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Effect of Cutting Parameters on Surface Roughness in End Milling of AlSi/AlN Metal Matrix Composite

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Abstract

This paper presents the effects of cutting parameters and the corresponding prediction model on the surface roughness in the machining of AlSi/AlN metal matrix composite (MMC). This new composite material was fabricated by reinforcing smaller sizes of AlN particles at volume fractions of 10%, 15% and 20% with AlSi alloy. The machining experiments involved of uncoated carbide tool and PVD TiAlN coated carbide and conducted at different cutting parameters of cutting speed (240–400m/min), feed rate (0.3–0.5mm/tooth) and depth of cut (0.3–0.5mm) under dry cutting conditions. Taguchi's L18 orthogonal arrays approach was performed to determine the optimum cutting parameters using a signal-to-noise (S/N) ratio according to the stipulation of the smaller-the-better. The test results revealed that the type of cutting tool is the most significant factor contributing to the surface roughness of the machined material. A mathematical model of surface roughness has been developed using regression analysis as a function of all parameters with an average error of 10% can be observed between the predicted and experimental values. Furthermore, the optimum cutting parameters was predicted; A1 (uncoated carbide), B2 (cutting speed: 320m/min), C2 (feed rate: 0.4mm/tooth), D2 (axial depth: 0.4mm) and E1 (10% reinforcement) and validation experiment showed the reliable results.

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Keywords: AlSi/AlN Metal matrix composite; Taguchi method; ANOVA; mathematical model; optimum parameters

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1. Introduction

Metal matrix composites (MMC) have been introduced in engineering applications for over thirty years due to their superior mechanical properties, such as high strength, hardness, wear resistance and strength to weight ratio [1-3]. The replacement of conventional material shows that this combination of a tough metallic matrix with hard ceramic reinforcement material offers a good potential in the automotive and aerospace industries [4, 5]. These

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materials are also able to be used in sports and recreation facilities, boat and shipbuilding, in wind energy generation for wind turbine blades, as well as in oil and gas offshore exploration [6]. A high hardness of particles, for example silicon carbide and aluminium oxide, are commonly used to reinforce an aluminium, titanium or magnesium metallic matrix [7, 8]. The manufacturing of MMCs are mostly by near net shape but a secondary machining process, either by conventional turning or milling, is always necessary [9]. Such as the process developed by Toyota in their development of a diesel engine piston, where Al alloy was reinforced with 5% Al2O3 short fibres as a material with which to develop an engine piston, it gone through secondary machining processes [10].

The difficulty of the machining of MMCs is one of the major problems that prevent its widespread use in engineering applications [11]. These composites materials are anisotropic, non-homogeneous and their hard ceramic reinforcing fibres or particles are very abrasive [12], which makes these materials difficult to form and machine. As a result the use of MMCs in the automotive and aerospace industries has been limited due to the higher machining costs [13], short cutting tool life, and larger sizes of hard particles reinforcing the matrix material [14]. However with a simpler method like stir casting, which can reduce the cost and reinforcement of smaller sizes of particles, the mechanical properties of MMCs can still be maintained [15]. Furthermore, the hardness of MMCs could be better achieved with smaller particle sizes compared to coarser particles, because for smaller particle diameters the work hardening and grain size influence contribute the most to the increase in yield strength [16]. It can be a solution to the reduction in poor machinability for these materials, because the cutting tool life can be increased further and at the same time the surface finish of MMCs could be improved.

2. Literature review

Surface roughness plays an important role in many areas, and is a factor of great importance in the evaluation of machining accuracy. Machining parameters such as cutting speed, feed rate, and depth of cut have a significant influence on surface roughness for a given cutting tool and workpiece setup [7, 17, 18]. The influence of machining parameters on the surface finish of MMCs had been investigated by many researchers [19-23]. The type of cutting tool used during the cutting process, cutting speed, feed rate, depth of cut and volume fraction of particles are examples of parameters that have been observed determine the optimum parameters and in the analysis of the influence of the parameters, using statistical analysis and the development of a mathematical model to predict the value of surface roughness.

