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OPTIMIZATION OF MATERIAL REMOVAL RATE (MRR) COATED AND UNCOATED CARBIDE CUTTING TOOL IN MILLING PROCESS OF MMC (Al-Si/10%AlN)

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ABSTRACT

Metal matrix composites (MMCs) are widely used in numerous industrial sectors because of its light weight, strong and hard. However, MMC Al-Si/10%AlN material that content elements of Aluminium, Silicon and Aluminium Nitride 10% is rough and abrasive in nature, which will greatly affect the tool wear. The purpose of this research is to determine the material removal rate (MRR) for Aluminium silicon alloy (AlSi) matrix composite, which has been reinforced with aluminium nitride (AlN), with three types of carbide inserts present. Experiments were conducted at various cutting speeds, feed rates and depths of cut, according to the Taguchi method, using a standard orthogonal array L_{27} (3^4). The signal-to-noise (S/N) ratio and analysis of Variance ANOVA are applied to study the characteristic performance of cutting speeds, feed rates, depths of cut and types of tool in measuring the MRR during the milling operation. Based on the results, the maximum MRR of 116.2 cm^3 is achieved a cutting speed of 370 m/min, feed rate of 0.8 mm/tooth, depth of cut of 0.4 mm using TiB2 carbide tool. ANOVA results showed the factor of cutting speed, depth of cut and type of insert significantly affected the MRR. It was found that most influential factor was type of insert of 40.4%. The other important factors were feed rate (17.5%) and interaction cutting speed and feed rate (13%). The total volume of it is to be one of the goals in manufacturing because it is closely related to machining costs and profits.

Keywords: Al-Si/10% AlN MMC; Material Removal Rate (MRR); Taguchi method

INTRODUCTION

Many creation and technological advancement in the field of composite materials have emerged in recent decades, allowing today's designers to have their freedom in choosing appropriate materials to meet the specific needs regarding the characteristics of the final product. Therefore, composite materials (plastics, metals and ceramics) have now largely replaced traditional materials in a range of applications that include recreational components, aerospace, automotive, marine, electronics and medical. MMC material (Al-Si) is one of the materials known by mechanical properties such as lighter, stronger, high level of toughness, dimensional stability and wear-resistant. MMC Al-Si/10%AlN comprises the elements namely aluminium, silicon and 10% aluminium nitride. The main problem encountered is the extensive tool wear caused by these hard and abrasive reinforced materials that will affect the life of the tool. The amount of material removal rate (MRR) largely depends on the parameters, which are feed rate, cutting speed and depth of cut [1]. It has been shown in previous study that the total volume of waste is the highest point of the tool's longest life span. Thus, this study was carried out to define the optimum parameter setup for the MRR of cutting tool uncoated carbide, TiN, and TiB2 carbide coated on end milling of MMC Al-Si/10%AlN material using Taguchi method.

METHODOLOGY

With four factors (each with three levels), the fractional factorial design used in this study is a standard L27 (3^4) orthogonal array [2]. A four-factor, 27-line and three-level was chosen due to its ability to control the interaction among factors [3]. On the other hand, the reason why orthogonal array was chosen is because of its minimum number of required trials.

Table 1: Factors and Levels Used in the Experiment

Factor / Level	0	1	2
A - cutting speed (m/min)	230	300	370
B - feed rate (mm/tooth)	0.4	0.6	0.8
C - depth of cut (mm)	0.3	0.4	0.5
D – types of tool	Uncoated	TiN	TiB2

The study was carried out in a CNC Vertical Milling Centre Lagun-GVC1000 milling machine. Cutting inserts were attached to the tool with a body diameter of Ø20 mm. The tool holder used is CoroMill R390-020C4-11L and the tool insert is uncoated cemented carbide with ISO catalogue no: R390-11T08E-NL, TiN coating developed by SIRIM and a commercial tool insert, KC410M PVD TiB2 coating. The study involves three different cutting speeds (230,300 and 370 m/min) with feed rates of 0.4, 0.6, 0.8

mm/rev and depth of cut (0.3, 0.4 and 0.5 mm) under dry cutting conditions. The target material was fabricated in the form of block with 120 mm length x 50 mm width x 50 mm thickness. The tools were examined in dry condition for milling MMC Al-Si/10%AlN. Criteria wear of the tool is based on the maximum flank wear VB max = 0.3 mm (ISO 8688-2 1989). This equation was used to measure the material removal rate.

