J. Mater. Environ. Sci. 7 (5) (2016) 1556-1561
ISSN : 2028-2508
CODEN: JMESCN

Optimization of Machining Parameters using Taguchi Method for Surface Roughness

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Received 24 Jan 2015, Revised 06 Jan 2016, Accepted 16 Jan 2016
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Abstract
For the present work, an experimental investigation is made on the effect of spindle speed, feed rate and wt % of alumina particle in reducing surface roughness during drilling of Al6063/Al_2O_3/Gr hybrid composite. TiN coated solid carbide drill bit of 6 mm diameter is used for drilling the composite. Taguchi's experimental design concept is used for optimizing the design parameters with three levels for better surface finish. The experimental outcomes and microstructure of machined surface reveal that the drilled samples at lowest feed rate shows better performance on surface roughness. The wt % of alumina also has its influence on minimizing surface roughness followed by spindle speed while drilling the fabricated samples.

Keywords: Drilling, Surface roughness, Taguchi method

1. Introduction
Aluminum matrix composite (AMC) are the recently emerging materials found in wider range of applications due to their quantified advantages. They are used in numerous structural, non-structural and functional applications in various engineering sectors [1]. In recent years, the particulate reinforced AMCs are replacing the conventional materials that are used in aircraft and automotive components. The most common applications are aircraft's engine cowlings, landing gear doors, automotive pistons, bearings, etc. In those major applications, the manufactured components are expected to be with good surface finish and accuracy. Particulate reinforced Aluminium (Al) based composite are found very difficult in machining due to the presence of hard ceramic oxide reinforcement [2]. Drilling is one of the main processes of machining commonly associated with production of machined holes. In practice, it was found very difficult to produce machined holes with good surface finish. Therefore, minimizing surface roughness in drilled parts is very difficult and it should be controlled.
The hard ceramic particles like Al_2O_3/SiC present in the matrix makes it difficult to machine which in turn reduces the surface finish by increasing the surface roughness of the composite. In such cases, the addition of graphite to the matrices reduces the tool wear while machining and improves the surface finish of the composite [3]. Most of the studies on Metal matrix composite (MMC) are focused on the study of tool wear characteristics during machining of aluminium alloy composite. The surface finish of the component can be varied along the process parameters such as spindle speed, feed etc.

The present work is focused on minimizing surface roughness in drilled Al/Al_2O_3/Gr particulate composite. From the various literatures available, it has been observed that feed rate, cutting speed and wt % of the reinforcements are key factors influencing surface roughness. Palanikumar and Karthikeyan [4] made an attempt on assessing the factors influencing surface roughness on machining of Al/SiC particulate composite. They have used K 10 tungsten carbide tool inserts for machining. The machining parameters considered were % vol fraction of SiC, cutting speed, depth of cut and feed rate. They employed ANOVA technique to optimize the machining parameters. Saravanakumar and Sasikumar [5] made a study on prediction of surface roughness in turning using design of experiments. They concluded that selection of reinforcements plays an important role in improving the material properties and machinability of the composite. Considering two levels of factors, they had developed a mathematical model for the proposed cutting parameters. Paulo davim and Conceicao Antonio [6] aimed at the selection of optimized values for the cutting conditions while drilling and turning. It was found that feed rate is the most constituent factor which affects surface finish rather than the cutting speed. Basavarajappa et al. [7] focused on drilling characteristics of Al 2219/15SiCp andAl2219/15SiCp–3Gr hybrid composite. They have used solid carbide multifaceted drills of 5mm diameter at various cutting conditions. They studied the effect of spindle speed, feed rate on surface finish. The results reveal that ceramic-graphite reinforced composite shows better machinability since graphite acts as a solid lubricant and reduces material wear. Sivasankaran et al. [8] conducted turning experiment and studied the effect of graphite addition to Al 7075 alloy and proved that the presence of graphite particles in the matrix reduces the surface roughness during machining. Due to the self lubricating property of the graphite particles during machining, it improves the machinability and surface finish. Saravanakumar et al. [9] in their study concluded that addition of Al_2O_3 more than 6 wt % to the matrix leads to the clustering and agglomerations resulting in poor distribution of the reinforcements. Metin kok [10] presents an experimental investigation on the effect of surface roughness factors in the machining of Al 2024/Al_2O_3 particulate composite. The test results revealed that surface roughness increases with increasing cutting speed and decreases with the increased size and volume fraction of the particles. Jeyaraman and Maheshkumar [11] have used grey relational analysis and taguchi method for optimizing the machining parameters in turning AA 6063 T6 aluminum alloy. The experimental outcomes shows that the best multiple performance characteristics was obtained with the lower cutting speed, lower feed rate and medium depth of cut in turning AA. Venkatesan et al [12] made an attempt on optimizing the machining parameters using Response Surface Methodology in machining of AA hybrid composite. They have used Al 356 hybrid matrix by varying weight fraction of SiC (5%, 10% & 15%) and keeping boron carbide as (5%) constant. The Response Surface Methodology results confirm that the surface roughness criteria increase with increase of feed and decreases at higher cutting speed. Juan carlos campos rubio et al.[13] performed an investigation on drilling reinforced and unreinforced polyamides using taguchi analysis in order to identify the best drilling setup of glass reinforced polyamides. The conclusions revealed that the quality of the drilled holes can be improved by proper selection of cutting parameters.

