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Multi Response Optimization of Face Milling Parameters Using Gray Relation Analysis

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Abstract
This work introduces the application of gray relation analysis as a multi optimization method in optimizing the machining parameters of face milling for hybrid Al-Si/Al_2O_3 /MWCNTs nanocomposites. The conventional vertical milling machine was used to carry out the experiments based on Taguchi orthogonal L27 array. Spindle speed, feed rate and depth of cut were considered as machining parameters. Surface roughness and flatness error were selected as a process response. The effect of various machining parameters was analyzed and the optimum combination of their levels were determined using both S/N ratio and ANOVA for gray relation grade. The results of this work showed that, the most significant parameter on multi-response was feed rate with contribution 26.34% followed by depth of cut with 19.99%. Also, the optimal levels of machining parameters are determined.

Keywords: Face milling**,** Nanocomposites, Surface roughness, Flatness error, Taguchi, Gray Relation Grade.

1. Introduction

Aluminum metal matrix is fabricated by the combination of aluminum alloy(matrix) with reinforcement of hard ceramic particulate (macro/micro) material. These hard particles in general improves the mechanical and tribological properties of the matrix alloy. Hybrid composites are fabricated by adding two or more reinforcing types of elements with different properties to the matrix alloy.

Tomadia et al. [1] applied Taguchi method and ANOVA to analyze and optimize the effect of machining parameters on surface roughness (Ra) in end milling of metal matrix composite. They result found that the cutting speed is more significant on Ra. Taguchi and ANOVA techniques were also applied for similar studies [2,3]. Ravikumar et al. [4] predicted surface roughness for end milling in CNC milling machine of aluminum using HSS tool by applying artificial neural networks (ANN). Their results indicated that feed rate the most influence on Ra. The same technique also applied for similar studies [5,6]. Jaykumar et al. [7] applied grey relation analysis (GRA) to optimize the cutting parameters in CNC end milling of Ti-6Al-4V alloy. They found that depth of cut has the most significant effect on Ra and MRR. The increase of depth of cut increases the Ra. Similar results were also reported in reference [8-10].

Generally composite materials are more difficult to be machined than the conventional materials because it contains an abrasive elements in addition of their non-homogeneous. However, the machining of these class of materials are depending on different conditions such as, percentage content and properties of reinforcement elements, properties of base or matrix material and main machining factors. Therefore, the main objectives of this study is to determine the relationship between the input control factors and output response and to determine the optimal combination machining conditions of face-milling parameters for various output performances.

2. Exprimental Work

2.1 Workpiece Material

The material in this work is aluminum silicon (Al-Si) alloy reinforced with hybrid multi walled carbon Nano tubes and Nano aluminum oxide particulates (0.50hybrid and 0.50MWCNTs). Nano aluminum oxide particulates has 99.9% parity and 20 nm average grin size. Multi walled carbon nano tubes (MWCNTs) has 20 and 40 nm inner and outer dimeters. The compositions of matrix aluminum silicon alloy are indicated in Table 1.

Table.1 The chemical compositions of the aluminum silicon alloy (wt. %)

Fe	Al	Si	Mn	Ni	Ti
0.221	Balance	5.50	0.014	0.62	0.14

2.2 Nano Composite Material Preparation

Stir casting route was used to fabricate the hybrid Al-Si/Al_2O_3 /MWCNTs nanocomposites as follows: A recalculated bar of the Al-Si alloy was charged into a graphite crucible and heated up to 750ºC for melting. After the complete degassing the melt with argon gas at low pressure for 30 second. Stirring the melt with a steel stirrer attached to a variable speed motor at stirring speed ranges from 750 to 1000 r.p.m. The (MWCNTs & Al_2O_3) nanoparticulates heated to 400 ºC for 10 minutes, were dispersed into the vortex developed during stirring. After complete turned off mixer and the molten mixture was poured into preheated permanent steel mold. The steel mold has a rectangular shape cavity with 300x100x25 mm.

