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OPTIMIZATION OF PROCESS PARAMETERS IN CNC DRILLING OF AA8011/ AL_2O_3/B_4C COMPOSITE USING WASPAS-TAGUCHI METHOD

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Abstract

Aluminium Metal matrix composite (AMMC) materials has been used worldwide especially in production industries like aerospace, automotive and marine. Drilling process is one of the important operations and obtained good quality of hoe is the major task, it can be achieved by optimization of input parameters effectively. In this paper Aluminium metal matrix composite reinforced by Al2O3 and B4C is prepared by Stir casting technique. Further, drilling experiments are conducted on it by using CNC machine according to Taguchi OA18 experimental design by taking input parameters of drill bit, speed, feed and coolant at different levels. Minimum quantity lubrication cooling system (MQL) also applied to reduce the coolant required, enhance the cooling effect etc. Then the experimental responses of power consumed, temperature of drill bit, tool vibration, surface roughness, burr height, tool wear is recorded and these are analyzed by using WASPAS (Weighted Aggregated Sum Product Assessment) method and optimum parameter levels are identified for minimization of these machining responses.

Keywords—AMMCs, Taguchi OA18, MQL, Tool wear, Amplitude, WASPAS, AA8011/Al2O3/B4C

1. INNTRODUCTION

Metal matrix composites are exhibited enhanced properties compared to conventional materials, hence they are used in many industries. In recent years hybrid metal matrix composites play a vital role in aerospace and automobile industry, in which two or more reinforce materials embedded in the matrix material to get the require properties. Stir casting is the one of the promising method to produce the metal matix composited compared to other properties like powder metallurgy etc., due to its simple and easy of doing [2,4,6,10,20].Many researchers done the investigation to assess the mechanical behavior of MMCs ,at different combinations of reinforce materials, with different fractions and various input parameters [1,3,5]. Manufacturing engineers encounter a difficult task when drilling MMCs. In contrast to machining conventional materials, drilling MMCs presents a number of challenges. Tool life of the drill bit affects adversely due to different reinforcement materials in the matrix 7]. Therefore many researchers study different coated tools to increase the life of tool [8]. B. Shivapragash, K. Chandrasekaran et.al [9] investigated the effects of changing the process variables viz., spindle speed, feed rate, and depth of cut on drilling composite Al-TiBr2. The factors were optimized using the Taguchi - grey relational analysis. S Jebarose Juliyana & J Udaya Prakash [11] is used Taguchi's Signal-to-Noise ratio analysis technique to optimize the drilling process parameters for aluminum matrix composites (LM5/ZrO2) to yield the lowest burr height. Ferit Ficici [12] studied the wear mechanism in drilling of PPA composite, TiN-coated HSS drills were used in the tests. SEM images and Energy Dispersive Spectrum (EDS) analysis is used in this method to study wear mechanism. S.V. Alagarsamy, S. Arockia Vincent sagayaraj, P. Raveendran [13] used the Taguchi Method to optimize the drilling process parameters for surface roughness and material removal rate.

D. D' Addona, R. Teti, (14) proposed a procedure for the standardization of cutting tool digital images captured during machining tests. These cutting tool images with standard size and pixel density can be utilized for intelligent processing of image data aimed at automatic and real time tool wear characterization. Shankar Chakraborty et.al [15] presented the WASPAS method (weighted aggregated sum product assessment) as a useful MCDM tool for resolving manufacturing decision-making issues. It is noted that this method is capable of accurately ranking the alternatives in all the selected problems. N.S. Manjunatha Babu & Rajesh Mathivanan N [16] used Taguchi Design of Experiments (DOE) and ANOVA to examine the impact of drill tool parameters on response variables. Here, an attempt is made to investigate the relationship between the response variables (cylinder city and ovality) and the input variables (tool material, cutting speed, and feed rate)

Chunhua Feng et al [17] investigated how to decrease the energy required for drill hole by simultaneously optimizing the tool path and the cutting parameters using the non-dominated sorting genetic algorithm (NSGA-II).Venkatasaikumar Chekuri and C.Thiagarajan [18] machined LDX 2205 duplex stainless steel, they examine the Material Removal Rate (MRR) of the uncoated High Speed Steel (HSS) drill bit with coating Titanium Carbonitride (TiCN). Mia et al. [19] used olive oil as coolant medium in turning process of hardened steel by using the technique MQL. They evaluated the machining performance with respect to the surface roughness and temperature produced at cutting zone and results yield that MQL was the best technique for sustainable machining system. After going through literature, the present work is done with objective of obtaining optimum input parameters (drill bit, coolant, speed and feed) in CNC drilling of Aluminium metal matrix composite (AA8011/ Al2O3/B4C) to get standardized hole with minimize the machining responses of Power, Temperature, Vibration Amplitude, Surface roughness and Tool wear and also applying minimum quantity lubrication cooling system (MQL) to reduce the coolant required, enhance the cooling effect etc.

