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A novel method in the production and Optimization of Process Parameters in turning LM6 Aluminium alloy with Borosilicate Reinforcement

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Abstract : This paper provides simple means for minimization of Surface Roughness in turning operation for Aluminium based Metal Matrix Composite (MMC) by taguchi method of optimization. The composite was produced by stir casting process using borosilicate powder as reinforcement and LM6 as the Matrix phase. Then turning operation was carried out using a CNC machine to find the optimal parameters that would yield a minimal surface roughness value. Microstructure analysis of the samples proved that there was homogeneous dispersion of the reinforced powder as that of LM6 alloy. The rods used for this turning operation are of 0% and 10% reinforcement of borosilicate powder respectively. Taguchi optimization method was used for the optimization of the surface roughness. Taguchi orthogonal array (L9) was used for the machining purpose. As per the orthogonal array, three levels with four parameters were chosen and according to which nine experiments were carried out. The four parameters used are Speed, Feed Rate, Depth of cut and tool nose radius. The effect of these parameters and their interactions were studied by creating contour plots using Design Expert Software. The optimum parameters are obtained for maintaining minimum roughness value. . The performance characteristics were studied using the Analysis of Variance (ANOVA) and Signal-Noise ratios.
Keywords. : Metal Matrix Composite; Borosilicate, LM6, Taguchi, ANOVA, Signal - Noise ratios.

Introduction

Metal Matrix Composites (MMC) have found an important place in this modern industries. Due to their various properties such as cast ability, High strength to weight ratio, Serviceability and tailoring of required properties through particular reinforcements etc., These have lead them to be used in naval, aviation, space and other structural applications [1]. Aluminium is the mostly used Engineering material. It is light in weight with density of 2.7g/cm ^{3} and can be developed into any type of alloys based on the purpose required. Aluminium has thus become the mostly sought material within the industries. Aluminium alloys can be easily produced using Stir casting and is one of the most economical processes in producing MMC's. The addition of ceramic particles into the melt and homogeneous distribution can be easily obtained through the process of Stirring at desired speed.

The base metal used in this work is LM6 or ASTM 714 alloy which is basically a eutectic alloy with aluminium as the major constituent. It consists of silicon upto 13%.The reinforcing material used is borosilicate powder of 75µm which is used in the manufacturing of glasses. This Metal matrix composite can thus be used in intricate castings, Engine liners, drive shafts etc.,

Among the various machining operations turning is the most basic material removal process. In a turning operation the part is rotated in parallel to a single point cutting tool[2]. Grooving ,taper turning, Straight turning ,profiling are different types of turning processes. Many factors such as feed rate, depth of cut, spindle speed, tool nose radius plays an important role in determining the surface finish. An optimal machining condition is thus necessary to minimize costs and to improve surface finish[3].

Thus Surface roughness plays a key role in determining the quality of a product. It has a direct impact on various mechanical properties such as fatigue, creep life etc., Proper selection of parameters is thus essential to obtain the required surface finish. Many optimization techniques have been developed for this purpose [4]. Many investigations has been carried out to find out the role of different parameters in optimizing the surface roughness of components in turning operation [5]. Various techniques have been developed for the optimization of process parameters to obtain the necessary roughness value. Many works in various materials have been developed. A study has been done to find the various parameters influence in turning of AISI 1045 steel Taguchi technique along with L9 orthogonal array [6].

Experimental work

This experiment was carried out using Taguchi methodology and hence Taguchi design of Experiments was used to carry out the Experiments. Experimentation method is highly complex in nature and many experiments have to be carried out if many parameters are to be used. For the purpose of studying all the parameters involved the Taguchi method uses orthogonal array to carry out minimum number of experiments [7]. The chosen material is LM6 with borosilicate powder of 75 µm as the reinforcement. The casting was done using Stir casting process[8]. At a temperature of 850˚C the LM6 is melted in a resistance crucible and then the borosilicate powder of 75 µm is added slowly.

The powder which was preheated at a temperature of 400˚C for 30 minutes is measured and added according to the sample requirement. To get a homogeneous distribution a stainless stirrer with an rpm of 300-600 was used. The stirring was done for 5 to 6 minutes after which the melt from the crucible is poured into the dies which were made from Green Sand Technique. The cylindrical dies that are prepared are of 25mm diameter and 200mm length. The rod is then used for the experimentation to be carried out in a CNC machine. The main aim of the experiment was to predict the influence of machining parameters (Speed, Feed, Depth of cut and Tool nose radius) on surface roughness 0% borosilicate reinforced LM6 Composite, and for 10% borosilicate reinforced LM6 Composite.

