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RESEARCH ARTICLE

Optimization of Machining Parameters for Surface Roughness of Cu/SiC and Cu/SiC/Gr Metal Matrix Composites on Shaper

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Abstract

In this study, Cu/SiC and Cu/SiC/Gr hybrid composite samples were prepared with liquid metallurgy technique by stir casting method. Optimization of machining parameters of hybrid Cu/SiC and Cu/SiC/Gr hybrid composites were carried out in this investigation. The effect of cutting speeds, feed rates and depth of cut on surface roughness were also investigated. Taguchi L9 orthogonal array was used as the experimental plan for both composites. Machining was done to check the surface roughness and measured for three different levels of speeds (100, 120 and 140 m/min), three different feed rates (0.2, 0.3 and 0.4 mm/min) and three depth of cut (0.5, 0.7 and 1.0 mm). The results of the experimental work show that surface roughness is affected by speed, feed rate and depth of cut. The optimum parameters were obtained for Cu/SiC MMC at speed of 140 m/min, feed rate of 0.2 mm/min and depth of cut of 0.5 mm and surface roughness around 5.91 µ. The optimum parameters obtained for Cu/SiC/Gr MMC at speed of 100 m/min, feed rate of 0.2 mm/min and depth of cut of 0.5 mm and surface roughness was 4.32 µ. Analysis of both composites for surface roughness shows that the addition of graphite decreases the surface roughness of the composite. We get better surface finish of the Cu/SiC/Gr hybrid composite in comparison with Cu/SiC composite on shaper machine.

Keywords: Hybrid composite, machining parameters, copper, silicon carbide, graphite, surface roughness.

Introduction

Metal matrix composites (MMC) are fast emerging class of engineering materials nowadays known as composites materials. Composite materials are the combination of two or more materials. Sometime, we do not get the desired properties of a pure material, but when it is added with pure material then the desired properties of a specific application is obtained. This is a new emerging class of material family that has wide scope for the devolvement of high strength, stiffness and corrosion resistance. A composite material is designed to display a combination of the best characteristics of each of the component materials.

Noor Ahmed and Ramesh (2004) have focused their intention on improving the tribological properties by reinforcing copper with hard ceramic reinforcements such as silicon carbide and titanium carbide. They made an effort to make use of soft phase graphite as an additional reinforcement to the conventional copper based hard reinforced composites. Graphite being a solid lubricant can improve the machinability of the composites. Presence of graphite in hybrid composite has lowering effect on the coefficient of friction of hybrid composite when compared with Cu-SiC composite**.**

Wu *et al.* (2008) presented that most of the studies have been concerned with the fabrication technique of the SiC/Gr/Al composites such as stir-casting and spray co-deposition. For SiC/Gr/Al composites fabricated by stir-casting, the mechanical properties of the composites are low due to the presence of coarse graphite particles, the segregation of particles and the presence of Al_4C_3 intermetallic compound. The spray co-deposition technique also has some drawbacks, such as the inhomogeneous distribution of particles and the relative low density, leading to poor mechanical properties of the composites.

To the best to our knowledge, the composite fabricated by squeeze casting exhibits better mechanical properties due to the presence of few common defects such as porosity and shrinking cavities and the elimination of segregation of the reinforcement. However, SiC/Gr/Al composites fabricated by this technique have seldom been reported on and details of their mechanical properties are still lacking. Therefore, the present study concentrated on the fabrication of SiC/Gr/Al composites, microstructure and mechanical properties of the composites.

Ramesh and Noor Ahmed (2009) developed a new class of copper based composite material by dispersing both hard and soft reinforcement in appropriate proportions to ensure optimum tribological characteristics. The silicon carbide varied from 3 to 10 wt.% and graphite content was 1 wt.% in prepared hybrid composite. Cu-SiC-Gr hybrid was made by liquid metallurgy route; the result showed that hybrid composite possesses higher strength, better wear resistance and low coefficient of friction. Barmouz *et al.* (2011) studied that multi pass friction stir processing (MFSP) is used for improvement of micro structural and mechanical properties of in situ Cu/SiC composites. Field emission scanning electron microscopy and optical microscopy images indicate that multi-pass FSP notably enhances the separation and dispersion of SiC particles and also reduces the grain size in the composite matrix, SiC particles size and porosity contents. According to the results, higher micro hardness values, remarkably enhanced tensile properties were caused by higher number of FSP passes. A negligible difference between the electrical resistivity of composites fabricated by 1, 4 and 8-pass FSP was also detected. Cu/SiC metal matrix composites have been the subject of extensive research since these composites have been prepared by powder sintering; squeeze casting, composite electroforming technology and sintering under ultrahigh pressure.