In the present study, an attempt has been made to optimize the machining parameters for better surface roughness in drilling of Al 6063/Al_2O_3/Gr particulate composite.

2. Experimental methods

2.1. Materials and methods

For the present work, Al 6063 has been chosen as the matrix material due to its lower strength and better machinability performance. In order to increase the strength of the matrix Al_2O_3 particles are added as the reinforcements where as graphite particles addition improves the machiniablity [8]. Al_2O_3 provides good wettability between the matrix and reinforcements and Gr particles acts as a solid lubricator which helps in easy machining of the composite. Particle size of alumina for about 20 microns and graphite particles to the average size of 75 microns is taken for fabrication. The composite have been fabricated using stir casting technique at an optimal speed to ensure even distribution of the reinforcements along the matrix. The composite are fabricated at three different compositions taking as 3-9 wt% in steps of 3 wt% to the matrix material. The composite were drilled on FEELER FV-800A CNC machining center. The samples are taken to the size of 100mm*25mm*10mm blocks for machining. TiN coated solid carbide drill bits manufactured by SGS, with 6mm diameter, 30° helix angle, 118° point angle are used for machining under dry conditions. The fabricated samples are drilled to a depth of 10 mm for each trial. The composite are drilled using fresh drills for each experiment in order to reduce tool wear which has its influence on surface finish. The machined composite are tested for surface roughness using Handy Surf surface roughness measuring device of E-DT5706 which consists of a probe connected to it. Figure 1 shows the drill bit used and the surface roughness measuring device. The mechanical properties of composites are given table 1 and process parameters and its levels are shown in table 2.

Table 1: Mechanical properties of Composites.

Composite	Hardness (HR 15T)	Compressive Strength (MPa)	Impact Strength in (J)
Al-3%Al_2O_3 -1%Gr	47.4	193.2	59
Al-6%Al_2O_3 -1%Gr	50.0	221.1	82
Al-9%Al_2O_3 -1%Gr	48.6	202.0	71

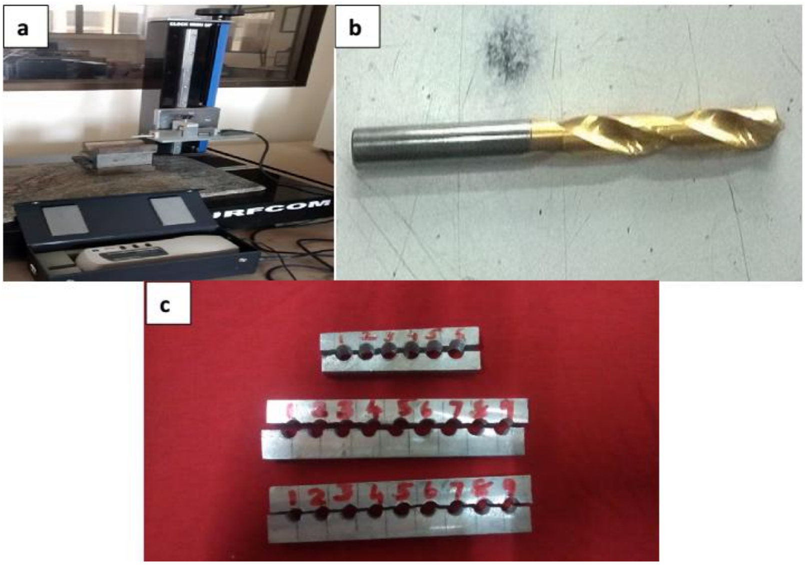

Figure 1: (a) Surface roughness measuring device, (b) Drill bit, (c) Samples.

Table 2: Process parameters and its levels.

Levels	Speed (A) (rpm)	Feed (B) (mm/min)	Wt of Al_2O_3 (C) (%)
1	1000	50	3
2	2000	100	6
3	3000	150	9

The experiments were repeated thrice to avoid the influences of noise factors. The machining parameters chosen are spindle speed, feed rate and wt % of alumina. The experiments have been conducted according to the trial conditions of L_9 orthogonal array in order to optimize the machining parameters shown in table 3.

