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Multi Response Optimization of Face Milling Parameters Using Taguchi Method and Analysis of variance

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Abstract

This work introduces the application of Taguchi method and analysis of variance (ANOVA) method in evaluating and optimizing the machining parameters of face milling for machining aluminum silicon reinforced with hybrid multi walled carbon nano tubes (MWCNTs) and nano aluminum oxide particulates (AL_2O_3). The conventional vertical milling machine was used to carry out the experiments based on Taguchi orthogonal L27 array. The type of nanofiller (0.50hybrid and 0.50MWCNTs), spindle speed, feed rate and depth of cut were considered as machining parameters. Surface roughness, flatness error and material removal rate were selected as a process response. The effect of various machining parameters was analyzed and the optimum combination of their levels of them were determined using both S/N ratio and ANOVA. The results of this work indicated that, the optimal levels of machining parameters are determined from main effects plot for SN ratios for different responses, for MRR the optimal combination levels are A_3 $B_3C_3D_3$, for surface roughness $A_2B_3C_3D_3$ while for flatness error $A_3B_3C_3D_3$. The most significant parameter on MRR was feed rate followed by depth of cut. Hybrid nano% was the most significant parameter on surface roughness followed by depth of cut, MWCNTs nano % was the most significant parameter on flatness error followed by spindle speed.

Keywords: Face milling, Nanocomposites, Surface roughness, Flatness error, Taguchi

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 cutting parameters on surface roughness in end milling of metal matrix composite. Cutting speed and feed rate were selected as control process parameters. The surface roughness was selected as a process response. They found that the cutting speed is more significant on surface roughness. 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). They selected spindle speed, feed and depth of cut as control variables. The surface roughness was only the process response. Their results indicated that feed rate the most influence on surface roughness. The same technic also applied for similar studies [5-7]. Jaykumar et al. [8] applied Taguchi orthogonal array method and grey relation analysis (GRA) to optimize the cutting parameters in CNC end milling. Cutting feed, spindle speed and depth of cut were selected as process parameter of Ti-6Al-4V alloy. They found that depth of cut has the most significant effect on surface roughness (Ra) and material removal rate (MRR). The increase of depth of cut increases the surface roughness. Similar results were also reported in reference [9,10].

Generally composite materials are more difficult to be machine than the conventional materials because it contains a very abrasive element in addition of their non-homogeneous. How ere, the machining of these class of materials are depending on different conditions such as, percentage content and properties reinforcement elements, properties of base or matrix material and main machining factors. Therefore, the main objectives of this study to find the relationship between the input control factors and output response and to determine the optimal combination machining condition of end-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 (MWCNTs) and nano aluminum and nano aluminum oxide Al_2O_3 with 99.9% parity and 20 nm average grin size, while multi walled carbon nano tubes (MWCNTs) has 20 and 4 0 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 Al-Si/Al_2O_3 and (MWCNTs & Al_2O_3)

nanocomposites as follows: A recalculated bar of the Al-Si alloy was charged into a crucible made from graphite and heated up to 750ºC for melting. After complete melting of the Al-Si alloy, a steel mixer fixed on the mandrel of the drilling machine was inserted into the crucible and started to stir the molten alloy at stirring speed ranges from 750 to 1000 rpm. The, MWCNTs (40 nm) or hybrid (MWCNTs & Al_2O_3) heated to 400 ºC for 10 minutes, were dispersed into the vortex developed during stirring. After complete mixing, the mixer was turned off 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

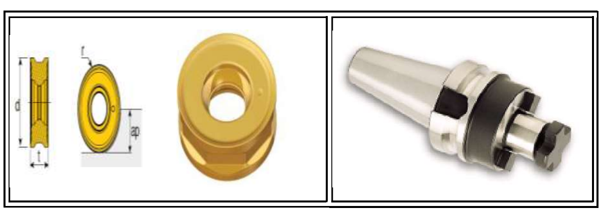
The experiments were carried out on vertical milling machine model "USM30S" and the specifications of the machine are approach angle of 45º ,table surface (35x 1150mm) and range of speed (35 – 1600 r.p.m), range of feed speed (4-240 mm/min) and range power of motor (0.75kw -1380rpm). The selection of 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.

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

The surface roughness parameter (R_a) of the workpiec after machining was measured with Surftest (Mitutoyo SJ-310) instrument shown in Figure.2, The flatness tester JENA GERMANY, L.R = 0.001 um, U= $\pm$ 0.002um shown in Figure.3.

