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Investigation of Surface Roughness and Material Removal Rate on Machining of TIB2 Reinforced Aluminum 6063 Composites: A Taguchi's Approach

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The utilization of TiB2 particles reinforced aluminum (Al6063) metal matrix composite materials in many different engineering fields has undergone a tremendous increase. Accordingly, the need of accurate machining of composites has increased enormously; an attempt has been made to assess the factors influencing surface roughness and material removal rate on machining the composite. The orthogonal array, the signal- to-noise ratio, and analysis of variance were employed to study the performance characteristics in turning operations of 5 and
10 wt. % TiB2 particles reinforced aluminum (Al6063) metal matrix composites. Taguchi method was used to find the optimal cutting factors for surface roughness (Ra) and material removal rate (MRR). Three cutting factors namely speed; feed and depth of cut were optimized with considerations of Ra and MRR. The experimental plan and analysis was based on the Taguchi L27 orthogonal array with three cutting factors using carbide tool (K20). The optimal parametric combination for K20 carbide insert was found to be feed, speed and depth of cut. The analysis of variance (ANOVA) result shows that feed the most significant process parameter on surface roughness followed by speed. For MRR result show that the speed and the feed are the significant parameters followed by the composition of composite material.

Keywords: TiB2 reinforced 6063 aluminum composites, Taguchi Method, analysis of variance, surface roughness, materal removal rate.

1. Introduction

Aluminium alloys are the most widely used non ferrous materials in engineering applications owing to their attractive properties such as high strength to weight ratio, good ductility, excellent corrosion resistance, availability and low cost [1]. However, their applications have often been restricted because conventional aluminium alloys are soft and notorious for their poor wear resistance. This problem is over by

reinforcing hard ceramic particles in aluminium and its alloys to produce a discontinuous reinforced metal matrix composite which possesses nearly isotropic properties. Aluminum based particulate reinforced metal matrix composites have emerged as an important class of high performance materials for use in aerospace, automobile, chemical and transportation industries because of their improved strength, high elastic modulus and increased wear resistance over conventional base alloys. Recently, In-situ techniques have been developed to fabricate aluminum-based metal matrix composites [3-4], which can lead to better adhesion at the interface and hence better mechanical properties. In-situ composites are multiphase materials where the reinforcing phase is synthesized within the matrix during composite fabrication. There are different routes to Synthesize Al–TiB2 composites, but in-situ approach is gaining importance due to simplicity of its fabrication. Among the reinforcements, TiB2 has emerged as a promising candidate for Al-based composites. This is due to the fact that TiB2 is stiff, hard and more importantly, does not react with aluminum to form reaction product at the interface of reinforcement and matrix. TiB2 is a refractory compound that exhibits outstanding features such as high melting point (2790°C), high hardness (86 HRA or 960 HV) and high modulus characteristics. Its resistance to plastic deformation even at high temperatures portrays it to be a good potential reinforcing candidate in an aluminum matrix. 5 and 10 wt. % TiB2 particles reinforced aluminum (Al6063) metal matrix composites produced by using master alloys of Al-Ti & B by stir casting process to obtain the material for the experiment [5-7]. Surface roughness has become the most significant technical requirement and it is an index of product quality.
In order to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product, a reasonably good surface finish is desired. Nowadays, the manufacturing industries specially are focusing their attention on dimensional accuracy and surface finish. In order to obtain optimal cutting parameters to achieve the best possible surface finish, manufacturing industries have resorted to the use of handbook based information and operators' experience. This traditional practice leads to improper surface finish and decrease in the productivity due to sub-optimal use of machining capability. This causes high manufacturing cost and low product quality [8-11]. In addition to the surface finish quality, the material removal rate (MRR) is also an important characteristic in turning operation and high MRR is always desirable [8, 12].
Hence, there is a need to optimize the process parameters in a systematic way to achieve the output characteristics/responses by using experimental methods and statistical models. Dr. Taguchi employed design of experiments (DOE), which is one of the most important and efficient tools of total quality management (TQM) for designing high quality systems at reduced cost. Taguchi emphasizes on the fact that Quality provides robustness and immune to the uncontrollable factors in the manufacturing state. This approach helps to reduce the large number of experimental trials when the number of process parameters increases. [14-16]

In the present investigation, optimization model based on Taguchi method and utility concept has been employed to determine the best combination of the machining parameters such as cutting speed, feed, and depth of cut to attain the minimum surface roughness and maximum MRR simultaneously. The predictive models obtained were used for performance measures.