3. Results and discussion

3.1. Taguchi method

Many literature's shows that taguchi's experimental design is used to minimize the quality loss by using the three options available in taguchi's design analysis. They are "the-nominal-the-best", "the-larger-the-better'', or "the-smaller-the-better" [14]. The concept of taguchi method is to find out the best combination of design parameters by conducting minimum number of experiments. As a result, it provides main effects and interaction effects which uses S/N ratio to quantify the data variation. For the present analysis, the machining parameters have to be optimized for minimum surface roughness. Therefore, "the-smaller-the-better" concept is chosen using the equation,

$$SN_s = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

Where, "n" is the number of replications of experiment and "y" is the quality score with smaller-the-better value of experimental data "i".

Statistical software Minitab 16 is used for the analysis and the results arrived are "main effects" and response table for the variables. The main plots for S/N ratio show the effects of the design parameters and the levels on to the response variables. The factor levels that maximize the appropriate S/N ratio are the optimal levels.Figure 2 shows the main effects plot for S/N ratio. It is observed that better surface finish can be obtained at the highest spindle speed (3000 rpm), lower feed rate (50 mm/min), wt of alumina (6%). It is also concluded that surface roughness of the composite increases with increasing feed rate and decreasing with spindle speed. Whenever increase in feed, it increase the load on the tool subsequently increases cutting force which leads to poor surface finish. Similar effect observed in lower spindle speed at all conditions.

Table 3: Experimental values of surface roughness

Spindle Speed (A) (rpm)	Feed rate (B) (mm/min)	Wt of Al_2O_3(C) (%)	Surface roughness (µm)	S/N ratio
1000	50	3	2.5	-7.96
1000	100	6	3.3	-10.37
1000	150	9	4.3	-12.67
2000	50	6	1.9	-5.58
2000	100	9	4.2	-12.46
2000	150	3	3.5	-10.88
3000	50	9	2.8	-8.94
3000	100	3	2.6	-8.30
3000	150	6	3.4	-10.63

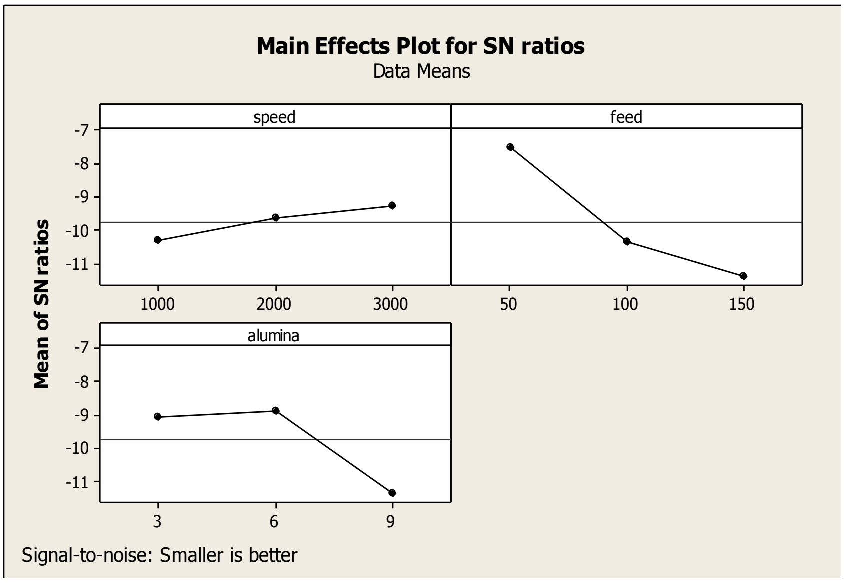

Figure 2: Main effects plot for S/N ratio

3.2. Response table for S/N ratio

The influence of machining parameters on surface roughness can be obtained using response table 4. Response table shows the average response characteristics for each level of each factor in the design. The rank orders the factors based on the delta values in the response table from the highest effect to the least effect depending on the characteristics of the response. Table 4 shows the response table for S/N ratio in which it is clearly visible that feed is the most influencing factor since it is ranked first followed by alumina and spindle speed in minimizing the surface roughness.

Table 4: Response table for S/N ratio

Level	Speed	Feed	Alumina
1	-10.333	-7.492	-9.047
2	-9.64	-10.378	-8.858
3	-9.291	-11.393	-11.359
Delta	1.042	3.901	2.501
Rank	3	1	2

3.3. Analysis of variance (ANOVA)

Analysis of variance can be used to investigate and model the relationship between a response variable and independent variables. It was also carried out to verify the factors which are statistically significant at 95% confidence level with the help of the P-value. The P-value which is less than or equal to 0.05 indicates the higher level of significance. The last column of the ANOVA table shown in table 5 indicates the percentage of contribution (Pc) in which feed has the highest level of contribution (58.9%) followed by alumina (27.89%) and speed (4.04%).