2. MATERIALS AND METHODS

2.1 Fabrication of AMMC (Al8011/ Al2O3/B4C)

The Aluminium aloy AA8011 is used as the matrix metal ,two reinforcement materials aluminium oxide (Al2O3) and boron carbide (B4C) in Nano form with 1% and 1.5% weight ratio respectively used as reinforcement materials for the fabrication of the composite. The physical properties and chemical composition of AA8011 are presented in Tables 2.1 and 2.2.

Table 2.1: Chemical composition of Aluminium Alloy Aa8011

Element	Si	Cu	Fe	Mg	Mn	Zn	Ti	Al
Weight %	**0.5**	0.13	0.7	0.3	0.5	0.1	0.02	Bal

Table 2.2: Properties of Aluminium Alloy Aa8011

Properties	Elastic Modulus (GPa)	Density (g/cc)	Poisson's Ratio	Hardness HRB	Tensile Strength(MPa)	Melting point °C
Values	70-80	2.71	0.33	60	140	660.2

The composite was fabricated by the stir casting technique. The melting was carried out in a stir casting furnace at 7800C. Experimental setup for AMMC preparation and metallic mold is shown in Fig.2.1.

Fig 2.1: Experimental setup for AMMC preparation

The melt has mechanically stirred by using a graphite stirrer with motor. In order to reduce the surface tension of the aluminum and improve the wetting property between the matrix and reinforcement material, 1% of magnesium was added gradually to the molten. The stirring process is conducted for 10 minutes at a temperature of 780°C and a stirring speed of 600 rpm. To measure the changes in molten metal temperature, one K-type thermocouple has been inserted into the graphite crucible.

2.2 Design of Experiments

The Taguchi OA18 experimental design(Table 2.4) is done by taking three levals of parameters such as such as coolant,speed, feed and two levals of drill bits as shown in Table 2.3.

S. no	Influential factors	Level 1	Level 2	Level 3
1	Drill bit (A)	HSS	Coated HSS	-
2	Coolant (B)	Vegetable oil	Mixed oil	Soluble
3	Speed (rpm) (C)	1000	1800	2500
4	Feed (mm/rev) (D)	50	120	250

Table 2.4: Taguchi OA18 Experimental design

Ex. No.	A	B	C	D
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

2.3 Drilling of AMMC and Measurement of Responses

The drilling experiments are conducted on AMMC(AA8011/ Al2O3/B4C) by CNC drilling machine (Fig 2.2) with HSS and Titanium Aluminium Nitride coated HSS drill bits of 8 mm dia (Fig 2.3). The drilling process is done by Minimum quantity lubrication cooling system (MQL) technique to reduce the cooling requirement, increase cooling effect etc. In which, the flow rate is used is 0.004gpm instead of 1.7 to 2.0 gpm used in flooded type cooling system. Response characteristics considered to study the parameters on drilling of AA8011/ Al2O3/B4C are Power, Temperature, Vibration Amplitude, Surface roughness, burr height and Tool wear. Power is measured by using Watt meter. Surface roughness is measured by Talysurf surface meter. Amplitudes of machine vibrations and temperatures at tool-work interface are measured by using Lab VIEW software. The software is connected to transducers. The transducers used for amplitude and temperature measurement are accelerometer and J-type thermocouple.

Through the use of Mat lab image processing, tool wear is measured. For the purpose of photographing drill tool images both before and after drilling holes, a setup (Fig. 2.4) has been created. It has the ability to adjust the camera's height and focal length. In this setup, a camera is fixed in front of the tool holder, which keeps the tool in place so that it can be photographed. In this work, the drill tool is fixed in the tool holder before beginning to drill, and an image of the tool is taken. The drill tool is taken out of the drilling machine after drilling and fixed in the tool holder so that an image can be taken. Tool wear is the difference between pixel regions of the image taken before and after drilling (Fig. 2.5). All the experimental responces are recorded(Table 2.5) and composite after machining is shown in Fig 2.6.