RESULTS AND DISCUSSION

Table 2: The experimental results and calculation for ratio S/N of the volume of waste

Test No	A	B	AxB	C	AxC	BxC	D	MRR (cm^3)	S/N ratio for MRR
1	0	0	0	0	0	0	0	217.4	46.7452
2	0	0	0	1	1	1	1	123.1	41.8052
3	0	0	0	2	2	2	2	437.9	52.8275
4	0	1	1	0	0	1	1	125	41.9382
5	0	1	1	1	1	2	2	495.2	53.8956
6	0	1	1	2	2	0	0	453.13	53.1245
7	0	2	2	0	0	2	2	461.31	53.2799
8	0	2	2	1	1	0	0	542.4	54.6864
9	0	2	2	2	2	1	1	185	45.3434
10	1	0	1	0	1	0	1	106.19	40.5217
11	1	0	1	1	2	1	2	317.67	50.0395
12	1	0	1	2	0	2	0	444.07	52.9490
13	1	1	2	0	1	1	2	108.7	40.7246
14	1	1	2	1	2	2	0	105.2	40.4403
15	1	1	2	2	0	0	1	137.52	42.7673
16	1	2	0	0	1	2	0	188.5	45.5062
17	1	2	0	1	2	0	1	140.5	42.9535
18	1	2	0	2	0	1	2	457.86	53.2147
19	2	0	2	0	2	0	2	247.38	47.8673
20	2	0	2	1	0	1	0	232.24	47.3187
21	2	0	2	2	1	2	1	177.1	44.9644
22	2	1	0	0	2	1	0	153.98	43.7493
23	2	1	0	1	0	2	1	96.57	39.6968
24	2	1	0	2	1	0	2	362.8	51.1933
25	2	2	1	0	2	2	1	208.62	46.3871
26	2	2	1	1	0	0	2	1116.2	60.9548
27	2	2	1	2	1	1	0	689.5	56.7707

The volume of recycled materials (Q) hugely depends on the parameters of the cutting speed, feed rate and depth of cut together. This study does not specify which parameter is having the most influence on the total volume of waste, since it is directly related to the life of the tool. In this study, tool with the longest life span contributed the highest volume of waste. Table 2 displays the total volume of waste from the uncoated, coated TiN and TiB2 during machining of MMC Al - Si/10 % AlN dry. Among the three points carbide tool, the total volume of waste from the eyes of most carbide tools were obtained at 116.2 cm^3 with a cutting speed of 370 m/min, feed rate of 0.8 mm/tooth and depth of cut of 0.4 mm by the coated TiB2, followed by the uncoated with cutting speed of 370 m/min, feed rate of 0.8 mm/tooth and depth of cut of 0.5 mm together with a total volume of 689.5 cm^3 recyclable materials.

Analysis Machining For Material Removal Rate

The total volume of waste derived from these experiments are shown in Table 2. The average value of S/N ratio was calculated for each factor cut. The values obtained were accordingly arranged to the level of demonstrated impacts or influences on tool‘s life. The highest value at the level of each factor shows the level of cuts in cutting factor as the most optimal [4].

As stated by Trent, Lindberg and Ibrahim [1][5][6], the estimated volume of recyclable materials is determined using mathematical equations. Apart from the total volume of waste, the quality of the workpiece such as geometry and dimensional accuracy and surface finish of the workpiece to be machined are to be taken into account to obtain the optimum parameters [7]. In this study, the cutting speed, depth of cut, feed rate and currency instruments gave a very significant impact on the volume of waste involved in cutting and feed rate.

From Table 3, for cutting factors identified for the type of cutting speed, the cutting speed level 1 of 230 m/min showed the average value of the ratio S/N, which is the highest number of 49.29 against the cutting speed of 370 m/min (48.77) and 300 m/min (45.56). For the feed rate (mm/tooth), level 2 feed rate of 0.8 mm/tooth showed the average ratio S/N of 51.01, which is the highest compared to the feed rate of 0.4 mm/tooth (47.23) and 0.6 mm/tooth (45.28).