2.3 Machine Specifications

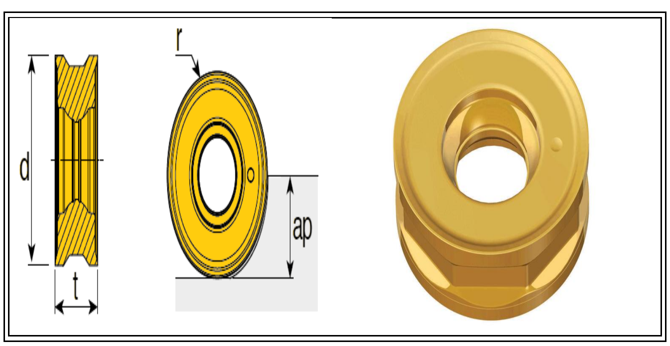
The experiments were carried out on vertical milling machine model "USM30S" and the specifications of the machine are approach angle of 45º ,table surface (35x 1150mm) and range of speed (35 – 1600 r.p.m), range of feed speed (4-240 mm/min) and range power of motor (0.75kw -1380rpm). The selection of the tool flutes was chosen according to the WIDIN manufacturing catalogue of considering workpiece material and the recommended other cutting parameter.

2.4 Tool Specifications

RNMU 10/12/16-MLTT9080 double-sided economical round cemented carbide coating layers aluminum titanium nitride AlTiN-TiN with PVD coating carbide. This insert for general milling applications with max. 8 index per side (total 16 corners) when the depth of cut and holder of limited family: BT-SEM ISO 3937 Face mill arbors with BT MAS-403 form AD Taper shanks. This type is suitable for machining nonferrous material and some types of alloy steel according to WIDIN company catloge. The tool geometry specifications in showed in Table.2 and the insert and holder in showed in Fig.1a, b.

Table 2 Tool Geometry Specifications

Designation	r "mm"	d "mm"	t "mm"	aP "mm"
RNMU 1205-ML	6.00	12.00	5.00	6.00



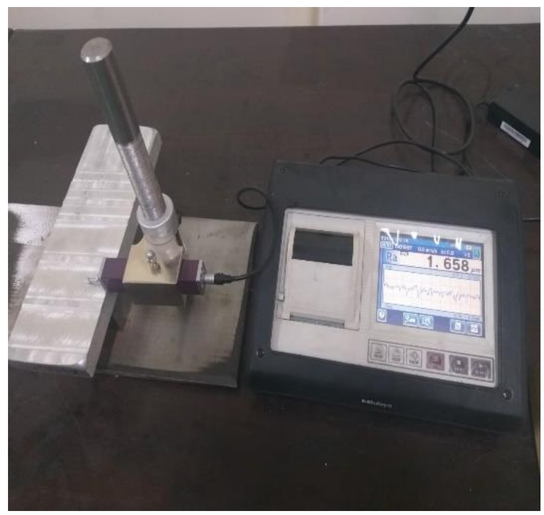
(a)

(b)

Fig 1 (a) insert and (b) holder

2.5 Surface roughness of measurement devices

Figure 2 showed the surface roughness parameter (R_a) of the workpiec after machining was measured with surftest (Mitutoyo SJ-310) instrument. However, Fig. 3 The flatness tester JENA GERMANY, L.R = 0.001 µm, U= ± 0.002 µm.



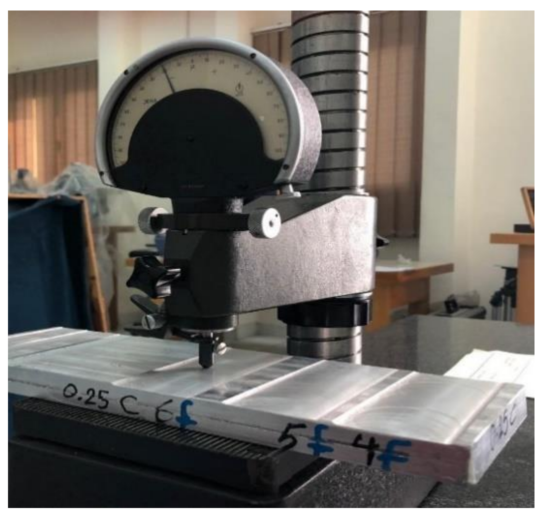


Fig.2 SJ-310 Surftest tester
Fig.3 Flatness tester

2.6 Design of exeriments using Taguchi method

The experiments have been conducting according to Taguchi L27 orthogonal array. The process parameters chosen for this work are spindle speed, feed rate and depth of cut. The values and their levels are indicated in Table 3

Table.3 The process parameters and thier levels

Parameter	Unit	Level 1	Level 2	Level 3
Spindle Speed (A)	(r.p.m)	640	1000	1600
Feed rate (B)	(mm /min)	12	17	24
Depth of cut (C)	(mm)	0.50	0.75	1.00

3. Results and discussion

3.1. Taguchi method

Taguchi mehod is used to minimize the quality loss function by using one of three options in design analysis . Table 4 lists the result of 27 experiments according to Taguchi OR L27.