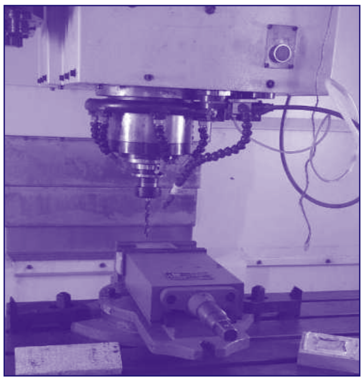


Fig 2.2: CNC drilling

Fig 2.3: Titanium Aluminium Nitride coated HSS and HSS drill bits

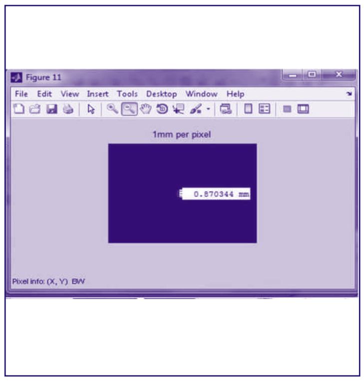


Fig 2.5: Tool wear of machined drill tool

Fig 2.4: Setup for capturing the images of drill tool

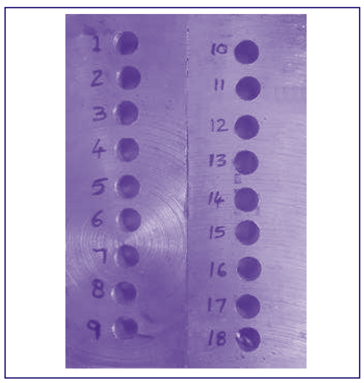


Fig 2.6 composite after machining

Table 3.1: WASPAS Grade and S/N Ratios

S. No	Power (Watts)	Temperature (ºC)	Tool Vibration (mm)	SR (µm)	Burr Height(mm)	Tool wear (mm)
1	660	41.2	0.3231	2.5033	1.55	0.7463
2	710	42.5	0.4202	2.5421	1.61	0.7762
3	890	44.8	1.1114	1.4823	1.56	0.9752
4	810	42.3	0.8105	1.4966	2.01	0.7548
5	1010	43.8	0.9203	1.4866	1.93	0.8627
6	1200	44.9	1.4167	1.4812	1.06	0.8959
7	860	40.2	1.4646	1.7166	1.07	0.9323
8	1010	41.2	2.2461	2.4121	1.57	0.9845
9	1120	44.4	2.9547	1.7301	1.97	1.1543
10	720	42.5	0.3163	1.3866	0.01	0.6077
11	910	43.2	0.3602	1.4833	0.06	0.7497
12	1060	52.1	1.2696	2.6101	1.02	0.8712
13	910	43.4	0.6496	1.3933	0.01	0.5414
14	1160	44.1	1.5409	2.4566	0.21	0.6912
15	1150	45.3	1.8191	2.4133	1.06	1.0213
16	970	39.9	0.3847	2.933	2.01	1.2118
17	1160	44.8	3.2445	1.5833	1.12	1.8725
18	1250	43.5	3.1546	3.64	1.65	2.1543

2.4 Optimization of Responses by Weighted Aggregated Sum Product Assessment (WASPAS) –Taguchi method

The WASPAS method combines the weighted sum model (WSM) and weighted product model (WPM), two widely used multi-criteria decision making (MCDM) approaches. For it to be applied, a decision matrix called X = [xij]mxn must first be created, where m is the number of candidate alternatives, n is the number of evaluation criteria, and xij is the performance of the ith alternative with respect to the jth criterion. The following lists the steps involved in solving multi-objective optimization problems..

Step 1: Set the initial decision matrix

Step 2: Normalization of the decision matrix by using the following equations:

$$\bar{X}_{ij} = \frac{x_{ij}}{max_i X_{ij}} \quad \text{For beneficial criteria,} \qquad (1)$$

$$\bar{X}_{ij} = \frac{min_i X_{ij}}{X_{ij}} \quad \text{For non-beneficial criteria,} \qquad (2)$$

Where x_{ij} is the assessment value of the *i*-th alternative with respect to the *j*-th criterion, and equation 1 and 2 are used for maximization and minimization criteria, respectively.