The mechanical properties of Cu/SiCp metal matrix composites, made by powder sintering and extra applications, an inductively coupled thermal plasma process was also used to produce Cu/SiC nano-composites. Esezobor and Oladoye (2011) investigated particulate copper silicon carbide (Cu-SiCp) composites find application as wear and heat resistant materials in electrical sliding contacts in homopolar machines, railway overhead current collector systems where high electrical/thermal conductivity combined with good wear properties is required. However, challenges occur during machining due to the presence of hard reinforcement in the matrix. This may lead to high turnover of tool wear and poor surface finish. The adoption of near-net shape technology to produce such hard-to-machine metal matrix composites and subsequent finish machining with its attendant cost has reported limited success. This study critically appraises the challenges and opportunities in the improvement of tribological characteristics of particulate Cu-SiC composites and identifies low cost reinforcement material that could be used to improve its tribological characteristics. Wang (2012) investigated particulate copper silicon carbide (Cu-SiCp) composites find application as wear and heat resistant materials in electrical sliding contacts such as in homopolar machines, railway overhead current collector systems where high electrical/thermal conductivity combined with good wear properties is required.

Against these backdrops, this study was aimed with the following objectives:

1. Fabrication of Cu/SiC and Cu/SiC/Gr MMC by stir casting.
2. Optimizing the machining parameters namely cutting speed, feed rate, depth of cut on shaper for surface roughness of Cu/SiC and Cu/SiC/Gr MMC.
3. Analysis of surface roughness of Cu/SiC and Cu/SiC/Gr composites.

Materials and methods

Experimental design: The experiment has been carried out using L-9 orthogonal array. This method is chosen for three parameter levels such as Ram Speed, feed and depth of cut. Experimental design consists of 9 shaper speeds, feed and depth of cut. Taguchi's method of experimentation was best suitable for this study.

Analysis of S/N ratio: This method uses S/N (Signal to Noise ratio) to describe the test results because this represents both means (average) and variations of the experimental results. The results are carried out using S/N ratio according to the need of a specific application. The selection of proper S/N ratio also depends upon the physical properties of the problem. The S/N ratio is considered as smaller-is better, larger is better, nominal-is-best for different output machine response variables. In this study, the value of S/N ratio for surface roughness is considered as smaller is better.

Analysis of mean of means: This response analysis is based upon the averages of the experimental result at each level for each parameter. For each level parameter, there are three different levels of experimentation. The effect of each parameter can be found by experimentation on each level and in this way the effect of each parameter is evaluated. Experimental results evaluate the average response analysis by S/N ratio.

Analyzing the experimental data: Once the experimental design has been determined and the trials have been carried out, the measured performance characteristics from each trial can be used to analyze the relative effect of the different parameters. To demonstrate the data analysis procedure, the following L9 array will be used, but the principles can be transferred to any type of array.
To determine the effect each variable has on the output, the signal-to-noise ratio or the SN number needs to be calculated for each experiment conducted. The calculation of the SN for the first experiment in the array is shown below for the case of a specific target value of the performance characteristic. In the equations below, yi is the mean value and si is the variance. Yi is the value of the performance characteristic for a given experiment.

$$SNi = 10 \log \frac{\bar{y}_i^{\,2}}{S_i^{\,2}}$$

Where, $\overline{y_i} = \frac{1}{Ni}\sum_{u=1}^{Ni} y_{i,u}$

$S_i^2 = \frac{1}{N_i-1}\sum_{u=1}^{Ni}(y_{i,u} - \bar{y}i)$

i= Experiment number
Ni=Number of trials for experiment
u= Trial number

For the case of minimizing the performance characteristic, the following definition of the SN ratio should be calculated.

