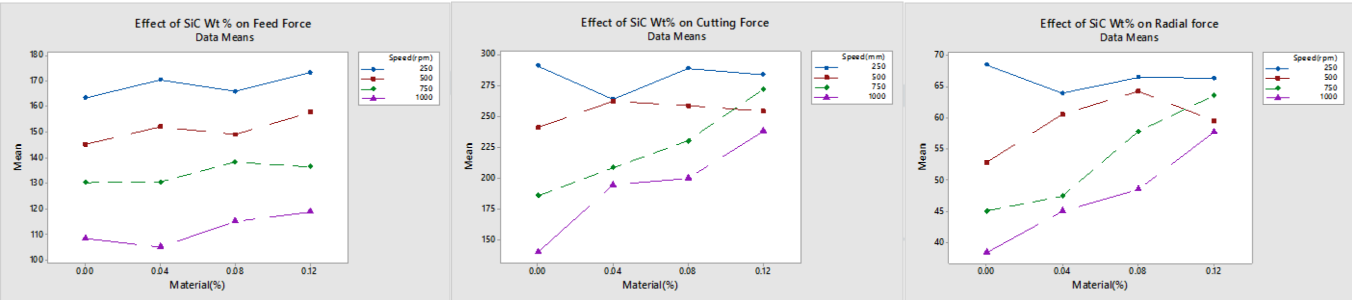


Figure 4. Interaction plot for SiC Wt%, speed on feed force, cutting force & radial force

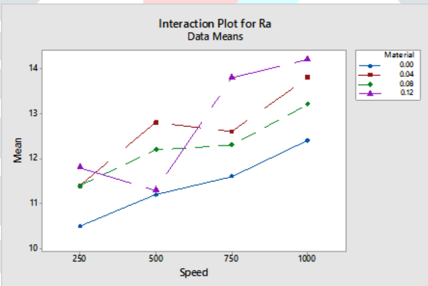


Figure 5. Interaction plot for SiC Wt%, speed on Surface roughness Ra

4. Conclusion

An attempt was made to study the different cutting force components using the lathe tool dynamometer for machining the LM6/SiC composite material. The metal matrix composites were fabricated by using the stir casting method with varying percentage of SiC. LM6/SiC composite with 4,8 and 12 wt% of SiC reinforcement ratio on machinability has been evaluated. The effect of machining parameters in turning (reinforcement Wt% of SiC, tool wear, cutting speed, Speed and depth of cut) on the feed force, cutting force, radial force and surface roughness were conducted.

Following conclusions have been obtained from the results.

- With increase in the Wt% of the reinforcement of SiC, cutting force components decreases. This is due to hard reinforcement component is embedded into the aluminium matrix.
- Cutting force component in the composites is lower than the base metal, this may be due to the thermal mismatch between the matrix and the reinforcement.
- The wt% of SiC increases, the surface roughness also increases.
- The results of ANOVA shows that, cutting speed contribution is more as compared to the other machining parameters. Hence it is the most dominating parameters followed by the material in the turning operation.
- Mathematical model developed through the regression analysis shows that, Experimental value of cutting force component and the predicted value using the regression analysis is almost nearer with the error of about 5%.

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