All equipment used for measurement are traceable to gauge blocks which were calibrated by optical interferometer at KRISS traceable to SI units .

Figure.2 SJ-310 Surftest tester

Figure.3 Flatness tester

2.6 Design of exeriment using Taguchi method

The experiments have been conducting according to Taguchi L27 orthogonal array. The process parameters chosen are volume% of alumina and carbon, spindle speed, feed rate and depth of cut , the values and their levels are indicated in Table 3 . The process parameters and their levels, each experiment was repeated three times to avoid the effect of noise factors.

Table.4 The layot of Taguchi model

Run	Nano %	Spindle Speed (r.p.m)	Feed rate (mm/min)	Depth of cut(mm)	RA µm	MRR (mm^3/min)	Flatness error µm
1	0	640	12	0.50	0.915	302.6634	0.100
2	0	640	12	0.50	0.823	301.5682	0.112
3	0	640	12	0.50	0.853	301.9324	0.111
4	0	1000	17	0.75	1.100	603.8647	0.080
5	0	1000	17	0.75	1.329	605.8158	0.089
6	0	1000	17	0.75	1.075	601.9262	0.090
7	0	1600	24	1.00	1.986	1133.787	0.146
8	0	1600	24	1.00	1.786	1128.668	0.130
9	0	1600	24	1.00	1.820	1123.596	0.144
10	.050h	640	17	1.00	1.799	641.0256	0.120
11	.050h	640	17	1.00	1.574	703.2349	0.134
12	.050h	640	17	1.00	1.796	704.2254	0.133
13	0.050h	1000	24	0.50	1.719	570.7763	0.133
14	0.050h	1000	24	0.50	1.928	566.8934	0.120
15	0.050h	1000	24	0.50	1.892	568.1818	0.134
16	0.050h	1600	12	0.75	2.933	451.2635	0.168
17	0.050h	1600	12	0.75	2.693	452.3522	0.150
18	0.050h	1600	12	0.75	2.983	450.7212	0.167
19	0.50c	640	24	0.75	1.343	1090.116	0.179
20	0.50c	640	24	0.75	1.469	1086.957	0.178
21	0.50c	640	24	0.75	1.320	1080.692	0.160
22	0.50c	1000	12	1.00	1.598	663.13	0.150
23	0.50c	1000	12	1.00	1.510	661.3757	0.168
24	0.50c	1000	12	1.00	1.601	662.2517	0.167
25	0.50c	1600	17	0.50	0.725	459.5588	0.150
26	0.50c	1600	17	0.50	0.738	460.4052	0.168
27	0.50c	1600	17	0.50	0.887	457.8755	0.167

3.2. Effect of Machining Parameters on MRR

Based on the experimental data S/N ratios are selected for each response. For surface roughness and flatness parameters “Smaller the better “criterion and for material removal rate “Larger the better” criterion has been selected. S/N Ratio of MRR is given in the figure (4). The figure indicates that the most influence factor on metal removal rate (MRR) is feed rate the highest slope, followed by depth of cut and then MWCNTs (0.50c) Nano% and the optimal combination is A3B3C3D3