2. Design of experiments

Experimental design is a statistical technique that enables an investigator to conduct realistic experiments, analyze data efficiently, and draw meaningful conclusions from the analysis. The aim of scientific research is usually to show the statistical significance of an effect that a particular factor (input parameter) exerts on the dependent variable (output/response) of interest. Specifically, the goal of DOE is to identify the optimum settings for the different factors that affect the production process. The primary reason for using statistically designed experiments is to obtain maximum information from minimum amount of resources being employed. An experiment (also called run) may be defined as a test in which purposeful changes are made to the input variables of a process so that the possible reasons for the changes in the output/response could be identified. The experimental strategy frequently practiced by the industries is **one factor at-a time approach** in which the experiments are carried out by varying one input factor and keeping the other input factors constant. This approach fails to analyze the combined effect, when all the input factors vary together which simultaneously govern the experimental response. A well designed experiment is important because the results and conclusions that can be drawn from the experimental response depend to a large extent on the manner in which data were collected.

2.1. *Factorial designs*

This is an experimental strategy, in which all the factors of study are varied together, instead of one at a time. If the factorial experiment has 2 factors at 2 levels (values) each, all possible combinations of the two factors across their levels are used in the design. As the number of factors of interest increases the number of experiments increases rapidly. Though this method is efficient, it is not feasible from the point of view of time and resources, when the number of factors and their levels are relatively large.

2.2. *Taguchi designs*

A Taguchi design, or an Orthogonal Array (OA), is a method of designing experiments that usually requires only a fraction of the full factorial combinations. Taguchi designs provide a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. Taguchi techniques have been used widely in engineering and scientific community because they are easy to adopt and apply for users with limited knowledge in statistics [13, 14]. An orthogonal array provides a set of well balanced experiments in which factor levels are weighted equally across the entire design. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor.

2.3. *Analysis of variance Analysis of Variance (ANOVA)*

ANOVA is a statistical decision making tool, used to analyze the experimental data, for detecting any differences in the response means of the factors being tested. ANOVA is also needed for estimating the error variance for the factor effects and variance of the prediction error. In general, the purpose of analysis of variance is to determine the relative magnitude of the effect of each factor and to identify the factors significantly affecting the response under consideration.

2.4. *Main effects*

The change in average response produced by a change in the level of a factor is called "Main Effect" of that factor. The main effects plot displays the response means for each factor level in the sorted order. The points (response means) in the plot are located with respect to a reference line drawn at the overall mean of the response data and connected by a line.When the line is horizontal (parallel to x-axis), then there is no main effect present. Each level of the factor affects the response in the same way, and the response mean is the same across all factor levels.When the line is not horizontal, then there is a main effect present. Different levels of the factor affect the response differently. The steeper the slope of the line, the greater the magnitude of the main effect.

2.5. *Interaction effects*

If the effect of one factor is different at different levels of another factor, the two factors are said to interact or to have interaction. The interaction between two factors A and B is termed as "first order or two factor" interaction, denoted by AB (A*B or AxB). Similarly, the interaction between three factors is referred as "second order or three factors" interaction. Minitab (Version 15) statistical software is used for designing experiments and for analyzing response data.

3. Experimental work

3.1. *Material*

The material used is of 0, 5 and 10wt % TiB2 reinforced with Al6063 composite material of size Φ20 x 60 mm length shown in Figure 1.

Figure 1 Composite Material 0, 5 & 10 wt%TiB_2 Reinforced with Al6063

3.2. *Experimental procedure*

The experiments were carried with four factors at three levels each as shown in the Table 1.