Table 1. Chemical Composition of LM6

Chemical Composition	Weight percentage
Copper	0.1 max
Magnesium	0.10 max
Silicon	10.0-13.0
Iron	0.6 max
Manganese	0.5 max
Nickel	0.1 max
Zinc	0.1 max
Lead	0.1 max
Tin	0.05 max
Titanium	0.2 max
Aluminium	Remainder

Table 2. Chemical Composition of Borosilicate powder

Chemical Composition	Weight percentage
SiO_2	80.6
B_2O_3	13
Na_2O	4
Al_2O_3	2.3

Objective Function- Determination

As per Taguchi method, Signal –to- Noise (S/N) ratio is the best approach for multiple runs analysis. By maximization of S/N ratio, the loss associated can be minimized. The best set of operating condition can be determined within the results obtained. The S/N ratio can be determined by

$$\frac{S}{N} = -10\log_{10}\left[\frac{1}{n}\sum_{1}^{n} Y_i^2\right]$$

where S/N is the observed value (unit: dB), and Yi is denoted value of the characteristic i and n is the number of observations or number of repetitions within a trial[9].

Classification of the factors along with their levels

Based on various literature reviewed, the following factors and levels playan major role in performing turning operation on Aluminum Alloys.

Table 3. The chosen parameters and their values

Speed	Feed	Depth of Cut	Tool Nose Radius
1000	0.1	0.4	0.4
2000	0.15	0.6	0.8
3000	0.2	0.8	1.2

Appropriate Orthogonal array (OA)- Selection

The different weight percentages of the borosilicate used are 0% and 10% respectively. To carry out the experiment Taguchi orthogonal L9 array was used[10]. According to the same, 9 sets of experiments were carried out with the chosen four parameters as per the order obtained using Design Expert software. The chosen Orthogonal array should provide enough degrees of freedom for the experiment. For which the following condition must be satisfied. The main and interaction effect can be studied when the number of degrees of freedom required and number of degrees of freedom for OA are equal.

Experimental work and data interpretation

The machining was carried out as per the run order obtained through Design Expert software. According to which the 0% rod was machined. Nine pieces of each 22mm length of work pieces were obtained. After which the 10% rod was machined. Therefore totally 18 pieces were obtained. To get the Surface roughness values, Mitutoyo tester was used. Using the Surf tester, three sets of passes are done for each machined component and the readings are noted in microns. The average of the reading values is taken as the obtained surface roughness value.In this work, S/N data interpretation was revealed. Investigation has been carried out on selected process variables along with the selected performance characteristics by plotting of main effects based on mean data, S/N data and response tables.

The optimum condition for each of the performance characteristics has been established through S/N data analysis the optimum condition for each of the performance characteristic has been arrived. The machining was carried out in CNC machine. The work piece to be machined is mounted on to the chuck and the machining is done as per the desired parameters .Once the piece is machined it is taken out and the next piece to be machined is mounted. Once all machining is over, the surface roughness is predicted using the surf tester.

Table 4. Run order and other parameters generated through Minitab

Run Order	Speed	Feed	Depth of cut	Tool Nose Radius
2	1000	0.15	0.6	0.4
7	3000	0.10	0.8	0.4
8	3000	0.15	0.4	0.8
5	2000	0.15	0.8	1.2
1	1000	0.10	0.4	1.2
6	2000	0.20	0.4	0.4
3	1000	0.20	0.8	0.8
4	2000	0.10	0.6	0.8
9	3000	0.20	0.6	1.2

Table 5. Surface roughness obtained for 0% and 10% borosilicate reinforced LM6 Composite

Run Order	Surface Roughness (average) 0%	Surface Roughness (average)10%
2	3.932	1.384
7	2.817	1.474
8	2.744	1.760
5	4.211	1.831
1	4.011	1.144
6	2.033	2.488
3	3.956	1.741
4	3.956	1.525
9	2.506	1.384

Fig. 1.Final Machined Component

Result and Discussion

Microstructure analysis

The micro structural analysis was carried out to find the dispersion of borosilicate powder with that of LM6. The testing was carried as per ASTM E407–07 & ASM book volume 9. The obtained image shows a good dispersion of borosilicate powder at 10 % reinforcement. This proves that Stir casting can be used effectively for the production of Aluminium based composites. It acts as a easiest and a novel way in the production of different composites. Also there was a increase in hardness and tensile strength after the reinforcement of borosilicate powder[8].