$$SNi = -10\log\left[\frac{1}{N_i}\sum_{u=1}^{N_i}\frac{{y_u}^2}{Ni}\right]$$

For the case of maximizing the performance characteristic, the following definition of the SN ratio should be calculated.

$$SNi = -10\log\left[\frac{1}{N_i}\sum_{u=1}^{N_i}\frac{1}{{y_u}^2}\right]$$

Problem formulation: Copper matrix composites are one of the important innovations in the devolvement of advanced materials. The addition of hard reinforcement like SiC makes machining of CMCs significantly more difficult and leads to high cutting forces, poor surface finish and tool wear. In order to improve machinability, to Cu/SiC composites, graphite has been added to the composites. The addition of natural lubricant like graphite enhances the self-lubricating capacity of the composites and reduces the wear. However, with the addition of graphite particles, mechanical properties of composites can be increased. Improving the machinability of hybrid MMC and developing machining data are the most promising ways to convince designers and manufacturers to use hybrid MMCs in their application The prominent quality indicator for machined products is surface roughness. In many critical applications, achieving the desired surface quality is of great importance for the effective use of the product. Due to these reason, Cu/SiC composites with graphite addition and optimizing the machining parameters of it for increasing the surface finish and production of these composites have been attempted in this study.

Experiment details: In experimental arrangement of this process, stir casting mythology is used using graphite crucible in the muffle furnace. The method used is the liquid metallurgy route technique. This method is the most economical route of all other routes for the production of MMCs production. The MMC is followed by the first step to introduce the reinforcement material into the melt. The metal matrix was placed in the graphite crucible and then it was placed in the heating furnace maintained around a temperature level of 1100ºC. Copper melting have been carried out at a temperature range of 1100º±100ºC. The particles of SiC and graphite were pre-heated up to a temperature of 1100ºC for 2-3 h. This mixture is then mixed with the molten copper for uniformly mixing with the help of automatic stirring device. The whole mixture is then heated in the separate furnace and temperature is controlled up to 1100ºC. The pouring of the slurry has been carried out in the sand mould to get the final solidified casted work pieces. This process has been carried out for both casted pieces of Cu/SiC MMC and Cu/SiC/Gr hybrid materials. These work-piece samples are used to study the machinability of both Cu/SiC composite and Cu/SiC/Gr hybrid MMC.

Experimental procedure: The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. In the present experimental study, shaper speed, feed and depth of cut have been considered as process variables with their units (Table 1). The input parameters of the machine were set according to the Taguchi as shown in Table 1 and their effects on the response variables were evaluated. Three experiments were performed in one set of experiment. Surface roughness tester measuring range of 800 µm with 0.000125 µm resolutions was used for measuring surface roughness of the specimens.

Table 1. Selected parameters for levels of experimentation.

Levels	Ram speed (N)	Feed (f)	Depth of cut (d)
1	100	0.2	0.5
2	120	0.3	0.7
3	140	0.4	1.0

Results and discussion

Experimental data obtained during shaping Cu/SiC (Without graphite): Surface roughness at different speed, feed and depth of cut in shaping of Cu/SiC is given in Table 2. Various combinations of parameters were obtained by conducting the experiments as per orthogonal array. The measured results were analyzed using the commercial software MINITAB 15 specifically design to study the results of experiments.

Figure 1 shows individual effect of process parameters at different levels of speed, feed and depth of cut and its effect on the surface roughness (Ra). It was observed that the surface roughness is low at low speed and it increases with speed gradually and at higher speed the surface roughness decreases. Hence, it may be concluded that we get low surface roughness at higher speeds and low surface roughness at low feed rate and depth of cut. Optimum parameters as per Taguchi analysis is speed of 140 m/min, feed rate of 0.2 mm/min and depth of cut of 0.5 mm.

Table 2. Taguchi's orthogonal array and results of surface roughness shaping Cu/SiC (Without graphite).