Sahin et al. [18] studied the surface roughness of Al_2O_3 particle-reinforced aluminium alloy composites with different types of cutting tool; TiN (K10) coated carbide tools and TP30 coated carbide tools at various cutting speeds. It was found that the surface roughness is mostly affected by the tool material and geometry of the chip breaker grooves. It was shown that the machinability of particle-reinforced composites with large sizes and high volume fractions of composites were poor. They found that the optimum surface roughness was obtained at a speed of 160 m/ min in the machining of 10% Al_2O_3 composites with a particle size of 16 μm. It was observed that the average surface roughness value increased with an increase in cutting speed when the volume fraction of the particle reinforcement is much higher and the particle sizes are much larger. With an increase in cutting speed, the cutting temperature increased which led to the binding between the particles and alloy matrix weakening and the tendency for the particles to be moved rather than cut or broken. Grooves will be generated on the surface of the workpiece when the tool edge makes contact with the hard particles. Sahin et al.'s findings are similar to those of Sornakumar and Kumar [8], in their study on the machinability of 10% alumina particles reinforced in a bronze metallic matrix, where the surface roughness increased with an increase in cutting speed. When he made a machining comparison between a bronze and bronze-alumina composite, he found that the surface roughness of the bronze-alumina composite was higher than in bronze. This could be due to the presence of hard particles in the composites leading to higher cutting forces and vibration. Kok [24] conducted an experimental investigation to analyze the effects of testing parameters and the characteristics of the materials on the surface roughness of the materials when machining MMC workpieces using the Taguchi method and ANOVA. In his research he found that the average surface roughness values of the triple layer coated cutting tool was lower than a single layer, TiN coated cutting tool. He also found that the surface roughness increased with an increase in cutting speed while it decreased with an increasing size and volume fraction of particles for both tools under all cutting conditions. Futhermore, the dependency of the surface roughness on the cutting speed was smaller when the particle size was smaller. Reddy et al. [20] observed surface roughness on the end milling of Al/SiC PMMC using TiAlN coated carbide end mill cutters. It was found that the surface roughness increased with an increase in feed rate in all cases under study. When the feed rate increased the chip thickness also increased, resulting in an increase in cutting force. This will increase the surface roughness value. Furthermore, it can be seen that the surface roughness decreased with an increase in cutting speed. As the cutting speed increases, machining becomes more adiabatic and the heat generated in the shear zone cannot be directed away during the very short interval of time in which the material passes through this zone. Then, the temperature rise softens the material aiding grain boundary dislocation, and reducing the surface roughness value. Shetty et al. [25] examined the significant factors influencing surface roughness during the turning of Al6061-15% vol. SiC of 25 μm particle size with Cubic Boron Nitride inserts (CBN) KB-90 grade, using steam as the cutting fluid and considering the methodology used. They concluded that steam pressure is the most significant parameter that contributed to the lower surface roughness, followed by cutting speed and feed rate. Basheer et al. [19] in their statistical analysis found that the size of reinforcement in the composite material significantly influences the roughness of the machined surfaces when its magnitude is comparable to that of the feed-rate and the tool-nose radius employed during the machining of Al/SiC composite material. A lower surface roughness will be achieved at the lowest value of feed-rate, the smallest particle size and the largest tool-nose radius.

To achieve the desired results, the experimental work should be planned and conducted according to design of experiment (DOE). Currently many types of DOE are used by researchers and industrial practitioners, such as the Taguchi method, response surface method (RSM), and the full factorial design [26, 27]. The Taguchi method is an engineering methodology that is appropriate for improving productivity during research and development [28], so that high quality products can be produced in a short time and at low cost by using a matrix experiment. The matrix experiment consists of a set of experiments, where the settings of the parameters can be changed from one experiment to another [28]. This method is suitable for solving problems with a minimum number of experiments, compared with RSM or with full factorial design [26]. The results obtained can be successfully implemented in machining research for the optimization of cutting parameters and the statistical analysis of the influences of cutting parameters on the machinability of materials [27, 29, 30]. With the Taguchi method, a standard orthogonal array (OA) can be designed by which the experimental results can be analyzed based on the signal-to-noise (S/N) ratio η [31, 32]. Generally there are three categories of performance characteristics commonly used in the analysis of the S/N ratio; smaller-the-better, nominal-the-better and larger-the-better [28].

Smaller-the-better;

$$\eta = -10log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} yi^2\right) \tag{1}$$

Nominal-the-better;

$$\eta = 10log_{10}\frac{\mu^2}{\sigma^2} \tag{2}$$

Larger-the-better;

$$\eta = -10log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \tag{3}$$

Where μ^2 is the mean of the observed data, σ^2 is the variance of observed data (y), and n is the number of observed data. In this study, the S/N ratio for smaller-the-better was used to minimise the surface roughness. In addition, a statistical analysis of variance (ANOVA) can be performed to determine which parameters are significant [24].