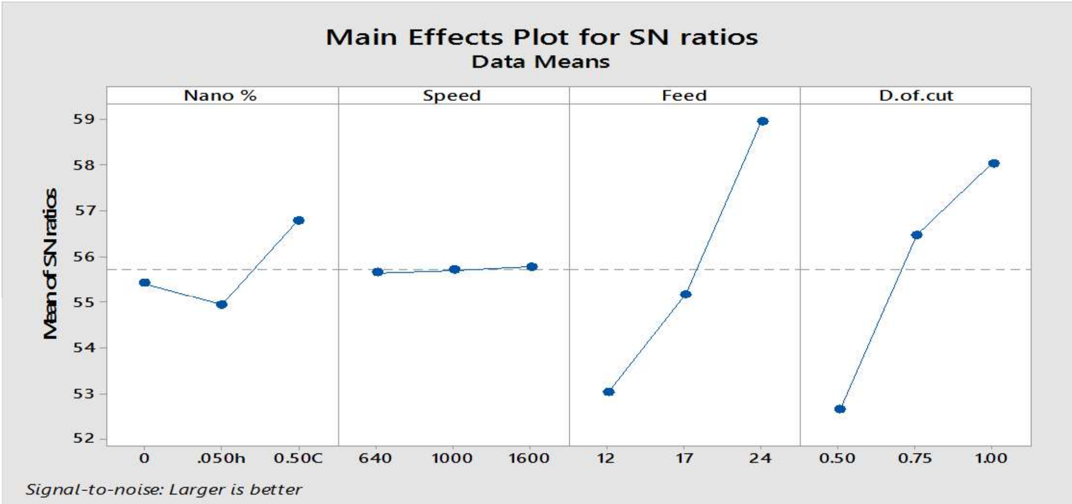


Fig.4 main effects plot for SN ratios of MRR

3.3. Effect of Machining Parameters on Surface Roughness

The main effects plot for SN ratios of surface roughness is given in the figure (5). It is clear that,
Hybrid (0.50h) Nano% the most significant on surface roughness (Ra), followed by depth of cut, followed by feed rate and spindle speed a low (smallest slope) effect factor on surface roughness and the optimal combination is A2B3C3D3

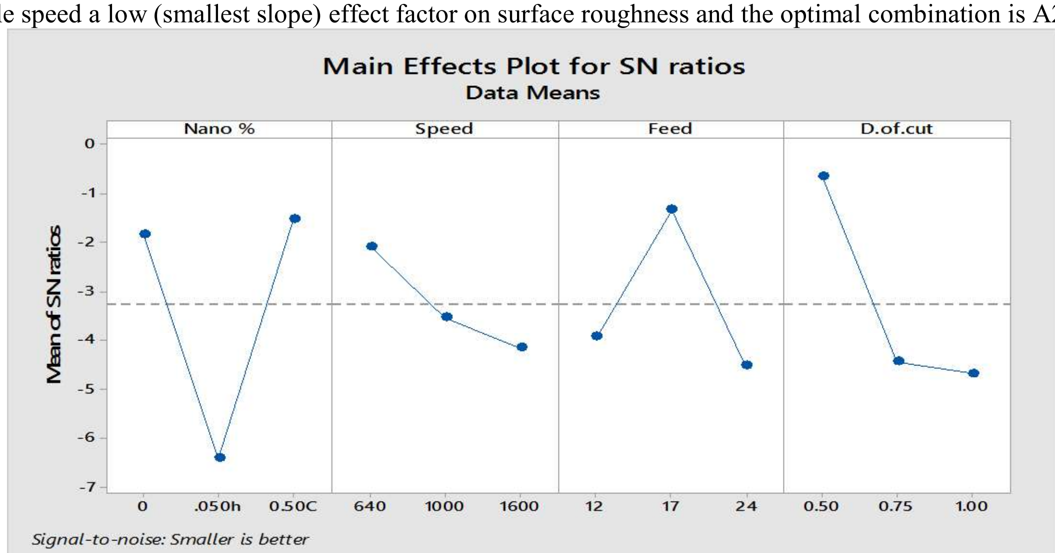


Fig.5 main effects plot for SN ratios of Ra

3.4. Effect of Machining Parameters on Flatness error:

Fig.6 showed the main effects plot for SN ratios of flatness. It is clear that the most influence factor on flatness is MWCNTs (0.50c) nano% followed by spindle speed, followed by feed rate, followed by depth of cut and the optimal combination is A3B3C3D3