Table 1 Response Table for Signal to Noise Ratios. Smaller is better

Level	Cutting speed	Feed rate	Depth of cut
1	-3.40434	-4.40471	0.08682
2	-2.41669	-3.48179	-1.56011
3	-2.44258	0.63027	-4.32829
4	-0.99692	-2.00431	-3.45896
Delta	2.40742	5.03497	4.41511
Rank	3	1	2

The factorial design used is a standard L27 (3A2013) orthogonal array. This orthogonal array is chosen due to its capability to check the interactions among factors. The turning trials were carried out on the CNC turning center (MITSUBISHI-EZ Motion NC E60) in dry machining condition as shown in Figure 2.

Figure 2 CNC turning center. (MITSUBISHI-EZ Motion NC E60)

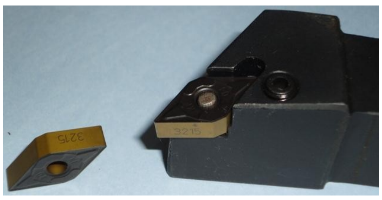

Figure 3 SANDVIK: DNMG 3215 Tool (K15 – K35)

Table 2 Factor settings, surface roughness data and MRR

Cutting speed (rpm)	Feed rate (m/rev)	Depth of cut (mm)	Surface Roughness (μm)	Material Removal Rate (mm^3/min)	S/N Ratio for SR	S/N Ratio for MRR
800	0.05	0.15	1.25	86.4	-1.94	38.73
800	0.15	0.2	1.45	81.35	-3.23	38.21
800	0.25	0.25	1.26	72.36	-2.01	37.19
800	0.35	0.3	2.1	101.4	-6.44	40.12
1100	0.05	0.2	2.27	71.42	-7.12	37.08
1100	0.15	0.15	0.95	98.65	0.45	39.88
1100	0.25	0.3	0.84	92.36	1.51	39.31
1100	0.35	0.25	1.68	84.26	-4.51	38.51
1400	0.05	0.25	1.97	87.26	-5.89	38.82
1400	0.15	0.3	2.05	88.78	-6.24	38.97
1400	0.25	0.15	0.93	79.56	0.63	38.01
1400	0.35	0.2	0.82	80.24	1.72	38.09
1700	0.05	0.3	1.36	83.65	-2.67	38.45
1700	0.15	0.25	1.76	74.25	-4.91	37.41
1700	0.25	0.2	0.76	78.36	2.38	37.88
1700	0.35	0.15	0.87	97.69	1.21	39.80

4. Experimental results and analysis

4.1. *Analysis of variance of Surface Roughness (Ra) and MRR*

The response data recorded in table 2, for surface roughness and MRR are subjected to ANOVA for finding the significant factors, at above 95% confidence levels and the result of ANOVA for these response parameters are presented in the Tables 3, 4 and 5, 6 respectively.

Table 3 ANOVA Analysis of S/N Ration for MRR

Source	DF	SS	MS	F Value	P Value
Cutting Speed	3	24.98	8.328	0.14	0.936
Feed Rate	3	248.26	82.753	1.34	0.346
DOC	3	620.04	206.681	3.35	0.097
Error	6	370.09	61.681		
Total	15	1263.37			

4.2. *Surface Roughness*

Average S/N ration for every level of experiment and the different values of S/N ration between maximum and minimum are shown in Table 3 for surface roughness. The feed rate, TiB2 reinforced Al6063 composite work material; cutting speed and depth of cut are the factors with different values of 6.12, 3.61, 2.34 and 2.02 respectively. Based on the Taguchi prediction that the bigger different values of S/N ratio will give more effect or more significant. Increase in the feed rate will increase the surface roughness significantly.

