# OPTIMIZATION OF MILLING PARAMETERS ON ALUMINIUM HYBRID METAL MATRIX COMPOSITE USING TAGUCHI METHOD

**S.Chandrasekhar[1], Sk.Surjan[2] and M.S.S.Prasanth Chowdary[3]**

[1]Assistant Professor Department of Mechanical Engineering, Sri Vasavi Engineering College,Tadepalligudem ,A.P, India

[2]Assistant Professor Department of Mechanical Engineering, Sri Vasavi Engineering College,Tadepalligudem ,A.P, India

[3]UG Student Department of Mechanical Engineering, Sri Vasavi Engineering College,Tadepalligudem ,A.P, India

**ABSTRACT**

***Metal Matrix Composites are widely used in aerospace, automobile, structural, marine industries because of good corrosive resistance and better strength to weight ratio. In this paper an attempt has been made to optimize the milling machine process parameters of hybrid Aluminium Metal Matrix Composite prepared by stir casting method. In this process pure Aluminium is metal matrix and hybriding with Silicon carbide and Tungsten Carbide. The microstructure of hybrid matrix is associated with scanning electron microscope. Scanning electron microscope analysis conforms the distribution of Silicon carbide, Tungsten Carbide in Aluminium matrix. To optimize the process parameters such as cutting speed, feed, depth of cut of Aluminium hybrid Metal Matrix Composite in CNC milling by using Taguchi method. L27 orthogonal layout used for experimental work and Taguchi method employed for optimization to get best material removal rate and good surface finish. Analysis of variance is used to find out the contribution of process parameters on responses.***

**Keywords***:* Stir casting method, Taguchi method, Surface roughness, Material removal rate, ANOVA

## 1. INTRODUCTION

According to D.M. skibo et al., the cost of stir casting of producing composite material is about one third of the other competitive methods and for high volume production the cost is reduced to one tenth [1]. K.Umanath et al., the base metal is melted at a temperature of 998K by stirring forcefully with Alumina coated stainless steel stirrer was used to stir at 600rpm for 20 minutes and then it is degassed with the help of nitrogen gas. The preheated particulates were introduced in to the molten material and it is poured into a mold which was preheated to 523K to manufacture specimen after casting. They concluded that the particulates silicon carbide and aluminium oxide are distributed homogeneously in the AL6061 matrix material [2]. V.Agarwala et al,. States that the heat treatment of the particles before dispersion into the melt aids their transfer by causing elution of adsorbed gases from the particle surface. Heating silicon carbide particles to 1173K assists in removing surface impurities, desorption of gases, and alter the surface composition by forming an oxide layer on the surface [3]. According to D.M.Stefanesfu et al., rapidly solidified structures gives better distribution of the particles due to finer dendrite size and limited settling of the particles resulting in reducing time during the composites are in molten state [4]. Himanshu Kala et al., talk about a two-step mixed method, which involves heating of the matrix material above liquids temperature and then the melt is cooled down to a temperature of a semi-solid state. At this point the preheated particulates are added and again the matter is heated to above liquidus temperature and mixed thoroughly. By this method the gas layer around the particles gets breaks and promotes wetting between matrix melt and particulates [5]. According to Arokiadas R et al., metal matrix composites can be fabricated through various techniques depending up on the types of material involved, strength required, shape of the end product and the size of the reinforced particle, these techniques are classified into solid-state, semisolid-state, and liquid state. Solid-state technique gives best mechanical properties, liquid state techniques are economical and nearer net shape process keeps them still in the area of composite fabrication [6]. Ting-Cheng Chang et al., says that Taguchi method is most frequently used method for optimization in design of experiments (DOE) methods which saves cost, time, and material and these dynamic experiments are simple, systematic and more efficient method in giving optimum machining parameters [7]. According to Ross PJ using experimental design Taguchi introduces his approach for designing the products or processes robust to environmental conditions and component variations and also to minimize variations around target value [8]. Njan CY et al., describes the steps involved in Taguchi method to optimize a process with multiple performance characteristics which includes identifying performance characteristics, selection of process parameters, determining no of levels, selecting orthogonal array and carrying experiment, calculating total loss functions and S/N ratio ,analyzing by ANOVA[9]. S. Das said that the application of composites in aerospace, defence and in automotive industries have been increased because of its unique properties like high specific strength, wear resistance, strength to weight ratio, strength to cost [10]. K.Umanath said that in reinforcement without developing inter-metallic phase SiC forms an adequate bond with the matrix and it is chemically compatible with Aluminium and other advantages like excellent thermal conductivity, good workability and low cost [11]. S Jerry Andrews Fabian et al., states that with increasing the WC content within the matrix material, resulted in significant improvement in mechanical properties like hardness, tensile strength, density and wear resistance [12].