The research by the above researchers shows the influence of the cutting parameters on the surface roughness during machining of various hard particle reinforcements in a metallic matrix. The effect of the type of tool, cutting speed, feed rate, depth of cut, and volume fraction of reinforcement have been examined. Most of the studies are limited to SiC or Al_2O_3 particle reinforcement. However, a study on MMC reinforced with AlN particles has not yet been reported. Therefore, from the literature review attempts have been made in this experimental investigation to analyze and investigate the significance of cutting parameters on surface roughness, develop a surface roughness model, and optimize suitable parameters for the machining of AlN particle reinforced aluminium alloy MMCs based on the Taguchi method.

3. Experimental works

3.1. Work material

The work material used for the experiment was a 100 mm × 150 mm × 50 mm block of age treated AlSi/AlN MMC. The chemical composition of the AlSi alloy, as shown in Table 1, was determined by a glow discharge profiler (Model-Horiba Jobin Yyon). The mean size of the reinforcement particles is <10 μm and the purity >98%. The AlSi/AlN work material passed through a double ageing process was hardened at 540 °C for 6 hours, which was followed by water solution treatment. It was then reheated for another 4 hours at 180 °C, immediately cooled in open air at room temperature. The purpose of the heat treatment process is to increase the mechanical properties; strength and hardness.

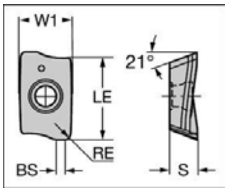
Table 1: Chemical composition of AlSi alloy (Wt %)

Si	Fe	Zn	Cu	Sn	Mg	Al
11.10	0.42	0.02	0.02	0.016	0.011	Balance

3.2. Cutting tool (insert)

The milling test was conducted using uncoated carbide inserts (Catalogue no: R390-11 T3 02E-KM H13A and R390-11 T3 02E-PM 1030) for PVD TiAlN coated carbide under dry cutting conditions. Cutting inserts were mounted on a tool body with a diameter of 20mm. The specification of the cutting tool is shown in Table 2. The wear progression on the cutting edge will be measured using a two-axis toolmaker's microscope with a digital micrometer for the x-axis and y-axis with 0.001 mm resolution. For these experiments, 0.3mm flank wear (VB) will be taken as the tool life criteria in milling according to ISO 8688-2 [33].

Table 2 Cutting tool specifications

Tool type	Uncoated and PVD TiAlN coated carbide (2.2 μm coating thickness) 
Manufacturer	Sandvik
Rake	Positive
Nose radius	0.2mm
W1	6.8 mm
BS	0.7 mm
LE	11.0 mm
S	3.59 mm
Lead angle	90°

Base Material	EH520, fine-grained carbide, WC-10%CO

3.3. Experimental procedure

The milling experiment was performed using a DMC635V eco DMGECOLINE vertical milling machine under dry cutting conditions. The purpose of this experimental investigation is to analyze the significance and effects of the cutting parameters on the surface roughness of AlSi/AlN MMC during end milling machining under dry cutting conditions. Taguchi's method was used as a DOE for this investigation. There are five factors to be investigated. The first factor is considered at two levels, and a further four factors are considered at three levels. Table 3 shows the experimental factors or cutting parameters to be designed and their levels. Since this is a Taguchi L18 orthogonal array, no interaction or correlation between the factors will be studied. The five factors taken into account are: type of cutting tool, cutting speed (m/min), feed rate (mm/tooth), depth of cut (mm), and volume fraction of particles (%). The surface roughness value (Ra) was measured using a contact-type stylus profilometer: Mahr Perthometer M1. The stylus traversing length, Lt, was set to 5.4 mm with the cut off, λc, at 0.8 mm. For each experiment, the average of at least five surface roughness measurements was taken and recorded for further analysis.

A statistical analysis will be done using ANOVA with a 95% confidence interval, to investigate the most significant factors affecting the surface roughness and the percentage contribution of each parameter. A mathematical model of the surface roughness will be developed for each cutting tool by multiple linear regressions. Finally, the optimum cutting parameters will be calculated based on the S/N ratio “smaller-the-better”, to obtain the lowest surface roughness and a confirmation test will be done to compute the percentage error between the Taguchi method and the experiment.