Table 5: Analysis of variance.

Source	Dof	Seq SS	Adj SS	F	P	Pc
Speed	2	1.688	1.688	0.44	0.694	4.0454
Feed	2	24.578	24.578	6.43	0.135	58.9033
Alumina	2	11.638	11.638	3.04	0.247	27.8915
Residual Error	2	3.822	3.822			9.1598
Total	8	41.726				100

Dof: degrees of freedom; Seq SS: Sequential sums of squares; Adj.SS: adjusted sums of squares; Pc- percentage of contribution.

3.4. Examination of microstructure

The microstructure of Al 6063- composite in Figure 3 which shows the cracks and voids formed during the machining of the composite. The samples with 9 wt % of Al_2O_3 composition while machining creates large distortions due to the presence of hard ceramic particles which makes it difficult to machine and provides poor surface finish to the material. Optical microscope analyses have shown that deep valleys, scratches and fine grooves have been noticed over the machined surface of the 3%Al_2O_3/1%Gr and 9%Al_2O_3/1%Gr composite. Cracks and pits (Figs.3a and 3c) are also observed on the both composite. It can be seen that from fig.3b the amount of cracks and pits are less on the machined surface of Al/6%Al_2O_3 /1%Gr composite.

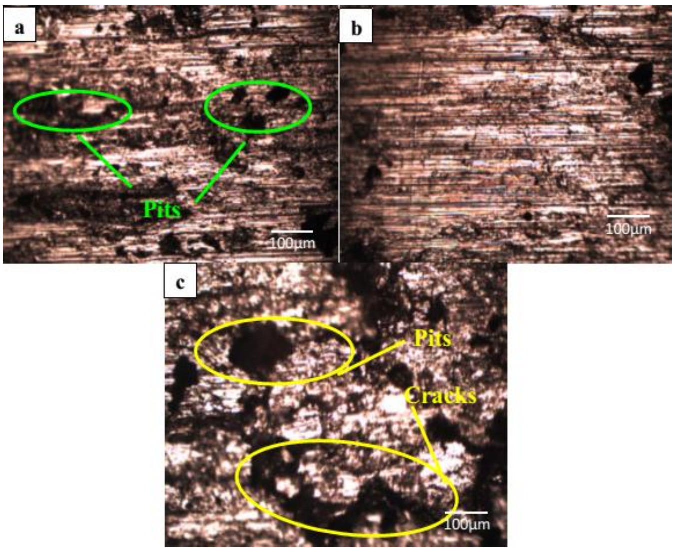

Figure 3: Microstructure of (a) 3 wt % , (b) 6 wt % , (c) 9 wt % of alumina.

3.5. Confirmation tests

A confirmation tests has to be carried out at the optimal level of parameters. The estimated S/N ratio γ' with the optimal level of design parameters can be calculated using the equation,

$$\gamma' = \gamma_m + \sum(\bar{\gamma}_i - \gamma_m)$$

Where, γ_m is the total mean S/N ratio, $\bar{\gamma}_i$ is the mean S/N ratio for the optimal level.

In order to check the predicted values (1.86) from optimal levels, a confirmation experiment is performed with the optimal levels which show the result of 1.64. Table 6 shows the error difference between the predicted and experimental responses. The parametric combinations obtained for minimum surface roughness was obtained as 3000 rpm (spindle speed), 50 mm/min (feed rate), 6% (wt of alumina).

Table 6: Confirmation tests.

surface roughness(µm)				
Initial level		Optimal level	Experimental	Predicted
A1B1C1	2.5	A3B1C2	1.64	1.86
Improvement in Surface finish from initial level				0.86 µm

Conclusion

In the present work, the process parameter which has the influence on surface roughness while machining $Al/Al_2O_3/Gr$ composite is optimized using taguchi's experimental design. The experimental out comes drawn are:

i. The surface roughness of the drilled hole decreases at increased speed and decreased feed rate.
ii. From the main effects plot for S/N ratio, it is clear that 6 wt % of alumina shows better surface finish compared to other alumina compositions.
iii. From the response table for S/N ratio, it is confirmed that feed rate is the most influencing factor followed by wt % of alumina and spindle speed in reducing surface roughness during machining of $Al/Al_2O_3/Gr$ composite.
iv. The optimal parametric conditions obtained for minimizing surface roughness are at highest spindle speed of 3000 rpm, lowest feed rate 50 mm/min, 6wt % of Al_2O_3.
v. Microstructure of the machined samples clearly shows the 6 % of Al_2O_3 composition shows lesser amount of distortions when compared to other samples while machining.

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