Speed (N)	Feed (f)	Depth of cut (d)	Surface roughness (Ra)	Mean of means
100	0.2	0.5	5.42	5.42
100	0.3	0.7	6.12	6.12
100	0.4	1.0	7.81	7.81
120	0.2	0.5	5.83	5.83
120	0.3	0.7	7.22	7.22
120	0.4	1.0	7.83	7.83
140	0.2	0.5	5.91	5.91
140	0.3	0.7	6.24	6.24
140	0.4	1.0	6.98	6.98

Table 3. Taguchi's orthogonal array and results of surface roughness shaping Cu/SiC/Gr (With graphite).

Speed (N)	Feed (f)	Depth of cut (d)	Surface roughness (Ra)	Mean of means
100	0.2	0.5	4.32	4.32
100	0.3	0.7	5.36	5.36
100	0.4	1.0	6.25	6.25
120	0.2	0.5	5.05	5.05
120	0.3	0.7	6.63	6.63
120	0.4	1.0	6.28	6.28
140	0.2	0.5	5.43	5.43
140	0.3	0.7	6.05	6.05
140	0.4	1.0	6.40	6.40

Fig. 1. Main effects plot for means (Ra) (Smaller is better) (Without graphite).

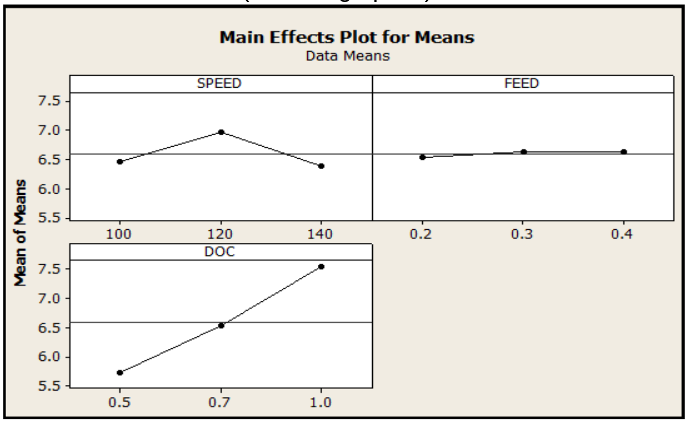
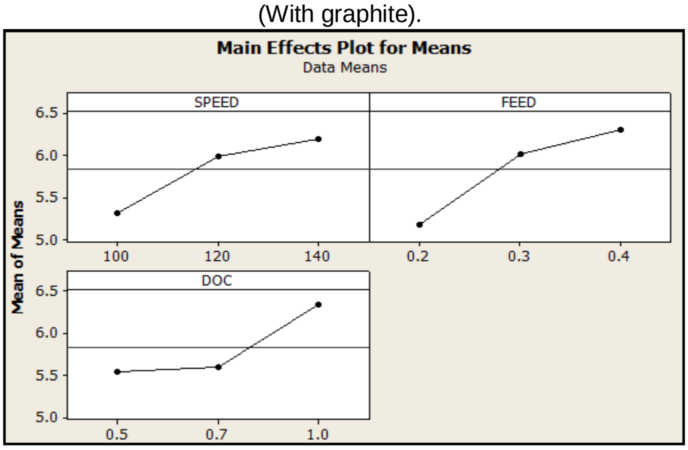


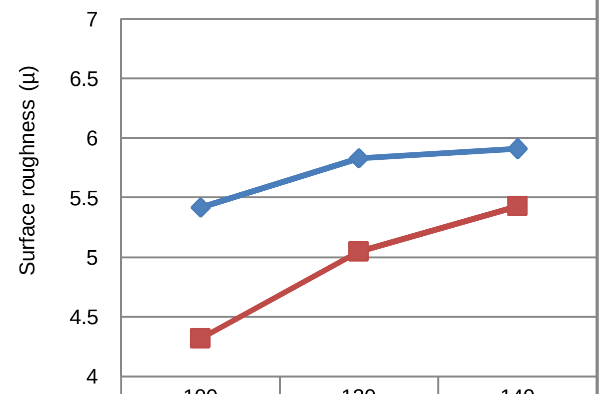
Fig. 2. Main effects plot for means (Ra) (Smaller is better) (With graphite).