For the factor in depth of cut (mm), level 2 with the cutting 0.5 mm indicated the average value of 50.35 for the ratio S/N, which is the highest compared to the 0.3 mm incision (45.19) and 0.4 mm (47.98). This might be associated with a larger flake thickness of 0.5 mm that will result in a volume of more recyclable materials. For the type of tool, the tool level 2 coated TiB2 showed a higher value of average S/N at 51.56 against the tool without coating that has the S/N ratio of 49.03 and the TiN coated with the average value of 42.93 in S/N ratio.

Table 3: Response Table for S/N ratios (bigger is better) of MRR

Factor		level			Mak-Min	Rank
		0	1	2		
cutting speed (m/min)	A	**49.29**	45.46	48.77	3.84	4
feed rate (mm/tooth)	B	47.23	45.28	**51.01**	5.73	2
depth of cut (mm)	C	45.19	47.98	**50.35**	5.16	3
types of tool	D	49.03	42.93	**51.56**	8.62	1

Table 4: ANOVA results for material removal rate (MRR)

No.	Factor	DF	SS	V	F	P	PD
1	Cutting speed (A)	2	77.849	38.925	40.81	0.000	8.9
2	Feed rate (B)	2	152.802	76.401	80.11	0.000	17.5
3	A x B	4	113.137	28.284	29.66	0.000	13
5	Depth of cut (C)	2	120.046	60.023	5.88	0.000	13.8
6	A x C	4	22.425	5.606	7.67	0.028	2.5
8	B x C	4	29.243	7.311	12.47	0.015	3.3
9	Type of tool (D)	2	353.919	176.959	185.55	0.000	40.4
	Residual error	6	5.722				0.6
	Total	**26**	**875.143**				**100**

DF: Degree of Freedom, **SS**: Sum of Square, **MS**: Mean of Square, **PD**: Percentage Distribution

Table 3 demonstrates the average value of the S/N of volume spilled, and the difference of maximum - minimum (Delta) is the biggest factor that gives the most significant impact on the life of the tool [1][8]. As a result, the decision in Table 3 shows the type of tool that has the biggest delta of 8:62, followed by the cutting of delta 5.73. This indicates that the type of tool is the biggest factor affecting the volume of waste. In life Taguchi method, cuts were analysed based on the ratio S/N (signal/interrupt). The value of S/N ratio of the volume of waste according to the method is shown in Table 3. In this study, several experimental results were taken into account, including the volume of recyclable materials and the interaction among cutting parameters. Indirectly, the experimental results showed a greater cutting parameters that affect the volume of recyclable materials. The analysis of variance was conducted to determine which machining parameter that significantly affects the material waste. ANOVA was then performed to determine whether or not the individual factors and their interactions that affect the MRR are meaningful. From the ANOVA results presented in Table 4, the factor of cutting speed, depth of cut and type of insert significantly affected the MRR with P-value that is less than 0.05. It was found that the most influential factor was found to be the type of insert by 40.4%. Other important factors are feed rate (17.5%) and depth of cut (13.8%). This indicates that the type of tool is the biggest factor affecting the volume of waste.

Only the interaction between the factors of cutting speed and feed rate gave a greater contribution compared to any other interactions. The volume of waste depends on the parameters of cutting speed, feed rate and depth of cut together. Similarly, the study established by Lindhberg (1983) and Ibrahim (2010) demonstrated that the increment of the total volume of waste can be done by increasing the cutting parameters or all parameters. Furthermore, this study has indicated that the volume of waste is of a TiB2 coated tool, which is based on the life of a longer tool will produce a total volume of more recyclable materials [1][9].

