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TOOL WEARS ON DRILL METAL MATRIX COMPOSITES (MMC) AL-SI/10%ALN MATERIAL

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ABSTRACT

Metal matrix composites (MMCs) represent a relatively new class of materials characterized by lighter weight and greater wear resistance than those of conventional materials. The particle-reinforced aluminium nitric composites, which are among the most widely used composites materials, are rapidly replacing the conventional materials in various industries like aerospace, marine, and automotive. These materials are known to be difficult to machine because of the hardness and abrasive nature of reinforcement element with Aluminium Nitride. In this study, based on tool wear in drilling of metal matrix composite using uncoated carbide, TiCN and TiN coated drill bit. Experiments are conducted on a CNC Vertical Milling Centre KONDIA B-640 using twist drills bit of 6mm diameter. The parameters of the drilling machining used are the speed of 1000 rpm, 1500 rpm, and 2000 rpm and the feed rate is 50 mm/min, 100 mm/min and 150 mm/min. The depth of the cutting are made constant. The experimental results are collected and analysed using Taguchi method commercial software package MINITAB 17. It was found that optimum parameters are: uncoated, 1000 rpm, 150 mm/min. The optimum parameter obtained will help the automotive industry to have a competitive machining operation in the drilling process from an economic perspective and manufacturing.

Keywords: drill bit, MMC, Al-Si/10%AlN, Taguchi method, tool wear.

INTRODUCTION

Metal Matrix Composites (MMCs) have many potential engineering applications - in many industries including automotive and aerospace industries - due to their superior mechanical properties such as high strength, high hardness, good wear resistance and excellent weight ratio [1]-[4]. MMCs possess the combined properties of metals and ceramics [5], [6]. The structure and properties of MMCs are affected by the type and properties of the matrix, reinforcement and interface [4]. For this reason, their ability to replace conventional materials in many applications is increasing [6]. With only a few published reports on the use of AlN as the reinforcement for Al alloy composites, there is a lack of knowledge concerning the characteristics of these new materials, especially the optimum cutting parameter for the material MMC [7]. Several studies done to examine the efficiency of different cutting tool materials such as cemented carbide, coated carbide and diamond in turning, milling, drilling, reaming and treading of MMC conclude that the main problem encountered is the extensive tool wear caused by these hard and abrasive reinforced materials [8].

In general, optimisation of the cutting parameters is determined by the researcher's experience and knowledge or by the Design of the Experiment (DOE) [9]. DOE is a powerful statistical tool used to study the effect of multiple variables simultaneously. This technique provides an approach to efficiently design real time experiments, which will improve the understanding of the relationship between product and process parameters with the desired performance characteristics [10]. In addition, a statistical analysis of variance (ANOVA) was performed to see which parameters were significant. The optimal cutting parameters were then predicted. Taguchi's parameter design is an important tool for a robust design, as it offers a simple and systematic approach to optimise designs for performance, quality and cost. Two major tools used in robust designs are [11] [12]:

- Signal to noise ratio, which measures quality with emphasis on variation, and
- Orthogonal arrays, which accommodate many design factors simultaneously.

Taguchi's approach is based on the statistical design of experiments [12]. This can economically satisfy the needs of problem solving and product or process design optimisation [5]. Several previous works that used the Taguchi method as a design tool for experiments in various areas, including metal cutting, are listed in the reference section [13] [14]. As many factors as possible should be included so as to identify non-significant variables at the earliest possible opportunity. Taguchi creates a standard orthogonal array to accommodate this requirement. Depending on the number of factors, interactions and levels needed, the choice is left up to the user to select the standard, column-merging, or idle-column method, etc. Two of the applications, within which the concept of S/N ratio is useful, are the improvement of quality through variability reduction and the improvement of measurement. S/N ratio characteristics can be divided into three categories when the characteristic is continuous [12]:

Nominal is the best characteristic:

$$S/N = 10\log\frac{\bar{y}}{s_y^{\;2}} \quad (1)$$

Smaller are better characteristics;

$$S/N = -10\log\frac{1}{n}\left(\sum y^2\right) \quad (2)$$

Larger are better characteristics;

$$S/N = -10\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right) \quad (3)$$

Where, $\bar{y}$ is the average of the observed data, s_y^2 is the variance of *y*, *n* is the number of observations, and *y* is the observed data.For each type of characteristics, with the above S/N ratio transformation, the higher the S/N ratio is, the better the result. This study will utilise the Taguchi L_9 orthogonal array to determine the optimum condition for tool wear in machining Al-Si/10%AlN MMCs, using larger is the better characteristic. ANOVA has been performed and compared to Taguchi method.

RESEARCH METHODOLOGY

Material and drilling process

The experimental study was carried out using Aluminum Nitride (AlN) particles reinforced aluminum alloy composites. Table-1 shows the chemical composition of AlSi alloy. The reinforcement is a particulate Aluminum Nitride with grain size ranging <10 µm and purity of >98%. The MMC AlSi/10%AlN material as fabricated by the stir casting method. Firstly, AlSi alloy ingot was heated in a graphite crucible at 750^{0}C and held for 30 min until the material melted completely. The preheated AlN particles were added to the molten metal and stirred for 5 min at table 1, then immediately cast into a permanent mould by the bottom pour technique [7]. Table-2 showed the mechanical properties of MMC Al-Si/10%AlN.

