Analysis of Effect of Machining Parameters on Surface Roughness and MRR of AA3003/SiC Composite Material

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Abstract In this research work, AA3003/SiC composite material is used as workpiece material for turning process using TNMG 16 04 08 insert. Experimentation was carried out using Taguchi L_9 orthogonal array. Three process parameters with three levels were selected. Chosen process parameters are speed (rpm), feed (mm/rev) and depth of cut (mm). Effect of these process parameters on surface roughness and material removal rate (MRR) was evaluated. ANOVA and signal to noise ratio analysis was carried out. ANOVA analysis showed that the speed is the major process parameters that affect the surface roughness and MRR severely compared to feed and depth of cut during turning process. Better surface finish and higher MRR was observed for speed of 1000 rpm, feed of 0.4 mm/rev and depth of cut of 2.5 mm. Better surface finish was observed for speed of 1200 rpm, feed of 0.6 mm/rev and depth of cut of 2 mm.

Keywords Aluminum alloys · Surface roughness · Composites · Machining · Material removal rate

1 Introduction

Today's manufacturing industries are in search of materials that possesses lightweight and better mechanical properties, this demand of automobile and aerospace industries is difficult to filled by the use of conventional alloys but can be fulfilled by the use of advanced materials such as composite materials [1]. The composite materials possesses attractive mechanical properties such as high strength to weight ratio, high

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modulus to weight ratio, higher wear resistance, higher coefficient of thermal expansion, higher corrosive resistance, excellent fatigue resistance, good damage tolerance, and therefore, these materials are becoming center of attraction for material research community [2]. As the research is going ahead in the field of composite materials, it is necessary to develop proper secondary manufacturing processes such as machining for these materials. Because machining is one of the important manufacturing process and machining cost plays major role in deciding the cost of a manufactured product. Machining cost can be reduced by optimizing the process parameters for machining a particular material. The demand for new cutting tools and economy in manufacturing all over the world will rise faster than industrial production as a whole in the near future. Turning process is one of the basic machining processes used to obtain cylindrical components. Usually, the machining process parameters were selected based on the skills and experience of the operators and also by referring the manual provided by machine tool manufacturer. This method may not be suitable for mass production where the higher precision and accuracy are necessary to meet customer demand. This is possible when there is a robust set of machining parameters is available for a particular material. Many of the researchers conducted studies on machining of materials by keeping one parameter constant and varying other parameter, which is a time consuming and not much accurate. Therefore, the use of optimization technique is helpful to get correct combination of process parameters with less time and less cost. There are different techniques are available for optimizing the process parameters among them Taguchi method is one of the most commonly used method [3]. Because it is simple and effective method. Taguchi statistical tool uses orthogonal array to optimize the process parameters. 3xxx series of aluminum alloys are used in many of the industrial applications, especially they are used in manufacturing of heat exchangers of power plants, packaging and chemical equipments. Especially, AA3003 is one of the widely used materials in 3xxx series of aluminum alloys due to their excellent formability properties and higher resistance to corrosion. But they possess medium strength; therefore, it is significant to incorporate the reinforcement particles such as SiC to base metals to enhance the strength. However, various literature are available to study the effect of machining parameters on different composites [4–6], but there is still lack of studies that need to be carried on machining of AA3003/SiC material. Hence, in the present work, AA3003/SiC composites were considered as material for turning. Accordingly, Taguchi tool is used to optimize the machining parameters during turning operation. The combined effect of process parameters on surface roughness and MRR is also studied. Experimental results are provided to confirm the effectiveness of Taguchi approach.