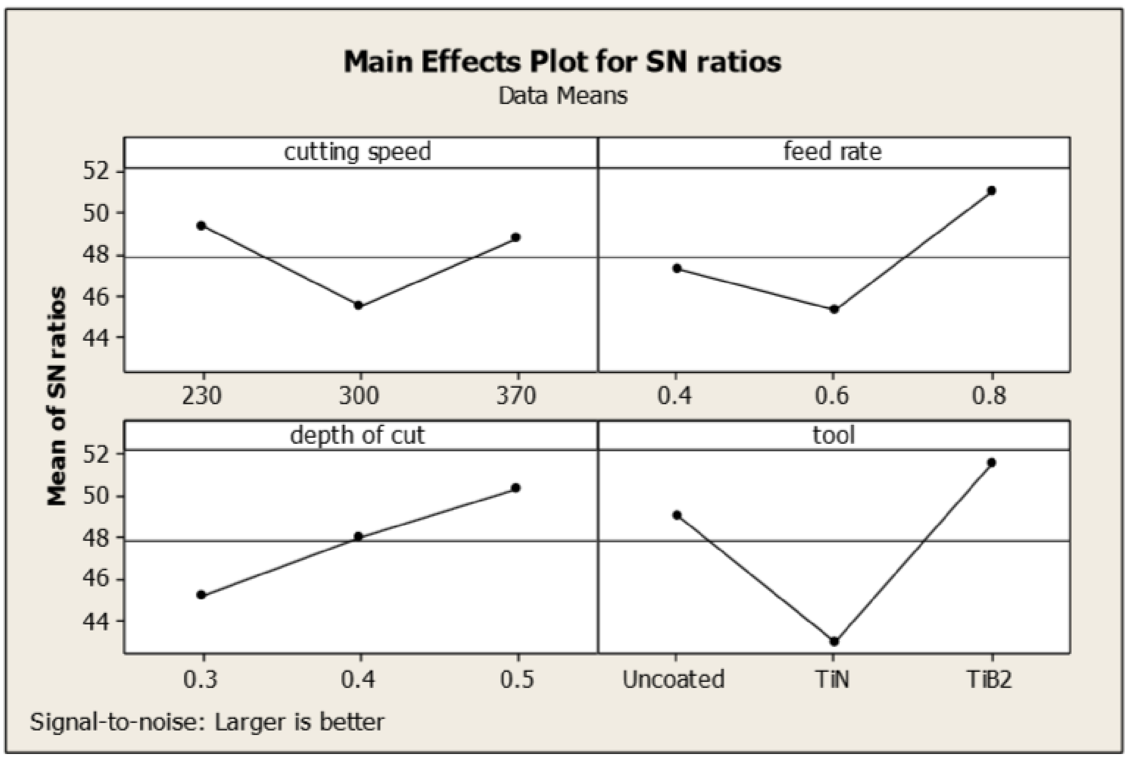

Figure 1: Factor interaction on the ratio S/N of the volume of waste for each level based on the Taguchi method

Figure 1 shows that the type of tool has a slope of a line that is slanted, thus showing that the type of tool has a greater impact than the other factors. This can be evidenced by the delta, where the delta value (8:39) for the type tool was found to be bigger than the others. Besides, factor in cutting also provides a significant gradient with a large delta value. While the cutting speed and feed rates also have a significant impact on the volume of waste, their effect was observed to be smaller, as it has been shown that the value of gradient is less than the average of tool and cutting or can be said as having a smaller delta. The total volume of waste was generated in parallel with the life of the tool [1][10].