Table-1. The chemical composite of Al-Si/10%AlN particles.

Elements	**Fe**	**Si**	**Zn**	**Mg**	**Cu**
Wt%	0.42	11.1	0.02	0.01	0.02
Elements	Sn	Co	Ti	Cr	Al
Wt%	0.016	0.004	0.0085	0.008	balance

Table-2. Mechanical properties of MMC Al-Si/10%AlN.

AlN (%)	**Hardness** (HV)	**Tensile Stress** (Mpa)	**Ductility** (%)
10%	112	146±8	6.2±3.5

The experiment was carried out in a CNC Vertical Milling Center KONDIA B-640. A cutting insert was attached to the tool shank diameter Ø6mm. The tool holder used was CoroMill R390-020C4. The machining was conducted at three different speeds (1000, 1500 and 2000 rpm) with the feed rate (50, 100 and 150 mm/min) and depth of cut (20mm) in through hole under dry cutting condition. The material being worked was fabricated in the form of block measuring 100mm length x 150mm width x 20mm thickness. The result of the flank wear of was measured using the Sometech SV-35 video microscope system. The cutting tool selection is made based on the characteristics of the workpiece and the tool capabilities. After careful study, the tools that can be used are uncoated carbide, carbide coated titanium carbon nitrate (TiCN), and titanium nitrate (TiN)

Figure-1. Tools a) Uncoated b) TiCN and c)

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TiN Design of.

Experiment

The present experimental investigation deals with the analysis of the experiment by the Taguchi methodology, which consists of the orthogonal arrays. A L_9 orthogonal array (OA) has been used to determine the importance of the factors or the parameters. Taguchi's design of experiment with a standard orthogonal array L_9 was used as it gives satisfactory result despite its minimum number of required experimental trials. The L_9 orthogonal array has nine rows corresponding to nine sets of variables setting. Each row of the matrix represents one trial. However, the sequence in which those trials were carried out was random. Nine experiments with a combination of different cutting parameters were randomly repeated. Three levels of cutting speeds, feed rates and types of tool tested. Factors and levels used in the experiment are shown in Table-3.

Table-3. Factors and levels used in the experiment.

Factor / Levels	1	2	3
Type of tools	Uncoated	TiN	TiCN
Speed (rpm)	1000	1500	2000
Feed rate (mm/min)	50	100	150

Table-4 given below is the L_9 orthogonal array, which is used for the experiments. The nine sets of settings were done to analyse the response that is the tool wear.

Table-4. L_9 orthogonal array Taguchi.

Experiment no.	**Type of tools**	**Speed** (rpm)	**Feed rate** (mm/min)
1	**Uncoated**	**1000**	**50**
2	Uncoated	1500	100
3	Uncoated	2000	150
4	TiN	1000	100
5	TiN	1500	150
6	TiN	2000	50
7	TiCN	1000	150
8	TiCN	1500	50
9	TiCN	2000	100

RESULT AND DISCUSSIONS

Based on the results, observation of the worn out drills in all figures shows that under the difference parameters, uncoated carbide drill bit suffered less damage, followed by TiN having the second least damage. This suggests that the hard coating material protects the tool and manages to substantially reduce the wear rate of the substrate.

Analysis of Taguchi method

The result of flank wear, Vb is shown in Table-5 by following the L9, which is used for the experiments. In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (deviation, SD) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the SD. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available, depending on the type of the characteristic; the lower the better, nominal is best and the higher the better. [15]. The lower is better characteristic is used for tool wear in this experiment. To measure the tool quality characteristics, the experimental value were transformed into S/N ratios. The parameter with the higher difference between the mean of S/N ratios is the most influential control factor.

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Table-5. Experiment data for tool wear.

Types of tool	Speed (rpm)	Feed rate (mm/min)	Flank wear, Vb (mm)	S/N Ratio	Mean
Uncoated	1000	50	0.086	21.31	0.086
Uncoated	1500	100	0.083	21.6184	0.083
Uncoated	2000	150	0.103	19.7433	0.103
TiN	1000	100	0.071	22.9748	0.071
TiN	1500	150	0.081	21.8303	0.081
TiN	2000	50	0.199	14.0229	0.199
TiCN	1000	150	0.093	20.6303	0.093
TiCN	1500	50	0.309	10.2008	0.309
TiCN	2000	100	0.209	13.5971	0.209

The ranking of process parameters using S/N ratios obtained for different parameter levels of tool wear is given in Table-6.

Table-6. Response table for signal to noise ratios of tool wear.