2 Experimentation

In the present work, cylindrical workpiece with 25 mm diameter AA3003/SiC material is considered for turning operation. Turning operation was carried out on a CNC machine. Various jobs were obtained for different combinations of process parameters. Liquid state processing such as stir casting route was employed for producing AA3003/SiC composites, because it is one of the simple and economical method for producing composites. For conducting the experiments according to Taguchi technique, three process parameters such as spindle speed, feed and depth of cut with three levels were considered. The selected levels are tabulated in Table 1. These levels were considered on the basis of **trial** experiments conducted. After turning process, surface roughness was measured using Talysurf as shown in Fig. 1. Material removal rate (MRR) was calculated and expressed as mm^3/min. In order to analyze the effect of machining process parameters, **namely**, spindle speed, feed and depth of cut and

Table 1 Experimental result for MRR

Trial no	Speed (rpm)	Feed (mm/rev)	DOC (mm)	MRR	S/N ratio	Mean
1	800	0.2	1.5	4672	73.3901	4672
2	800	0.4	2	3876	71.7677	3876
3	800	0.6	2.5	4876	73.7613	4876
4	1000	0.2	2	5332	74.5378	5332
5	1000	0.4	2.5	3424	70.6907	3424
6	1000	0.6	1.5	2987	69.5047	2987
7	1200	0.2	2.5	3876	71.7677	3876
8	1200	0.4	1.5	2532	68.0693	2532
9	1200	0.6	2	4139	72.3379	4139

Fig. 1 Talysurf used for surface roughness measurement

Table 2 Experimental results for SR

Trial no	Speed rpm)	Feed mm/rev)	DOC (mm)	Surface roughness (Ra)	S/N ratio	Mean
1	800	0.2	1.5	22.23	26.9388	22.23
2	800	0.4	2	28.45	29.0816	28.45
3	800	0.6	2.5	19.65	25.8673	19.65
4	1000	0.2	2	25.78	28.2257	25.78
5	1000	0.4	2.5	31.54	29.9772	31.54
6	1000	0.6	1.5	24.33	27.7228	24.33
7	1200	0.2	2.5	27.23	28.7010	27.23
8	1200	0.4	1.5	22.12	26.8957	22.12
9	1200	0.6	2	19.23	25.6796	19.23

the interactions on the experimental data, analysis of variance is performed at 95% level. Before conducting the actual experiments, a set of trial and error experiments was conducted to find the range of cutting parameters for good surface finish and MRR. Tables 1 and 2 represent the ranking of each machining process parameter using Taguchi design of experiment (DOE) and analysis for S/N ratio, and means (larger is better) obtained at different process parameter levels.

3 Results and Discussion

Surface roughness is considered as one of the most important quality indicators during turning process. In the present work, surface roughness and MRR are considered as output responses. Surface roughness indicates the irregularities or unevenness present on the surface of manufactured parts. Process parameters such as cutting speed, feed and depth of cut affect the surface roughness and MRR. To obtain good surface finish and desired MRR, it is important to optimize the process parameter for a particular material. In this work, three process parameters with three levels were considered.

The S/N ratio for all machined components is determined by the following Eq. 1 (Sachinkumar et al. 2018).

$$\eta = -10 \log \frac{1}{n} \sum_{i=1}^{n} \frac{1}{T_i^2} \tag{1}$$

In Eq. 1, T_i is experimental value of the ith quality characteristic and n is the number of tests.

Followings are the steps involved in Taguchi parametric design optimization: (1) detection of process parameters to be optimized; (2) finding the number of levels for the selected parameters; (3) selecting orthogonal array; (4) running of experiments;

(5) analyzing the results using S/N ratio and ANOVA;(6) finding the optimal level of process parameters; (7) prediction of results; (8) running confirmation experiments.

Material removal rate (MRR) and surface roughness (SR) values were analyzed to study the effect of machining process parameters using Taguchi L_9 orthogonal array. Accordingly, the experimental values were calculated and tabulated in Tables 1 and 2, respectively, for MRR and SR. In this investigation, S/N ratio is selected according to the principle of "higher the better" in order to maximize the MRR. S/N ratio for SR selected according to the principle of "smaller the better" in order to minimize the SR. S/N ratios and means for MRR were calculated by using statistical software Minitab and presented in Tables 3 and 4, respectively. S/N ratio main plots are presented in Figs. 2a and 3a for MRR and SR, respectively. Means for MRR and SR are calculated and presented in Figs. 2b and 3b, respectively.