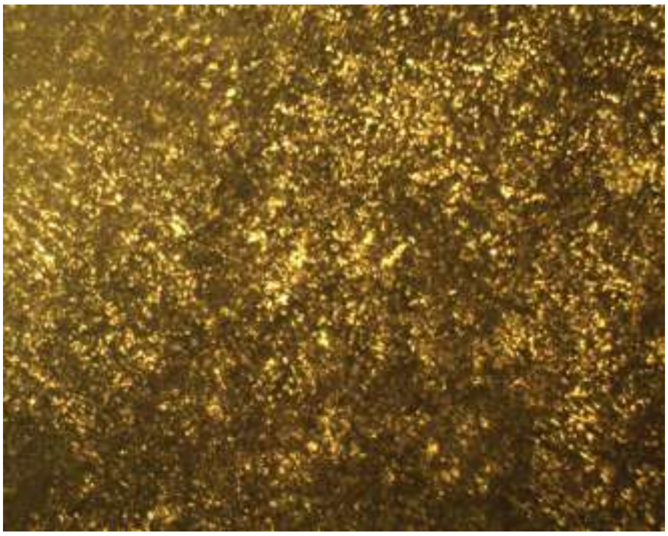

Fig. 2.Microscopic image of 0% reinforced MMC.

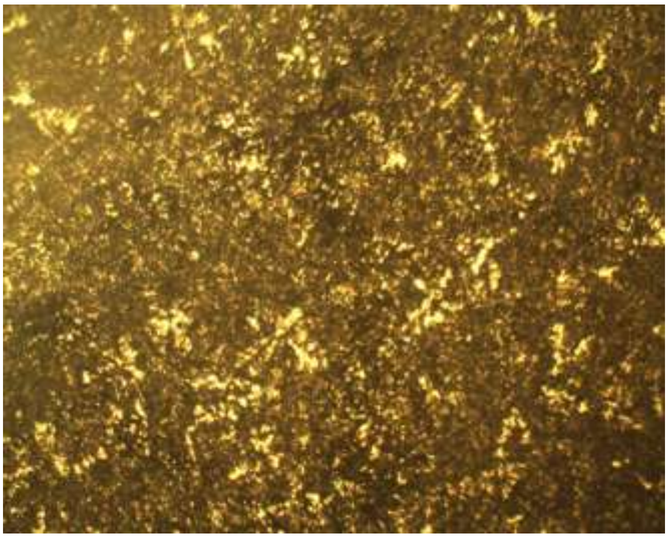

Figure 3. Microscopic image of 10% reinforced MMC (showing equal dispersion of borosilicate powder)

Evaluation of S/N ratios for optimal design

Table 6. Response Table for Signal to Noise Ratios for 0% reinforcement Condition: Smaller is better

Level	Speed	Feed Rate	Depth of Cut	Tool Nose Radius
1	-11.967	-11.013	-8.998	-9.017
2	-10.209	-11.149	-10.167	-10.897
3	-8.581	-8.3696	-11.143	-10.844
Delta	3.386	2.353	2.144	1.880
Rank	1	2	3	4

From the response table 6 for signal to noise ratio it is concluded that for 0 % borosilicate reinforcement , the most influential parameters are in the order of Speed, Feed Rate, Depth of cut, and Tool Nose Radius. Based on levels it is evident that the S/N ratio of greater value contributes towards better surface finish. From this analysis the best parametric levels are For Speed 1000 rpm, for feed rate 0.15 mm, Depth of Cut 0.8 mm, for tool nose radius 0.8.

Table 7. Response Table for Signal to Noise Ratios for 10 % borosilicate reinforcement Condition : Smaller is better

Level	Speed	Feed Rate	Depth of Cut	Tool Nose Radius
1	-7.472	-4.297	-5.083	-6.231
2	-5.450	-5.842	-5.909	-5.638
3	-3.286	-6.069	-5.217	-4.610
Delta	4.186	1.771	0.826	1.621
Rank	1	2	4	3

From the response table 7 for signal to noise ratio it is concluded that for 10 % borosilicate reinforcement the most influential parameters are in the order of Speed, Feed Rate and Tool Nose Radius, Depth of cut, Based on levels it is evident that the S/N ratio of greater value contributes towards better surface finish From this analysis the best parametric levels are For Speed 1000 rpm, for feed rate 0.2 mm, Depth of Cut 0.8 mm, for tool nose radius 0.8.

Conclusion

Once the best parametric combination is known, then LM6 reinforced borosilicate can be used for wider applications such as engine components etc.Taguchi method can be effectively used to optimize the surface roughness in turning operation.

From this work, it is evident that minimum surface roughness value can be obtained using the stated parameter combination for both 10% and 0% reinforcement respectively.

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