Table.4 The layot of Taguchi model

Run	Spindle Speed (r.p.m)	Feed Rate (mm/min)	Depth of Cut (mm)	Ra (µm)	Flatness (µm)
1	640	12	0.50	1.115	0.120
2	640	12	0.50	1.023	0.132
3	640	12	0.50	1.053	0.131
4	640	17	0.75	1.999	0.140
5	640	17	0.75	1.774	0.154
6	640	17	0.75	1.996	0.153
7	640	24	1.00	1.543	0.199
8	640	24	1.00	1.669	0.198
9	640	24	1.00	1.520	0.180
10	1000	12	0.75	1.798	0.170
11	1000	12	0.75	1.710	0.188
12	1000	12	0.75	1.801	0.187
13	1000	17	1.00	1.300	0.100
14	1000	17	1.00	1.529	0.109
15	1000	17	1.00	1.275	0.110
16	1000	24	0.50	1.919	0.153
17	1000	24	0.50	2.128	0.140
18	1000	24	0.50	2.092	0.154
19	1600	12	1.00	3.133	0.188
20	1600	12	1.00	2.893	0.170
21	1600	12	1.00	3.183	0.187
22	1600	17	0.50	0.925	0.170
23	1600	17	0.50	0.938	0.188
24	1600	17	0.50	1.087	0.187
25	1600	24	0.75	2.186	0.166
26	1600	24	0.75	1.986	0.150
27	1600	24	0.75	2.020	0.164

3.2 Gray Relation Analysis

This method is most useful for optimization of multi-objective process responses. In the grey relational analysis, first, experimental data of the output responses are normalized between the ranges of 0 to 1 as lists in Table.5 by using equation (1). There are two different cases of normalization.

$$\mathrm{Xi}\ (\mathrm{k}) = \frac{\max \mathrm{Y_i}(\mathrm{k}) - \mathrm{Y_i}\ (\mathrm{k})}{\max \mathrm{Y_i}\ (\mathrm{k}) - \min \mathrm{Y_i}\ \ (\mathrm{k})} \quad (1)$$

Where X_i is the value obtained after grey relational generation. Min $Y_i(k)$ is smallest value of $Y_i(k)$ and max $Y_i(k)$ is the maximum value of $Y_i(k)$.

Table.5 Normalized values of multi response

Ex.no	**Ra [µm]**	**Flatness error [um]**
1	0.916	0.798
2	0.957	0.677
3	0.943	0.687
4	0.524	0.596
5	0.624	0.455
6	0.526	0.465
7	0.726	0.000
8	0.671	0.010
9	0.736	0.192
10	0.613	0.293
11	0.652	0.111
12	0.612	0.121
13	0.834	1.000
14	0.733	0.909
15	0.845	0.899
16	0.560	0.465
17	0.467	0.596
18	0.483	0.455
19	0.022	0.111
20	0.128	0.293
21	0.000	0.121
22	1.000	0.293
23	0.994	0.111
24	0.928	0.121
25	0.442	0.333
26	0.530	0.495
27	0.515	0.354

The second step, grey relational coefficient is calculated to express relationship between actual and desired experimental data shown in Table.6 by using equation (2).

$$\Delta(\boldsymbol{i}) = \frac{\Delta\min + \frac{1}{2}\Delta\max}{\Delta_{0i}\,(i) + \frac{1}{2}\Delta\max} \quad (2)$$

Table. 6 Grey relation coefficient

Ex.no	**Ra [µm]**	**Flatness error [µm]**
Ideal.seq	**1**	**1**
1	0.084	0.202
2	0.043	0.323
3	0.057	0.313
4	0.476	0.404
5	0.376	0.545
6	0.474	0.535
7	0.274	1.000
8	0.329	0.990
9	0.264	0.808
10	0.387	0.707
11	0.348	0.889
12	0.388	0.879
13	0.166	0.000
14	0.267	0.091
15	0.155	0.101
16	0.440	0.535
17	0.533	0.404
18	0.517	0.545
19	0.978	0.889
20	0.872	0.707
21	1.000	0.879
22	0.000	0.707
23	0.006	0.889
24	0.072	0.879
25	0.558	0.667
26	0.470	0.505
27	0.485	0.646

The last step, overall grey relational grade is calculated by averaging the grey relation coefficient of the output responses shown in Table.7 using equation (3)

$$\ddot{\alpha}_i = 1/n \sum_{k=1}^{n} \gamma i_{(k)} \quad (3)$$

Where n is total number of responses (n=2).