From Table 1 it can be noted that, higher MRR is observed for trial No. 4, i.e., for spindle speed of 1000 rpm, feed of 0.2 mm/rev and depth of cut of 2 mm, higher MRR is observed compared to other **trial** numbers. Amount of cutting force generated at this combination of process parameter may be sufficient that is why higher MRR is observed. But for 800 rpm and 1200 rpm, cutting force applied is not sufficient or excess as a result lower MRR is observed for these speeds, similar effect w.r.t. feed and depth of cut on MRR are observed.

Surface roughness values such as arithmetic mean (Ra) is measured for all machined components and also signal to noise ratios were calculated and tabulated in Table 2. Surface roughness was analyzed according to the principle of smaller the better. **Trial** No. 9 shows minimum surface roughness indicating better surface finish for the machined components obtained at spindle speed of 1200 rpm, feed of 0.6 mm/rev and depth of cut of 2 mm.

Table 3 Response table for signal to noise ratios for MRR

Level	Spindle speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1	72.97	73.23	70.32
2	72.97	73.23	70.32
3	72.07	71.87	72.07
Delta	2.25	3.06	2.56
Rank	3	1	2

Table 4 Response table for signal to noise ratios for SR

Level	Spindle speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1	27.30	27.96	27.19
2	28.64	28.65	27.66
3	27.09	26.42	28.18
Delta	1.55	2.23	1.00
Rank	2	1	3

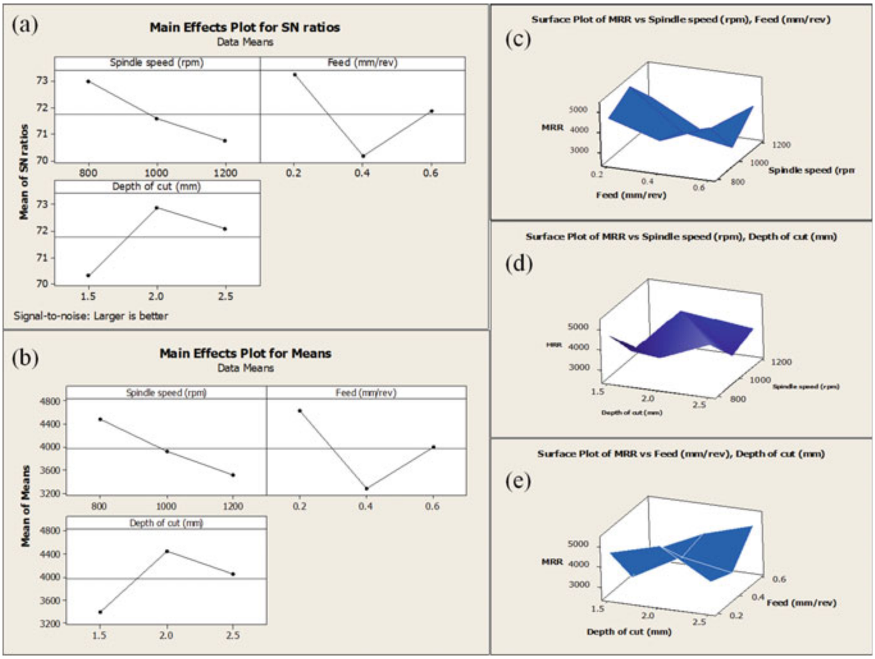

Fig. 2. **a** Main effects plots for S/N ratios for MRR, **b** main effects plots for means for MRR and surface plots for MRR showing combined effect of **c** spindle speed and feed **d** spindle speed and depth of cut, **e** feed and depth of cut.

ANOVA is one of the most widely used tools for analyzing the statistical data easily to identify the percentage contribution of each parameter on deciding the output response. In this work, ANOVA study was conducted at 95% confidence level. With the help of ANOVA study it is possible to get the clear pictures of effect of process parameters on output responses and the significance level of each process parameters. ANOVA results for MRR are presented in Table 5. From Table 5, it can be noted that feed rate plays major role in deciding MRR compared to speed and depth of cut. Therefore feed rate stands on rank 1, whereas depth of cut and speed stands at rank 2 and 3 respectively. Combined effect of each process parameters is analyzed through