## 2. MATERIALS AND METHODS

Aluminum matrix composite components are widely used from few decades due to improved their physical and mechanical properties due to the reinforcements of micro and nano size particles. Metal matrix composites with TiC, Al2O3, B4C, TiB2, SiC, WC hybrid matrix etc.., as the reinforcement have a specific advantage than their elemental materials. Metal matrix composites contain mainly two properties namely ductility and toughness, because of these properties the metal matrix composites are more popular in aerospace, marine, automobile, electronic and sports industry. Many proprieties of the material such as particle type, size, volume fraction, reinforcing percentage in to the matrix and bond strength influence the process parameters. Literature shows the fabrication of materials by some new advanced techniques like powder metallurgy, stir casting, reacting with salts, pressure less self- in filtration technique, semi-solid stirring with ultrasonic vibration etc.. Rate of Removal of Material is the parameter to improve the productivity, Surface finish is the parameter referred for Quality. In manufacturing industries the components of good Quality with higher rate of production is a challenging task. CNC End milling is one of the machining process to achieve good Quality with higher production rate by optimizing the machining parameters. To optimize the machining parameters taguchi method is used because it saves time, cost materials and number of iterations.

In this study Taguchi method is used to optimize the machining parameters to get the minimum difference from required values in milling of Al-SiC-WC hybrid material which is produced by stir casting technique and machined with HSS end milling tool. Analysis of Variance (ANOVA) is used to find the percentage of contribution of input parameters on responses.

**Table 1:** Chemical Composition of Al-SiC-WC Composite

| Element | Mg | Fe | Si | Mn | SiC | WC | Al |
|---|---|---|---|---|---|---|---|
| Weight % | 0.1 | 0.03 | 0.02 | 0.01 | 2.5 | 2.5 | Remain.. |

## 3. EXPERIMENTAL WORK

The produced Al-SiC-WC hybrid MMC is cast in to 50X50X15mm for experimental work. Hi-Tech CNC milling center is used for experimental work, HSS End milling cutter is used as cutting tool. Speed, feed, depth of cut are used as machining parameters and rate of removal of material and surface roughness are used as responses. Factors and their level the experimental work are tabulated in table 1.L27 orthogonal array is used for experimentation. Surface roughness is measured by tally surf and Material removal rate is calculated by using the formula

MRR=L x W x D / Cycle time

L: Length of cut

W: Width of cut

D: Depth of cut

**Table 2:** Factors and levels

| Factors | Units | Levels | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Speed | rev/min | 1200 | 1400 | 1600 |
| Feed | mm/min | 25 | 50 | 75 |
| Depth of cut | mm | 0.25 | 0.5 | 1 |

**Table 3:** L27 Orthogonal array for 3 factors

| S.No | Speed | Feed | Depth of cut | MRR | SR |
|---|---|---|---|---|---|
| 1 | 1200 | 25 | 0.25 | 0.10480 | 0.825 |
| 2 | 1200 | 25 | 0.5 | 0.19608 | 0.637 |
| 3 | 1200 | 25 | 1.00 | 0.30116 | 0.733 |
| 4 | 1200 | 50 | 0.25 | 0.38009 | 0.802 |
| 5 | 1200 | 50 | 0.5 | 0.08027 | 0.543 |
| 6 | 1200 | 50 | 1.00 | 1.45161 | 1.004 |
| 7 | 1200 | 75 | 0.25 | 0.05714 | 0.516 |
| 8 | 1200 | 75 | 0.5 | 0.29474 | 0.888 |
| 9 | 1200 | 75 | 1.00 | 2.51046 | 1.795 |
| 10 | 1400 | 25 | 0.25 | 0.14925 | 4.861 |
| 11 | 1400 | 25 | 0.5 | 0.64748 | 0.793 |
| 12 | 1400 | 25 | 1.00 | 1.22034 | 2.609 |
| 13 | 1400 | 50 | 0.25 | 1.04615 | 0.850 |
| 14 | 1400 | 50 | 0.5 | 0.60223 | 1.548 |
| 15 | 1400 | 50 | 1.00 | 2.28947 | 1.003 |
| 16 | 1400 | 75 | 0.25 | 1.49206 | 2.093 |
| 17 | 1400 | 75 | 0.5 | 0.64368 | 1.024 |
| 18 | 1400 | 75 | 1.00 | 1.67568 | 2.403 |
| 19 | 1600 | 25 | 0.25 | 0.71351 | 1.559 |
| 20 | 1600 | 25 | 0.5 | 0.25781 | 2.182 |
| 21 | 1600 | 25 | 1.00 | 1.43119 | 3.090 |
| 22 | 1600 | 50 | 0.25 | 0.62428 | 0.585 |
| 23 | 1600 | 50 | 0.5 | 1.37143 | 0.940 |
| 24 | 1600 | 50 | 1.00 | 1.18841 | 1.060 |
| 25 | 1600 | 75 | 0.25 | 0.77301 | 1.545 |
| 26 | 1600 | 75 | 0.5 | 1.08861 | 0.936 |
| 27 | 1600 | 75 | 1.00 | 1.30964 | 2.555 |