Step 3: Based on WSM method the total relative importance of i_{th} alternative is calculated as follows

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{X}_{ij} . W_j \qquad (3)$$

Step 4: Based on weighted product method (WPM),the total relative importance of the i_{th} alternative is calculated as follows:

$$Q_i^{(2)} = \prod_{j=1}^{n} \bar{X}_{ij}^{\,W_j} \qquad (4)$$

Entropy Approach for Weights Determination

wj is the weight of the j^{th} criterion

$$W_j = \frac{(1-e_j)}{\sum_{j=1}^{n}(1-e_j)}$$

Entropy value, e_j= -k $\sum_{i=1}^{m} P_{ij} \ln(P_{ij})$ $P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}}$; X_{ij} = is normalized matrix

Where K= $\frac{1}{\ln(m)}$; m = 18 (no. of experiments)

Step 5: A joint generalized criterion of weighted aggregation of additive and multiplicative methods is then proposed as follows

$$Q_i = 0.5.Q_i^{(1)} + 0.5.Q_i^{(2)} \quad (5)$$

Step 6: Finally, Taguchi S/N ratio analysis has been adopted on overall WASPAS grade to obtain the optimal machining condition. Higher is better criterion of Taguchi has been taken in consideration to maximize the overall WASPAS grade.

$$S/N = -10*\log(\Sigma(Y2)/n) \quad (6)$$

where Y = responses for the given factor level combination and n = number of responses in the factor level combination

3. RESULTS AND DISCUSSION

3.1 WASPAS-Taguchi Method:

To identify the most appropriate process parameters for multiple responses, the integrated WASPAS Taguchi approach is used which integrates the Taguchi method's algorithm with WASPAS analysis. The experimental data of machining responses such Power, Temperature, Vibration Amplitude, Surface roughness, burr height and Tool wear are analyzed using integrated WASPAS-Taguchi method.

Table 3.1: WASPAS Grade and S/N Ratios

S.NO	Q1	Q2	Q1*	Q2*	WASPAS Grade	S/N Ratios on WASPAS
1	0.438927122	9.53E-08	0.219463561	4.77E-08	0.2195	-13.1713
2	0.168045209	6.07E-08	0.084022604	3.03E-08	0.0840	-21.5144
3	0.114933677	2.66E-07	0.057466839	1.33E-07	0.0575	-24.8066
4	0.133401141	6.01E-08	0.066700571	3.00E-08	0.0667	-23.5175
5	0.123320362	2.38E-07	0.061660181	1.19E-07	0.0617	-24.1943
6	0.107789366	6.13E-07	0.053894683	3.06E-07	0.0539	-25.3682
7	0.101836856	1.74E-07	0.050918428	8.72E-08	0.0509	-25.8656
8	0.075067581	9.11E-07	0.037533791	4.56E-07	0.0375	-28.5194
9	0.077925716	1.47E-06	0.038962858	7.36E-07	0.0390	-28.1787
10	0.996420873	3.87E-09	0.498210436	1.94E-09	0.4982	-6.0519
11	0.327876936	3.73E-08	0.163938468	1.86E-08	0.1639	-15.7084
12	0.092434175	3.13E-06	0.046217088	1.56E-06	0.0462	-26.7072
13	0.923011874	1.97E-08	0.461505937	9.86E-09	0.4615	-6.7166
14	0.120504271	8.04E-07	0.060252135	4.02E-07	0.0603	-24.3937
15	0.080831455	2.47E-06	0.040415728	1.24E-06	0.0404	-27.8724
16	0.1648215	3.42E-07	0.08241075	1.71E-07	0.0824	-21.6815
17	0.078585167	2.71E-06	0.039292583	1.36E-06	0.0393	-28.1121
18	0.050518423	1.36E-05	0.025259211	6.81E-06	0.0253	-31.9376