Table 3 Cutting parameters and their levels

Parameter	Factor	Level		
		1	2	3
Type of coating	A	Uncoated (u)	Coated (c)	
Cutting speed (m/min)	B	240	320	400
Feed rate (mm/tooth)	C	0.3	0.4	0.5
Axial depth of cut (mm)	D	0.3	0.4	0.5
% reinforcement	E	10	15	20

4. Results and discussion

The results of the surface roughness values for the 18 experiments are presented in Table 4. The effects of the type of cutting tool (A), cutting speed (B), feed rate (C), depth of cut (D), and volume fraction of particles (E) will be studied. Statistical analysis was conducted on the roughness data. Firstly, ANOVA was used to analyze the significant effects of the factors and identify the factors contributing to surface roughness. Then, a mathematical model of surface roughness prediction was developed. The generated values of prediction equations were compared to the experimental data, in order to determine the error between both methods: prediction and experimental. The optimum combination of cutting parameters was also calculated using the S/N ratio “smaller-the-better” by means of Taguchi analysis via Minitab software, to obtain the lowest surface roughness. Lastly, confirmation tests were performed to compare the optimum parameters obtained from the Taguchi method and experimental tests.

Table 4 Surface roughness values based on Taguchi method orthogonal array

Exp. no.	Tool type	Cutting speed (m/min)	Feed rate (mm/tooth)	Depth of cut (mm)	Volume fraction	Surface roughness (μm)
1	u	240	0.3	0.3	10%	0.405
2	u	240	0.4	0.4	15%	0.3825

3	u	240	0.5	0.5	20%	0.6075
4	u	320	0.3	0.3	15%	0.5125
5	u	320	0.4	0.4	20%	0.437
6	u	320	0.5	0.5	10%	0.51
7	u	400	0.3	0.4	10%	0.425
8	u	400	0.4	0.5	15%	0.355
9	u	400	0.5	0.3	20%	0.565
10	c	240	0.3	0.5	20%	0.745
11	c	240	0.4	0.3	10%	0.655
12	c	240	0.5	0.4	15%	0.56
13	c	320	0.3	0.4	20%	0.5375
14	c	320	0.4	0.5	10%	0.47
15	c	320	0.5	0.3	15%	0.6725
16	c	400	0.3	0.5	15%	0.6325
17	c	400	0.4	0.3	20%	0.744
18	c	400	0.5	0.4	10%	0.4975

4.1. Influences of cutting parameters on surface roughness

Table 5 shows the percentage contribution of each cutting parameter, which indicates that the type of cutting tool is the most significant factor contributing to a better surface finish. It reveals that the type of cutting tool has a 45.5% contribution to the value of the surface roughness. As shown in Fig. 1, an uncoated cutting tool gives better results with regard to surface finish compared to a coated carbide tool. This is due to the coated carbide was prone to poor mechanical shock resistance. Furthermore, the coated material of the tool was peel-off from the rake and flank face due to the friction between the tool and the workpiece and it results the poorer surface finish. Other researchers also made a similar statement in assessing the surface roughness of MMCs [17,18].

Factor E or the volume fraction of AlN is the factor making the second largest contribution to the surface finish of the machined material, contributing 20.2% to the surface roughness. When the volume fraction of AlN is increased, the value of the surface roughness also increased. This is due to the cutting tool is smeared with the material and more particles are scratched over the machined surfaces, and this phenomenon will increase the surface roughness value. Since the high hardness of AlN, it will affect the surface quality of machined material. Factor D or depth of cut is the third factor that is significant to the surface roughness. It contributed 13.2% to the surface roughness value. While factor B (cutting speed) and factor C (feed rate) give the least contribution to the value of surface roughness compared to the other factors.