Levels	1	2	3	Delta	Rank
Type of tools	20.86	19.61	14.81	6.08	1
Speed (rpm)	21.64	17.88	15.79	5.85	2
Feed rate (mm/min)	15.18	19.4	20.73	5.56	3

Among all the factors, type of tool is the most significant parameter that affects the quality of machining. This result is supported by the value of means for tool wear in Table-7.

Table-7. Response table for means of tool wear.

Levels	1	2	3	Delta	Rank
Type of tools	0.09067	0.117	0.20367	0.113	1
Speed (rpm)	0.08333	0.15767	0.17033	0.087	3
Feed rate (mm/min)	0.198	0.121	0.09233	0.10567	2

Figure-2 shows the plot of S/N ratios for tool wear while Figure-3 shows the plot of mean for tool wear. The analysis of these experimental result using S/N values gives the optimum conditions resulting in minimum tool wear. Figure-2 shows the optimum parameters tested for tool wear are tool drill of uncoated, speed of 1000 rpm, and feed rate of 150mm. This is supported by the results of the sensitivity graph of the mean tool wear as shown in Figure-3.

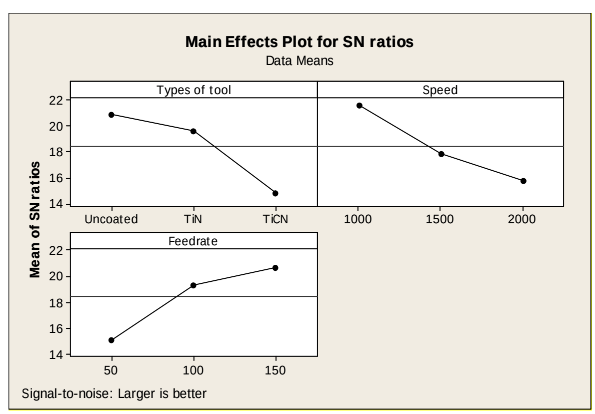

Figure-2. Main effects plot for SN ratios of tool wear.

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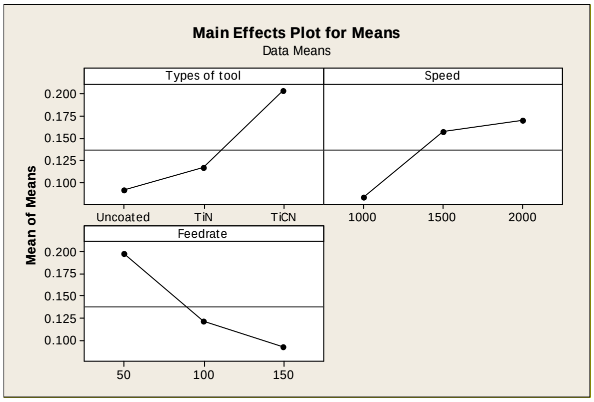

Figure-3. Main effects plot for means of tool wear.

The ANOVA was conducted to determine which machining parameters significantly affect the tool wear. By performing ANOVA, it can be decided which independent factor dominates over the other as well as its percentage contribution of that particular independent variable. Table 8 shows the result of ANOVA for tool wear. This analysis was carried out for a confidence level of 95 percent, that is for a significance level of $\alpha = 0.05$. Sources with a P-value less than 0.05 are considered to have a statistically significant contribution to the performance measure. From the ANOVA result presented in Table-8, the type of tools significantly affects the tool wear, where the P-value is less than 0.05. In Table-8, the last column shows the percentage distribution (PD) of each parameter on the total variation, indicating their degree of influence on the result. It can be inferred from the result that the type of tool is the major contributing factor having the highest statistical influence (36.7592 percent) towards the improvement of tool wear followed by speed (31.4308 percent) and feed rate (30.0847 percent).

The coefficient of determination (R^2) is defined as the ratio of the observed variation to the total variation. It is a measure of the degree of fit. When R^2 approaches unity, the result is a better response model fitting the actual data. The value of calculated for tool wear model was 0.983, which is reasonably close to unity, and is thus acceptable. Hence, it can be concluded that this model provides reasonably good explanation of the relationship between the independent machining factor and the result.

Table-8. ANOVA result for tool wear.

Source	DF	SS	MS	F	P*	PD
Types of tool	**2**	**61.661**	**30.831**	**21.31**	**0.045**	**36.7592**
Speed	2	52.723	26.361	18.22	0.054	31.4308
Feed rate	2	50.465	25.233	17.44	0.054	30.0847
Residual Error	2	2.893	1.447			1.7247
Total	8	167.743				100

DF: Degree of freedom, SS: Sum of Square, MS: Mean of Square, PD: Percentage Distribution *Significance level = 0.05

CONCLUSIONS

The Taguchi method was applied in experimental design to optimise multi-response process parameters of drilling, while the machining of Al-Si/10%AlN MMC was optimised using an L_9 orthogonal array. The results of this study were drawn from the experiments. This project are the optimum parameters are uncoated, 1000 rpm, 150 mm/min, and the most influential factor was found to be the type of tool of 36.70%.The optimum parameter obtained will help the automotive industry to have a competitive machining operation in drilling process from an economic and manufacturing perspective.

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