Experimental data obtained during shaping Cu/SiC (With graphite): Table 3 shows the Taguchi's result for surface roughness (Ra). Mean of means are calculated by values of surface roughness in the Minitab software. From the experimental data we got better surface finish at low speeds, at low feed rates and low depth of cuts. Optimum parameters as per Taguchi analysis is speed of 100 m/min, feed rate of 0.2 mm/min and depth of cut of 0.5 mm.

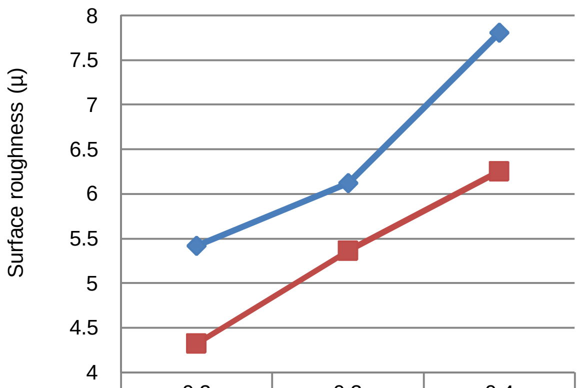
Figure 3 shows the comparison of both the composites, with reference to surface roughness at speed 100 m/min. Surface roughness was 5.42 and 4.32 µ at speed 100 m/min. Surface roughness was 5.83 and 5.05 µ at speed 120 m/min. It was noted that surface finish results were better in case of Cu/SiC/Gr as compared to Cu/SiC. Figure 4 shows the comparison of both the composites, with reference to surface roughness at feed 0.2 mm/min. Surface roughness was 5.42 and 4.32 µ at feed 0.2 mm/min. Surface roughness was 6.12 and 5.36 µ at feed 0.3 mm/min. It was noted that surface finish results were better in case of Cu/SiC/Gr as compared to Cu/SiC. Figure 5 shows the comparison of both the composites, with reference to surface roughness at depth of cut 0.5 mm/min. Surface roughness were 5.42 and 4.32 µ at depth of cut 0.5 mm. Surface roughness was 7.81 and 6.25 µ at depth of cut 1.0 mm. It was noted that surface finish results were better in case of Cu/SiC/Gr as compared to Cu/SiC.

Fig. 3. Analysis of surface roughness Vs. cutting speed (m/min).



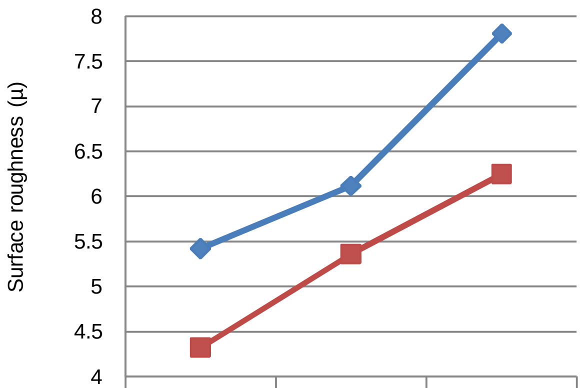
	100	120	140
Cu/SiC	5.42	5.83	5.91
Cu/SiC/Gr	4.32	5.05	5.43

Fig. 4. Analysis of surface roughness Vs. feed (mm/min).



	0.2	0.3	0.4
Cu/SiC	5.42	6.12	7.81
Cu/SiC/Gr	4.32	5.36	6.25

Fig. 5. Analysis of surface roughness Vs. depth of cut (mm).



	0.5	0.7	1
Cu/SiC	5.42	6.12	7.81
Cu/SiC/Gr	4.32	5.36	6.25

Conclusion

In this study, an effort is made to obtain the effect of input parameters such as cutting speed, feed and depth of cut and by optimization of these parameters; it is clearly shown that varying these parameters greatly influenced the material behavior and its machining characteristics. The addition of reinforcement like graphite also affects the MMC characteristics and its surface characteristics. It was noted that surface finish results were better in case of Cu/SiC/Gr as compared to Cu/SiC.

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