## 4. DATA ANALYSIS

From the table the factors which are greatly influence the material removal rate is Depth of cut followed by feed rate. Analysis of variance is conducted for responses to study the influence of milling parameters.

**Table 4:** Response Table for Means for MRR

| Level | Speed | Feed | Depth |
|---|---|---|---|
| 1 | 0.5974 | 0.5580 | 0.5934 |
| 2 | 1.0852 | 1.0038 | 0.5758 |
| 3 | 0.9731 | 1.0939 | 1.4864 |
| Delta | 0.4878 | 0.5359 | 0.9106 |
| Rank | 3 | 2 | 1 |

**Table 5:** Analysis of Variance for MRR

| Source | DF | Adj SS | Adj MS | F-value | P-value | %contribution |
|---|---|---|---|---|---|---|
| Speed | 2 | 1.175 | 0.5875 | 2.95 | 0.075 | 14.80 |
| Feed | 2 | 1.482 | 0.7411 | 3.73 | 0.042 | 18.67 |
| Depth | 2 | 4.881 | 2.4407 | 12.27 | 0.000 | 61.50 |
| Error | 20 | 3.978 | 0.1989 | | | 5.03 |
| Total | 26 | 11.516 | 3.9682 | | | 100.00 |

**Regression Equation:**
mrr = 0.8852 - 0.288 speed_1200 + 0.200 speed_1400 + 0.088 speed_1600 - 0.327 feed_25+ 0.119 feed_50 + 0.209 feed_75 - 0.292 depth_0.25 - 0.309 depth_0.50 + 0.601 depth_1.00

**Table 6:** Response Table for Means for SR

| Level | Speed | Feed | Depth |
|---|---|---|---|
| 1 | 0.8603 | 1.9210 | 1.5151 |
| 2 | 1.9093 | 0.9261 | 1.0546 |
| 3 | 1.6058 | 1.5283 | 1.8058 |
| Delta | 1.0490 | 0.9949 | 0.7512 |
| Rank | 1 | 2 | 3 |

**Table 7:** Analysis of Variance for SR

| Source | DF | Adj SS | Adj MS | F-value | P-value | %contribution |
|---|---|---|---|---|---|---|
| Speed | 2 | 5.245 | 2.6224 | 3.93 | 0.036 | 38.33 |
| Feed | 2 | 4.520 | 2.2600 | 3.39 | 0.054 | 33.03 |
| Depth | 2 | 2.583 | 1.2914 | 1.94 | 0.170 | 18.87 |
| Error | 20 | 13.339 | 0.6670 | | | 9.77 |
| Total | 26 | 25.687 | 6.8408 | | | 100.00 |

**Regression Equation:**
sr = 1.458 - 0.598 speed_1200 + 0.451 speed_1400 + 0.147 speed_1600 + 0.463 feed_25- 0.532 feed_50 + 0.070 feed_75 + 0.057 depth_0.25 - 0.404 depth_0.50 + 0.347 depth_1.00

## 5. RESULTS AND DISCUSSION

Energy-dispersive X-ray spectroscopy analysis is carried out for the produced hybrid metal matrix composite and corresponding report is illustrated in the Figure 1. It is understandable from the Figure 1, the aluminum Silicon carbide and tungsten carbide peaks are detected in the pattern. Quantitative elemental analysis report divulges the 4.71 weight percentage of WC, SiC phases are found. The proposed weight percentage of WC, SiC is 2.5,2.5. Scanning electron microscopic image of the produced composite is exposed in the Figure 2. Approximately, 0.5 to 1 µm size of TiB2 particles can be seen in the Figure 2.