Table 5 ANOVA analysis and percentage contribution of each parameter

	Term	DOF	SumSqr	MeanSqr	F Value	Prob>F	% Contribution
Model	A	1	0.146792	0.15	6.041686	0.0093	45.4623
Model	B	2	0.018598	9.299E-003	28.35719	0.0007	5.759942
Model	C	2	0.008164	4.082E-003	1.796387	0.2268	2.528545
Model	D	2	0.04268	0.021	0.788592	0.4869	13.21818
Model	E	2	0.065241	0.033	4.122433	0.0588	20.20542
	Error	8	0.0418	0.0209			12.83
	total	17					100

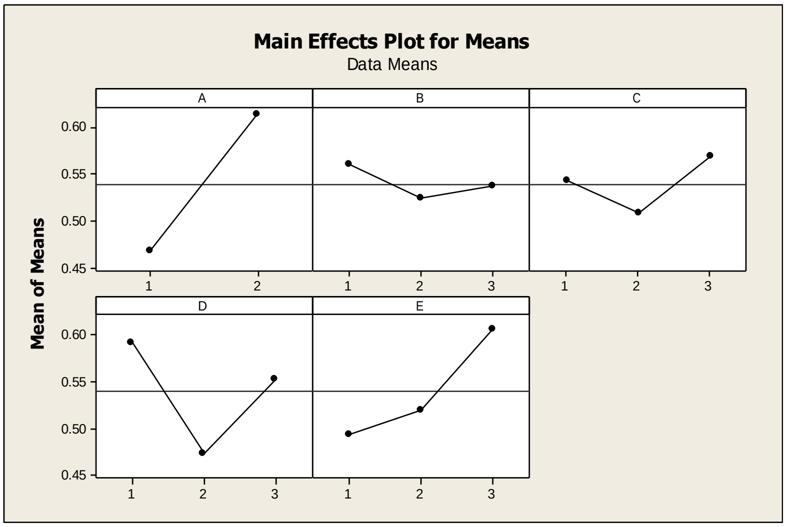


Fig. 1 Main effects plot for means of surface roughness – lower values give a lower surface

4.2. Development of mathematical model predictions

In this experimental investigation, in order to develop the mathematical model predictions for surface roughness, all the input factors are taken into consideration: type of cutting tool, cutting speed, feed rate, depth of cut, and volume fraction of particle reinforcement. A linear model equation was developed to describe the relationship between the factors and surface roughness. Regression analysis is performed using Design Expert software, and the following two equations – one for uncoated carbide and another for coated carbide – are established:

$$\mathrm{R_a}\ (\mathrm{uncoated}) = 0.4 - 0.000036 * \mathrm{v} - 0.13 * \mathrm{f} - 0.29 * \mathrm{DOC} + 0.015 * \% \quad (4)$$

$$\mathrm{R_a}\ (\mathrm{coated}) = 0.58 - 0.000036 * \mathrm{v} - 0.13 * \mathrm{f} - 0.29 * \mathrm{DOC} + 0.015 * \% \quad (5)$$

From equations (4) and (5), v is the cutting speed (m/min), f is the feed rate (mm/tooth), DOC is the depth of cut (mm), and $\%$ is the volume fraction of AlN. The mathematical prediction model is intended to facilitate the calculation of predicted values of surface roughness for other machining parameters. By using the mathematical model, the predictions of the surface roughness on the machined surfaces of AlSi/AlN MMC could be made.

The predicted values of surface roughness generated from the mathematical model equation, were then compared with the experimental results. The percentage error between them was determined, as shown in Table 6. With the lower value of error for all experiments, it shows that this mathematical model is reliable.

Table 6 Surface roughness value: experimental and prediction

Exp. no.	Surface roughness (experiment) (µm)	Surface roughness (prediction) (µm)	Error
1	0.405	0.414	2%
2	0.3825	0.446	14%
3	0.6075	0.478	27%
4	0.5125	0.485	6%
5	0.437	0.517	15%
7	0.425	0.380	12%
8	0.355	0.412	14%
9	0.565	0.530	7%
10	0.745	0.685	9%
11	0.655	0.582	13%
12	0.56	0.614	9%
13	0.5375	0.711	24%
14	0.47	0.521	10%
15	0.6725	0.640	5%
16	0.6325	0.605	5%
17	0.744	0.723	3%
18	0.4975	0.534	7%

Fig. 2 provides a comparison between the actual/experimental results and those predicted using the generated equation. As shown in this Fig. 2, experiment 10 obtained the highest surface roughness value compared to the other experiments. The parameters for experiment 10 are: coated carbide, cutting speed 240m/min, feed rate 0.3mm/tooth, DOC 0.5mm, and 20% volume fraction of AlN. On the other hand, experiment 8 showed the lowest surface roughness value, with parameters of: uncoated carbide, cutting speed 400m/min, feed rate 0.4mm/tooth, DOC 0.5mm, and 15% volume fraction of AlN. It was observed that the surface roughness value decreased with an increase in cutting speed and feed rate. The use of the uncoated carbide tool also contributed to a lower surface roughness value, and a decrease in volume fraction will decrease the surface roughness.

