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Optimization of Cutting Parameters for Face Milling Process of Al-Si/MWCNTs Metal Matrix Nanocomposites

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Abstract: The dimensions, geometrical tolerance and surface roughness of products are a great importance of all machining process. This paper has been aimed to evaluate the cutting parameters in face milling of aluminum silicon and multi walled carbon nano tubes MWCNTs. The experiments were designed using Taguchi OR L27. The volume fraction of MWCNTs, spindle speed, feed rate and depth of cut were selected as cutting parameters. The material removal rate (MRR), surface roughness (Ra), flatness error and temperature evaluated using S/N ratio and ANOVA. The results of the study showed that; the most significant factor on MRR the feed rate with contribution of 49.29% followed by depth of cut with contribution 47.05%. Depth of cut is the most significant factor that affects the surface roughness with contribution of 41.32% followed by feed rate with contribution of 36.755 % . The MWCNTs nano% is the most significant parameter that effect the flatness error with a percentage of contribution of 61.73%.

KEYWORDS: **:** Face milling**,** Nanocomposites, Surface roughness, Flatness error, ANOVA.

1. INTRODUCTION

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

XuefengWua et al. [1] carried out experiments for prediction of surface roughness in CNC milling machine of mold steel by using machining simulation. The input parameters were cutting speed, milling parameter optimization, surface roughness were the output parameters. They found that cutting speed was the most significant input parameter on surface roughness. A respectively similar results were also reported [2,3]. NavneetKhannaa et al. [4] investigated the surface roughness monitoring in end milling using ANOVA and L 9 orthogonal array Taguchi method. The cutting parameters were cutting speed, feed rate and surface roughness was the response. They found that feed rate was the most influence parameter on surface roughness, followed by cutting speed .A some technic is used [5,6]. Milon D. Selvam et al. [7] predicted surface roughness for face milling process vertical CNC by applying Taguchi method. They selected number of passes, spindle speed, feed and depth of cut as a control variables. The surface was only the process response. Their result indicated that feed rate the most influence on surface roughness. Taguchi technique were also applied for similar studies [8,9,10,11].

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. EXPERIMENTAL WORK

2.1. Materials

An aluminum silicon (Al-Si) cast alloy with the chemical compositions listed in Table 1 was adopted as a matrix material. Multi-wall carbon nanotubes (MWCNTs) were used as a reinforcing agent. The MWCNTs have average inner and outer diameters of 20 and 40 nm, respectively. The MWCNTs were dispersed into the aluminum matrix with 0.5 % and 1% by volume.

Table 1. Chemical composition of the Al-Si alloy.

Alloy	Chemical compositions (wt%)					
	Si	Fe	Mn	Ni	Ti	Al
Al-Si	5.50	0.221	0.014	0.62	0.14	Bal.

2.2. Fabrication of the Nanocomposites

Stir casting route was used to fabricate the Al-Si/MWCNTs nanocomposites as follows: About, 1 Kg of the Al-Si alloy was charged into the crucible made from graphite and heated up to 750 ºC for melting. After complete melting of the Al 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,which was heated to 400 ºC for 10 minutes,weredispersedinto 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 mold has a rectangular shape with 300 mm (length), 100 mm (width) and 25mm (height).

2.3. Milling machine

The specifications of the machine are used carried on experiments vertical milling machine model "USM30S" an max. rotations angle of table45ºand table surface300 x 1150mm. The range of speed (35 – 1600 rpm), range of feed speed (4-240 mm/min) and range of feed motor (0.75Kw-1380rpm).