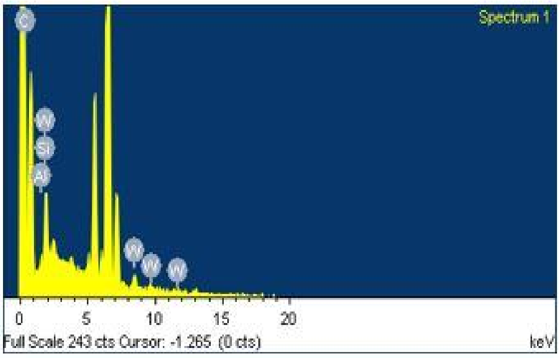


**Figure 1** EDAX Pattern of the composite

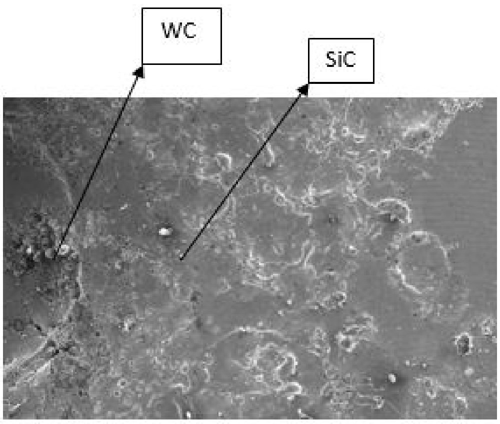


**Figure 2** SEM image of the composite

L27 Orthogonal array is generated by using mini tab 18 and corresponding material removal rate values and surface roughness values are entered. Response graph for the material removal rate is created and illustrated in the figure 3. It is found from the figure 3, 1600rpm of tool speed, 1mm depth of cut and a feed of 75mm are the optimum process parameters to attain the most advantageous removal rate of material with in selected levels of parameters. It is also observed from the response graph that with increase in speed, feed and depth of cut material removal rate increases. For the same L27 layout, the analysis of variance for the material removal rate is also performed and exhibited in table 5. Table 5 clearly brings out the percentage of the contribution of each parameter on material removal rate. Depth of cut plays dominant role than the other parameters. The contribution of depth of cut is 61.5%, feed has 18.67% and speed has 14.80%.

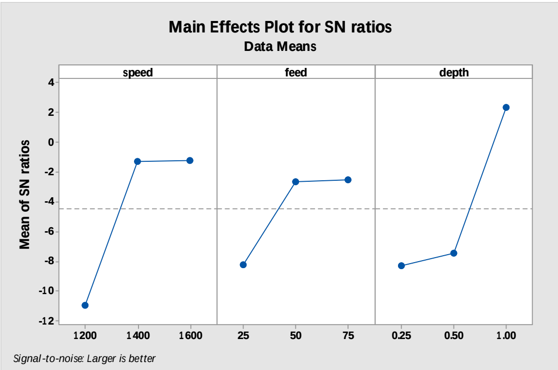


**Figure 3:** Response graph for MRR

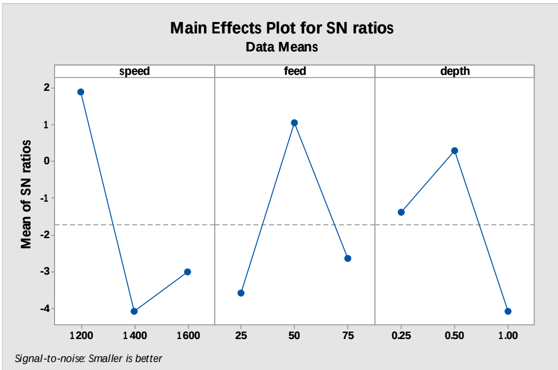


**Figure 4:** Response graph for sr

The response graph produced for the surface roughness for machined surface is disclosed in the figure 4. Figure 4 make known that 1400rpm speed, 25mm feed and a depth of cut of 1mm is the optimal parameters to conquer good surface roughness of the machined part within selected level of parameters. It is clear from the figure, with increase in speed, feed and depth of cut up to certain level the surface roughness value increases but with go on increasing it is decreased. For the same L27 ANOVA is performed and exhibited in table 7. The percentage contribution of each parameter surface roughness is shown in table 7. Table clearly brings out the percentage of the contribution of each parameter on surface roughness. Speed plays dominant role than the other parameters. The contribution of speed is 38.33%, feed has 33.03% and depth of cut has 18.87%.

## 6. CONCLUSION

Al-SiC-WC composite is successfully produced by stir casting method. SiC & WC phases and its volume fraction are confirmed by scanning electron microscopy and energy-dispersive X-ray spectroscopy analysis. Optimization of the machining parameters in machining the composite is discussed. Higher levels of speed, feed, and depth of cut are suitable for attaining optimal material removal rate. Medium levels of parameters are found for good surface roughness. Depth of cut influences strongly the material removal rate and surface roughness. The generated regression equation helps to predict the material removal rate and surface roughness with considerable accuracy.

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