Table. 7 Grey relation grade

Ex.no	G.R	Rank
1	0.784	3
2	0.764	4
3	0.757	5
4	0.533	10
5	0.525	11
6	0.498	16
7	0.490	17
8	0.469	22
9	0.519	12
10	0.489	18
11	0.475	20
12	0.463	23
13	0.875	1
14	0.749	6
15	0.798	2
16	0.507	14
17	0.519	13
18	0.485	19
19	0.349	26
20	0.389	25
21	0.348	27
22	0.707	7
23	0.674	8
24	0.619	9
25	0.450	24
26	0.507	15
27	0.472	21

3.3. Effect of Machining Parameters on Gray Relation Grade

Based on the experimental data S/N ratios are selected for multi-objective response for surface roughness and flatness error parameters. Main effects plot S/N Ratio of multi-response is given in the Fig (4). The figure indicates that the most influence factor on multi response is feed rate the highest slope, followed by depth of cut and then spindle speed and the optimal combination is $A_1B_2C_1$.Table 8 lists the ANOVA results for gray relation grade. The feed rate has the most significant influence on multi response (P_c = 26.34%) followed by depth of cut with contribution (Pc = 19.99 %).

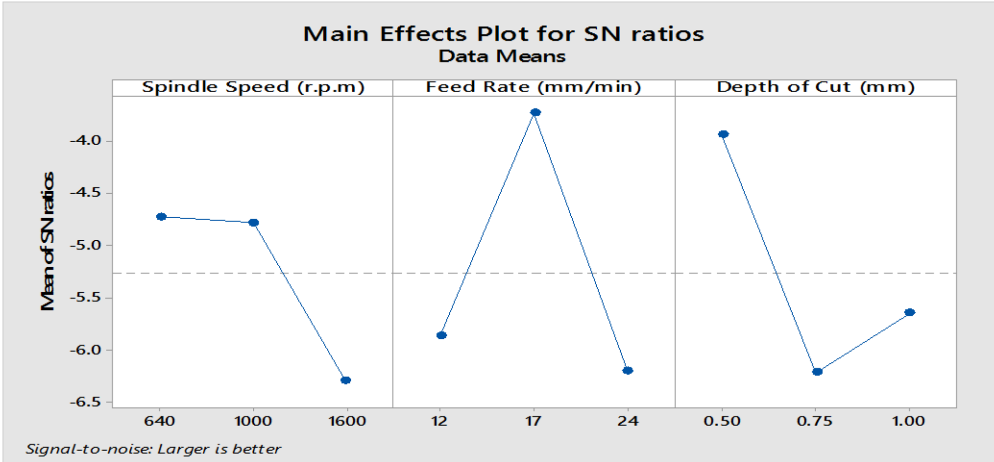


Fig.4 Main effects plot for SN ratios of gray relation grade

Table.8 ANOVA for Gray Relation Grade

Source	DF	Adj SS	Adj MS	F-Value	P-Value	contribution
Spindle Speed (r.p.m)	2	0.05161	0.025804	2.10	0.148	9.319922
Feed Rate (mm/min)	2	0.14590	0.072948	5.94	0.009	26.34715
Depth of Cut (mm)	2	0.11073	0.055363	4.51	0.024	19.99603
Lack-of-Fit	2	0.22750	0.113750	113.58	0.000	41.08278
Pure Error	18	0.01803	0.001002			3.255923
Total	26	0.55376				100%

Conclusions

In this study the optimization of cutting conditions on the multi response (surface roughness and flatness error) during dry milling machine using Taguchi method and ANOVA for gray relation grade have been presented. The following results are recommended:

(1) For maximum multi-response, the optimal parametric combination at spindle speed 640 r.p.m, feer rate 17 mm/min and depth of cut 0.50mm.

(2) The feed rate has the most significant effect on multi-objective response with 26.34% contribution followed by depth of cut 19.99 with 29.40 %.

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