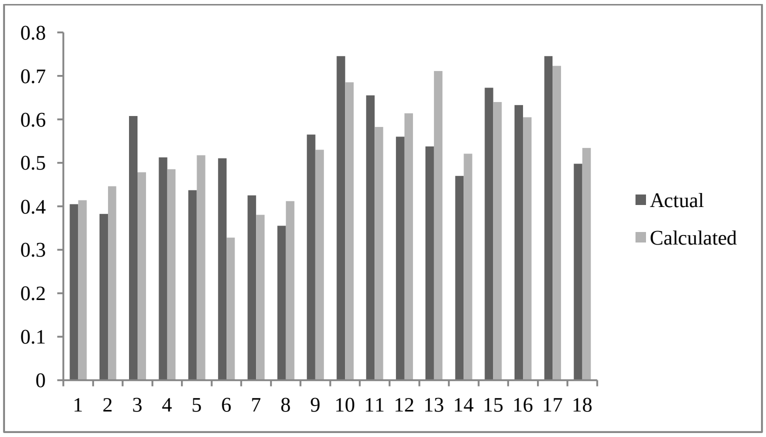


Fig. 2 Comparison between experimental results and equation model

4.3. Optimization of cutting parameters using S/N ratio and confirmation test

To improve productivity and minimise machining costs, the optimization of cutting parameters is essential. In this experimental investigation, the Taguchi method was implemented using orthogonal array (OA) L18 to optimise the combination of cutting parameters to obtain a better surface finish based on the signal-to-noise (S/N) ratio η. One factor is determined as noise in this experiment: a different batch of material. Two replicates were conducted for each experiment and the average value of surface roughness was calculated. The average value of surface roughness for all experiments was been calculated for the S/N ratio. The S/N ratio was calculated using the condition “smaller-the-better” for a lower surface roughness according to equation 3. The S/N ratios are shown in Table 7.

Due to the orthogonal experimental design, the effects of each parameter were separated at different levels. For example, the mean S/N ratio for the type of coating at levels 1 and 2 were calculated by averaging the S/N ratios for experiments 1–9 and 10–18, respectively. The mean S/N ratio for the cutting speed at level 1 was calculated by averaging the S/N ratio for experiments 1–3 and 10–12. The mean S/N ratio for the cutting speed at level 2 was calculated by averaging the S/N ratio for experiments 4–6 and 13–15, and the mean S/N ratio for the cutting speed at level 3 was calculated by averaging the S/N ratio for experiments 7–9 and 16–18. The mean values of the S/N ratio for each cutting parameter were calculated and are summarized in Table 8 and Fig. 3. The highest mean value of S/N ratio for each parameter was chosen, representing the optimum condition. It can be seen from Fig. 3 that the optimum levels for a minimum surface roughness were; A1 (uncoated carbide), B2 (cutting speed: 320m/min), C2 (feed rate: 0.4mm/tooth), D2 (axial depth: 0.4mm) and E1 (10% volume fraction).

Table 7 S/N ratio for average surface roughness

Exp. no.	Surface roughness for 1st batch material	Surface roughness for 2nd batch material	Average surface roughness value (μm)	S/N ratio
1	0.405	0.409	0.407	7.851
2	0.3825	0.393	0.38775	8.347
3	0.6075	0.627	0.61725	4.329
4	0.5125	0.513	0.51275	5.806
5	0.437	0.443	0.44	7.190
6	0.51	0.522	0.516	5.849
7	0.425	0.427	0.426	7.432
8	0.355	0.365	0.36	8.995
9	0.565	0.572	0.5685	4.959
10	0.745	0.741	0.743	2.557
11	0.655	0.661	0.658	3.675
12	0.56	0.565	0.5625	5.036
13	0.5375	0.543	0.54025	5.392
14	0.47	0.492	0.481	6.558
15	0.6725	0.687	0.67975	3.446
16	0.6325	0.63	0.63125	3.979
17	0.745	0.752	0.7485	2.569
18	0.4975	0.5	0.49875	6.064