Table 5 ANOVA results for MRR

Parameters	Degree of freedom	Sum of square	Mean square	F	Contribution rank
Spindle speed (rpm)	2	1,392,590	696,295	0.403	3
Feed (mm/rev)	2	2,735,788	1,367,894	2.26	1
Depth of cut (mm)	2	1,696,867	848,433	1.60	2

surface plots and are presented in Fig. 2 (b, c and d) for MRR. Similarly, ANOVA results for SR are presented in Table 6. Feed is the major machining parameter affecting surface finish also, whereas depth of cut and speed stands at rank 2 and 3 respectively. Combined effect of each process parameters is analyzed through surface plots and are presented in Fig. 3 (b, c and d) for SR. Further, the theatrical results are confirmed by conducting confirmation test run and the results are presented in Table 7. From Table 7, it is clear that there is n much difference between the predicted values and experimental values, both the values are matched well.

Table 6 ANOVA results for SR

Parameters	Degree of freedom	Sum of square	Mean square	F	Contribution rank
Spindle speed (rpm)	2	33.559	16.7794	1.60	2
Feed (mm/rev)	2	61.014	30.5071	2.92	1
Depth of cut (mm)	2	15.813	7.9065	0.53	3

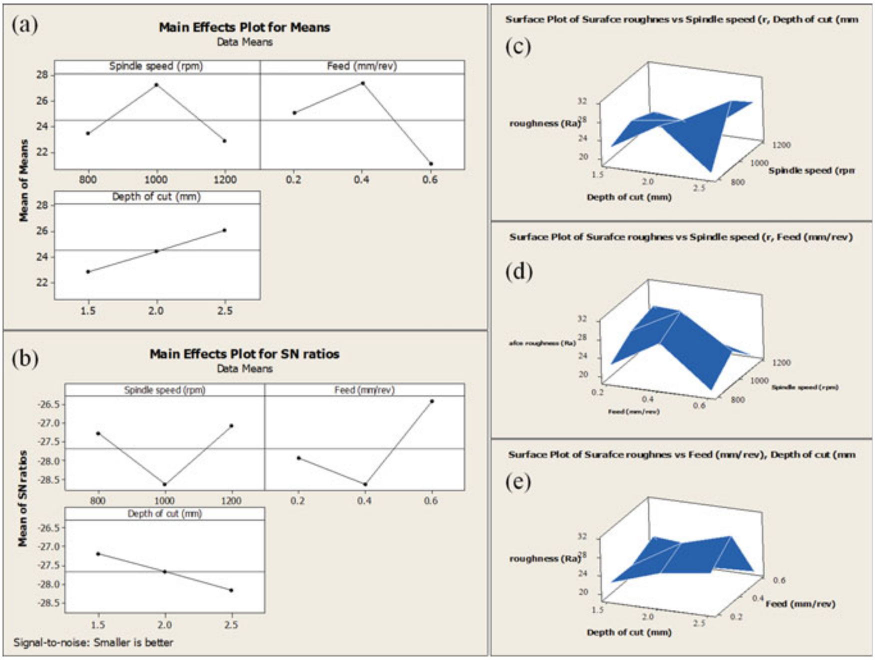

Fig. 3 **a** Main effects plots for S/N ratios for SR, **b** main effects plots for means for SR and surface plots for SR showing combined effect of **c** spindle speed and feed **d** spindle speed and depth of cut, **e** feed and depth of cut

Table 7 Results of confirmation experiments

Particulars	MRR	SR
Parameter level	A2B1C2	A3B3C3
Predicted value	5220	19.68
Experimental value	5332	19.23

4 Conclusions

Turning process was used successfully for machining of AA3003/SiC composite material using TNMG 16 04 08 insert. Taguchi L_9 orthogonal array was applied and optimal combination of process parameters was identified to give best responses of MRR and SR. ANOVA analysis showed that the feed is the major process parameters that affect the surface roughness and MRR severely compared to speed and depth of cut during turning process for this material. Higher MRR was observed for speed of 1000 rpm, **feed of 0.2 mm/rev** and depth of cut of 2 mm. Better surface finish was observed for speed of 1200 rpm, feed of 0.6 mm/rev and depth of cut of 2 mm.

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