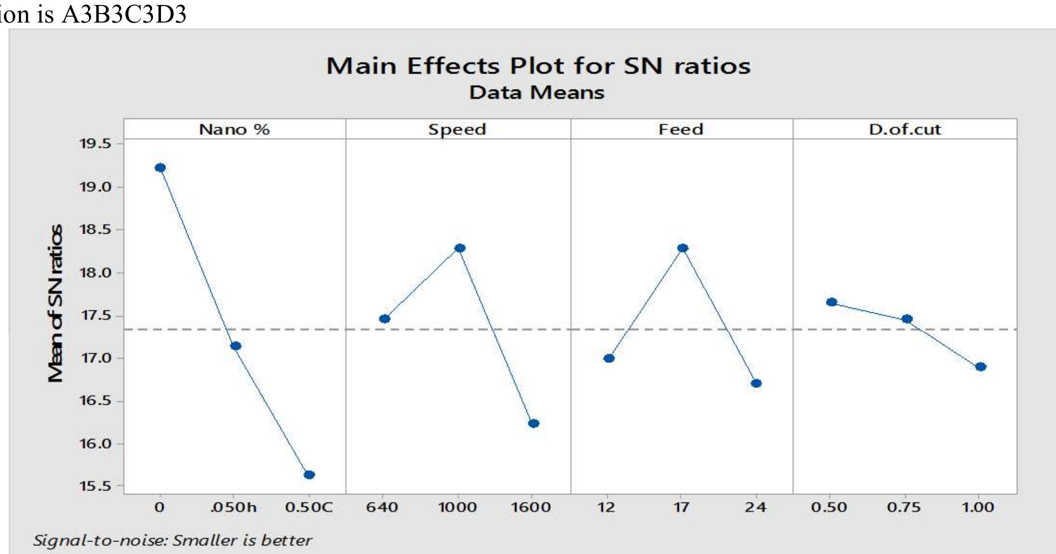


Fig.6 main effects plot for SN ratios of flatness

3.5Analysis of variance (ANOVA)

ANOVA is a statistical decision making tool, used to analyze the experimental data, for detecting any differences in the response means of the factors being tested, the purpose of analysis of variance is to determine the relative magnitude of the effect of each factor and to identify the factors significantly affecting the response under consideration. In table (5), it is obvious that, the most influence factor on metal removal rate (MRR) feed rate , followed by depth of cut. In table (6), showed that feed rate is the most significant factor on surface roughness (Ra) is hybrid nano%, followed by depth of cut, in table (7), the most influence factor on flatness MWCNTs nano % followed by spindle speed.

Table.5 ANOVA for metal removal rate model

Source	DF	Adj SS	Adj MS	F-Value	P-Value	contribution
Nano %	2	131498	65749	431.63	0.000	7.002911
Spindle Speed	2	32868	16434	107.88	0.000	1.750382
Feed Rate	2	1018299	509150	3342.44	0.000	54.2294
Depth of cut	2	692355	346178	2272.57	0.000	36.87129
Error	18	2742	152			0.146025
Total	26	1877762				100%

Table.6 ANOVA for surface roughness model

Source	DF	Adj SS	Adj MS	F-Value	P-Value	contribution
Nano %	2	4.6109	2.30546	200.22	0.000	47.13995
Spindle Speed	2	1.2222	0.61112	53.07	0.000	12.49527
Feed Rate	2	1.5655	0.78274	67.98	0.000	16.00503
Depth of cut	2	2.1754	1.08770	94.46	0.000	22.2404
Error	18	0.2073	0.01151			2.11935
Total	26	9.7813				100%

Table.7 ANOVA for flatness error

Source	DF	Adj SS	Adj MS	F-Value	P-Value	contribution
Nano %	2	0.013084	0.006542	84.84	0.000	61.67625
Spindle Speed	2	0.003810	0.001905	24.70	0.000	17.95984
Feed Rate	2	0.002387	0.001194	15.48	0.000	11.252
Depth of cut	2	0.000545	0.000273	3.54	0.051	2.569058
Error	18	0.001388	0.000077			6.542849
Total	26	0.021214				100%

Conclusions

In this study the effect of Nano% reinforced of hybrid and cutting conditions on the material removal rate, surface roughness and flatness during dry milling using Taguchi method and ANOVA have been presented. The following results are recommended:

1. The most significant parameter on MRR was feed rate with a contribution of 54.22 % followed by depth of cut with a contribution of 36.87 %.
2. The hybrid nano% was the most significant parameter on surface roughness with a contribution of 47.14 % followed by depth of cut with a contribution of 22.24 %.
3. The MWCNTs nano % was the most significant parameter on flatness error with 61.67 %, followed by spindle speed with 17.95 % contribution.
4. The optimal levels of control parameters are determined from main effects plot for SN ratios for different responses, for best MRR the optimal levels are A_3 $B_3C_3D_3$, for best surface roughness $A_2B_3C_3D_3$ and flatness error $A_3B_3C_3D_3$.
5. The optimal values corresponding to the optimal levels for best MRR are as follows;
MWCNTs nano %= 0.50c%, spindle speed= 1600 r.p.m, feed rate= 24 mm/min, depth of cut = 1.00mm
6. The optimal values corresponding to the optimal values for best surface roughness: hybrid nano %= 50h%, spindle speed= 1600 r.p.m, feed rate= 24 mm/min, depth of cut = 1.00mm And flatness error are as follows: MWCNTS nano %= 0.50c%, spindle speed= 1600 r.p.m, feed rate= 24 mm/min, depth of cut = 1.00 mm .

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