Table 8 Mean value of S/N ratio for each factor

Level	A	B (m/mm)	C (mm/tooth)	D (mm)	E (%)
1	**6.751**	5.299	5.503	4.718	**6.238**
2	4.364	**5.707**	**6.222**	**6.577**	5.935
3		5.666	4.947	5.378	4.499
diff Δ	2.387	0.408	1.275	1.859	1.739

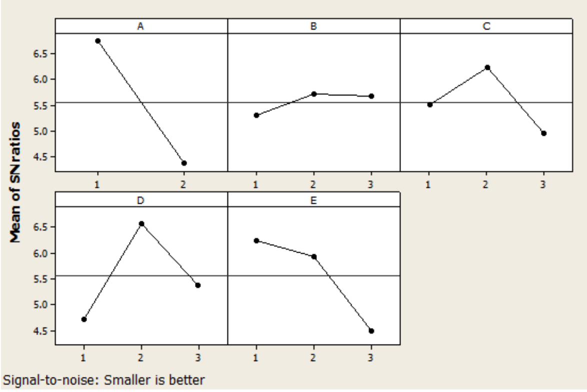


Fig. 3 Main effect plot for means of surface roughness – lower values give a lower surface roughness

The confirmation test is a method used to validate the optimum cutting parameters obtained from the analysis. In this experimental investigation, optimization was done using orthogonal array L18 based on the S/N ratio. The optimum level of each cutting parameter was selected. In the Taguchi method, a nominal level has also been selected by choosing the level of each parameter very near to the mean value of the S/N ratio [28]. The mean value of the S/N ratio in this experimental investigation is 5.558, as shown in Fig. 3. The comparison between nominal and optimum values was conducted to confirm that the Taguchi method gives a better combination of optimum cutting parameters for obtaining a lower surface roughness in the machining of AlSi/AlN MMC. The percentage improvement is about 23%. This means that the surface roughness value obtained from the optimum conditions was a 23% improvement on the nominal condition. The confirmation experiment was conducted for both conditions: nominal and optimum. The results are shown in Table 9. The predicted values were determined by calculation, while the observed values been taken through validation tests. For the optimum condition, the error between the predicted and observed values of surface roughness is 4.5%. It shows that the prediction of optimization using the Taguchi method is reliable, since the observed value is close to the predicted value.

Table 9 Validation experiment

	Control factor setting	Surface roughness (Ra)	
		predicted	Observed
nominal	A1B3C1D3E2	0.4465	0.47
optimum	A1B2C2D2E1	0.3442	0.36
% improvement		22.9%	23.4%

5. Conclusion

The effects of cutting parameters on surface roughness in the machining of a new composite material formed by reinforcing AlN particles with AlSi alloy at amounts of 10%, 15% and 20% volume fraction of particles was considered. The Taguchi method was applied and ANOVA analysis was performed to investigate the most significant cutting parameters contributing to the surface roughness. A mathematical model was generated to predict the surface roughness value for the selected cutting parameters. Furthermore, optimum cutting parameters were investigated and validated to obtain a lower surface finish based on S/N ratio. The following conclusions are drawn from this experimental investigation:

1. The type of cutting tool is the most significant factor, contributing to a lower surface roughness with the highest percentage of contribution of 45.5%. An uncoated cutting tool gives better results with respect to surface finish compared to a coated carbide tool. The volume fraction of AlN is the second factor giving supporting the surface finish of the machined material, which contributed 20.2% to the surface roughness value. As the volume fraction of AlN increased, it will increase the value of the surface roughness. For overall observations, the surface roughness of the machined material was lower due to the smaller size of the reinforcement particles.
2. The percentage error between the prediction mathematical model and experimental values is between 2 to 24 percent, with a value of R2 of 0.87. The lower value of error for all experiments shows that the mathematical model obtained from multiple linear regressions is reliable. This model is intended to facilitate the prediction of values of surface roughness for other machining parameters.
3. The optimum levels for minimum surface roughness were; A1 (uncoated carbide), B2 (cutting speed: 320m/min), C2 (feed rate: 0.4mm/tooth), D2 (axial depth: 0.4mm) and E1 (10% reinforcement).
4. The percentage error for optimization purposes between the predicted and validated values of surface roughness is 4.5%. It shows that the prediction of optimization using the Taguchi method is reliable, and the validated values are close to the predicted values. This experimental investigation, in order to develop the mathematical model predictions for surface roughness, all the input factors are taken into consideration: type of cutting tool, cutting speed, feed rate, depth of cut, and volume fraction of particle reinforcement.

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