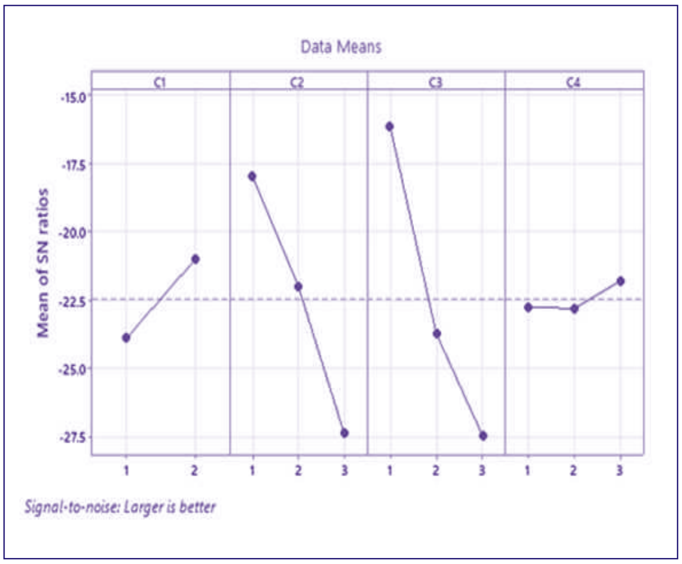
In this method, the optimal parameter combinations corresponding higher WASPAS grade is 10th experimental run (Table 3.1). Further S/N ratio analysis is done on WASPAS grade values, response table for Signal to Noise ratios(Table 3.2) and Main plots for S/N ratios are presented in Fig 3.1.From this S/N ratio analysis the optimal values of influential parameters are identified which are corresponding to higher S/N ratio. The optimal influential parameters setting: Drill bit type: Titanium Aluminium Nitride coated HSS drill bit, Coolant type: Vegetable oil, Speed: 1000rpm, Feed: 250mm/rev i.e 2-1-1-3.

Table 3.2: Response Table for Signal to Noise Ratios

Level	C1	C2	C3	C4
1	-23.90	-17.99	-16.17	-22.76
2	-21.02	-22.01	-23.74	-22.82
3		-27.38	-27.48	-21.80
Delta	2.88	9.39	11.31	1.02
Rank	3	2	1	4

Larger is better

Fig 3.1: Main effects plots for S/N Ratios



The combination of inputparameters 2-1-1-3 is already exists in experimental run 10, the corresponding output parameters are repreented in Table 3.3

Table 3.4: Optimum parameter setting with machining responses

Optimal Parameter setting	Power (Watts)	Temperature (ºC)	Tool Vibration (mm)	SR (µm)	Burr Height(mm)	Tool wear (mm)
2-1-1-3	720	42.5	0.3163	1.3866	0.01	0.6077

3.2 ANOVA of WASPAS Grade values

ANOVA is performed on WASPAS grade values using Mini Tab software to know the relevance of each input parameter on the measurements of process performance and results are presented on Table 3.4.

Table 3.5: ANOVA of WASPAS Values

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
A	1	0.030984	0.03098	2.40	0.153	15.11
B	2	0.053242	0.02662	2.06	0.178	25.97
C	2	0.099501	0.05975	4.62	0.038	48.53
D	2	0.014351	0.00218	0.17	0.847	7.00
Error	5	0.006931	0.01293			3.38

From the ANOVA table, the spindle speed (48.53%) influences more followed by coolant type , drill type, and feed, which is also known from Table 3.2.

4. CONCLUSIONS

The Taguchi S/N analysis and WASPAS-Taguchi method are applied successfully in this study to establish the optimal process variables for obtaining the improved performance of CNC drilling of AA8011/ Al2O3/B4C composite. Based on results, The optimal influential parameters setting: Drill bit type: Titanium Aluminium Nitride coated HSS drill bit, Coolant type: Vegetable oil, Speed:1000 rpm, Feed:250mm/rev. According to Analysis of variance of experimental data, the spindle speed (48.53%) influences more on drilling of AA8011/ Al2O3/B4Ccomposites followed by coolant type (25.97%), drill type (15.11%) and feed (7.00%) on overall machining responses. Moreover, the identified optimal parameters combination of CNC Drilling process parameters can be used to minimize the machining responses of Power, Temperature, Vibration Amplitude, Surface roughness, burr height and Tool wear. Due to the Minimum Quantity lubrication cooling system, the coolant used in CNC drilling process is reduced drastically compared to flooded system. The outcome obtained from this exploration will be a wide-ranging support to the manufacturers for enhancing the rate of production and quality of holes produced during CNC Drilling of AA8011/ Al2O3/B4C composite.

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