Table 4 ANOVA Analysis of S/N Ration for Surface Roughness

Source	DF	SS	MS	F Value	P Value
Cutting Speed	3	0.2452	0.08175	0.36	0.786
Feed rate	3	1.3065	0.4355	1.91	0.23
DOC	3	1.0889	0.36298	1.59	0.288
Error	6	1.3713	0.22855		
Total	15	4.012			

Table 4 shows that the feed rate and the TiB2 reinforced Al6063 work material have more influence on the surface roughness value. Significant factor (P) values for both are 0.024 and 0.158 respectively. In statistical analysis of taguchi method, the smallest P value gives more significant effect on responded surface roughness parameters. The significant values for the feed rate and the TiB2 reinforced Al6063 composite work material and their contributions are 38.52% and 13.22% respectively. The speed and TiB2 reinforced Al6063 work material interaction contributes about 11.20%, where as the contribution of the cutting speed is about 9.53% and the other interactions and depth of cut are insignificant. The most significant factor, which affects the surface roughness.

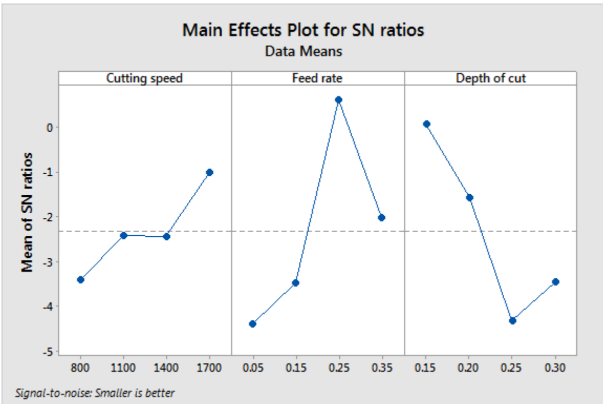

Figure 4 Main effect plots for SN rations of Process factors on MRR

Figure 4 shows that the A1 (low cutting speed) is the minimum value with -8.68 of S/N ratio, and it increases dramatically to A2 (-0.66) and then to A3 (2.37). The main effect plot for the feed, and depth of cut have same trend lines but the TiB2 reinforced Al6063 composite work material shows inverse trend as wt% of TiB2 increases the MRR decreases

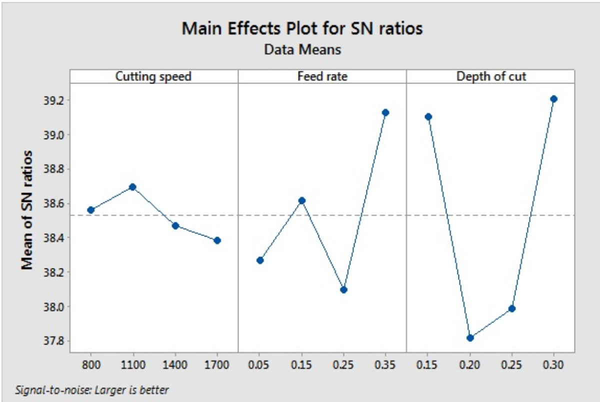

Figure 5 Main effect plots for SN rations of Process factors on Surface finish

The interactions among the factors are shown in figure 7 for the MRR. The cutting speed and the feed contribute the most of about 6.75% and become less significant. The other interactions are insignificant.

5. Conclusions

Taguchi robust design method is suitable to optimize the surface roughness and the material removal rate is adopted in the present work.The significant factors in turning 5 and 10 wt. % TiB2 particles reinforced aluminum (Al6063) metal matrix composites material on surface roughness were feed rate and the type of work material, with contribution 38.52% and 13.22% respectively. For MRR the cutting speed and the feed rate are most significant factors, with contribution of 32.28% and 31.85% respectively. The depth of cut is contributed about 16.64%.The optimal condition of cutting parameters for lesser surface roughness for the Al6063/TiB2 composite material are the cutting speed of 113.07m/min; feed rate of 0.05 mm/min and the depth of cut of 0.25mm.

The optimal condition of cutting parameters for higher material removal rate for the Al6063//TiB2 composite material are the cutting speed 113.07m/min, feed rate of 0.15 mm/min and the depth of Cut of 0.75mm.

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