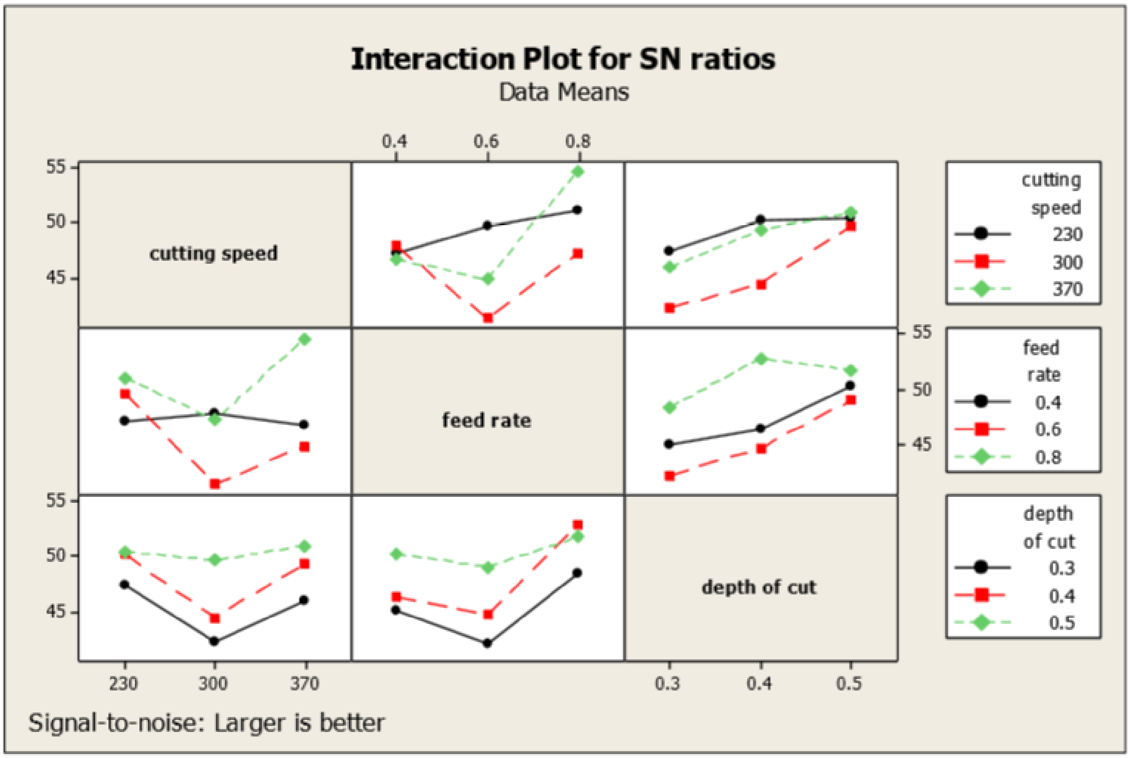

Figure 2: The main effect of each factor on the volume of waste

Figure 2 shows the S/N ratio of the volume of waste for interaction among various levels of the cutting parameters. The cutting speed in level 1 (A2) gave the greater slope value than the value of the slope on the other floors. Gusri (2010) stated that the S/N with a larger gradient shows a significantly higher value. Therefore, it can be said that the interaction of cutting speed on level 1 with the cuts on various levels is very significant. Thus, the cutting speed in level 1 was chosen as a more significant impact. Better results were also shown in the interaction between the feed rates at level 1 (B1) and the cutting as shown in Figure 2. Hence, either the interaction is between cutting speed (A2) with the feed rate or the feed rate of interaction (B1) with the cutting, each provides better results [4]:

$$\eta = \eta_m + \sum_{i=1}^{q} (\eta_i - \eta_m)$$

Based on calculations forecasting S/N ratio of the volume of waste, the value obtained is 54.211 equivalents to 491.234 cm^3 of waste. If the validity test is carried out, the volume of waste collected will rather increase slightly by 700 cm^3 as shown in Table 1. The difference between the forecast and the validity of the experiment is of 13.2%. The increase in the volume of waste at the optimum cutting was compared to the initial disconnection, demonstrating that the Taguchi method is suitable to be used in predicting the optimum cutting of the desired performance characteristics [11][12]. Therefore, based on the analysis of S/N ratio, optimum cutting parameters for the volume of waste were determined, which are; TiB2 coated carbide tool, the cutting speed of 230 m/min, the feed rate of 0.8 mm/tooth, and the cutting depth of 0.5 mm.

Table 5: Predictive value and validity testing of the optimum cutting the volume of waste

	Initial Factor	Optimum cutting factor	
		forecast	confirmation test
level	$A_2B_2C_1D_2$	$A_1B_2C_2D_2$	$A_1B_2C_2D_2$
MRR (cm^3)	1116.2	491.234	556
S/N (dB)	60.954	54.211	54.901

Increase S/N = 1.95dB

CONCLUSION

The Taguchi method was applied in experimental design to optimise the multi-response process parameters of end milling, while the machining of Al-Si/10%AlN MMC was optimised using an L27 orthogonal array. The results of this study were drawn from the experiments. The optimum machining parameters found for MRR are: cutting speed of 230 m/min; feed rate of 0.8 mm/tooth; depth of cut of 0.5 mm and TiB2 carbide tool insert. The total volume of it is considered one of the goals in manufacturing as it is closely related to machining costs and profits.

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