2.4 Tool Materialand its specification

Using carbide tip insert of ISO designation of "RNMU 10/12/16-ML", double-sided economical round inserts for general milling applications with max. 8 index per side (total 16 corners) when the depth of cut is limited and this is mounted on a tool holder of "BT40 SEM 22X60 ". ISO 3937 face mill arbors with BT MAS-403 form AD Taper shanks

Table 2 Tool Material Specification

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

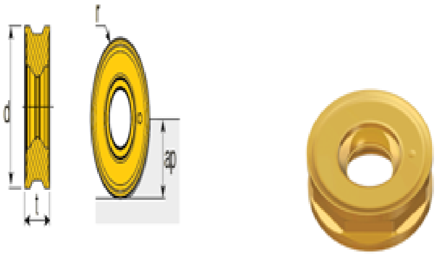

Fig 1 carbide tip insert of tool material

2.5 Measurement devices

The surface roughness parameter (R_a) of the workpiec after machining was measured with Surftest SJ-310(Mitutoyo SJ-310) instrument shown in Fige.2, while the flatness tester JENAGERMANY, L.R = 0.001 um shown in Fig.3.The uncertainty evaluation is carried out in accordance with the JCGM 100:2008.U is the expanded uncertainty using a coverage factor K = 2, providing a level of confidence of approximately 95 %.(U = $\pm$ 0.002 um)

Fig 2 SJ-310 Surftest tester

Fig 3 Flatness tester

2.6. Design of Experiment

In the present investigation, the effect of the milling process parameters, typically, the spindle speed, feed rate and depth of cut as well as the MWCNTs on the surface roughness, flatness error and material removal rate.Taguchi has suggested various orthogonal arrays (OA) for performing the experiments. The OA is selected on the basis of the total degree of freedom (DOF) of all the input parameters. So an L27 OA having 26 (= 27-1) DOF has been selected for conducting the experiments. Table3 summarizes the experimental parameters with the corresponding levels.

The surface roughness parameter (R_a) of the workpiece after machining was measured using Mitutoyo Surftest SJ-310 surface roughness tester. The flatness was measured using flatness taster JENA**.** The analysis of experimental results was carried out using analysis of variance (ANOVA) approach. The ANOVA is a very useful statistical method in understanding the effect of milling process parameters on the surface roughness, flatness error and MRR of MWCNTs. The S/N (signal-to-noise) ratio was calculated using the average values by considering the quality characteristics the larger-the-better for the MMR and the smaller-the-better for the R_a and flatness error. The ANOVA and S/N ratio calculations were calculated using Minitab 18 commercial statistical software.

Table3.Parametersand level values used for orthogonal arrays.

Parameter	Unit	Level 1	Level 2	Level 3
MWCNTs Nanoparticles(A)	%	0.00	0.25	0.50
Spindle Speed (B)	r.p.m	640	1000	1600
Feed Rate (C)	mm/min	12	17	24
Depth of cut (D)	mm	0.50	0.75	1.00

3. RESULTS AND DISCUSSION

The L_{27} experiments have been carried out according to the experiments according to design of experiment. After completing the experiments, a statistical analysis was done for the experimental data obtained which are shown in Table 4.

Table 4 layout of Taguchi

Run	MWCNTs	Spindle Speed	Feed Rate (mm/min)	Depth of cut	Ra µm	MRR (mm^3/min)	Flatness µm
1	0.00	640	12	0.50	0.915	300	0.088
2	0.00	640	12	0.50	0.823	300	0.089
3	0.00	640	12	0.50	0.853	300	0.080
4	0.00	1000	17	0.75	1.100	637.5	0.110
5	0.00	1000	17	0.75	1.329	637.5	0.100
6	0.00	1000	17	0.75	1.075	637.5	0.111
7	0.00	1600	24	1.00	1.986	1200	0.110
8	0.00	1600	24	1.00	1.786	1200	0.111
9	0.00	1600	24	1.00	1.820	1200	0.100
10	0.25	640	17	1.00	1.316	850	0.099
11	0.25	640	17	1.00	1.331	850	0.090
12	0.25	640	17	1.00	1.262	850	0.100
13	0.25	1000	24	0.50	1.444	600	0.089
14	0.25	1000	24	0.50	1.891	600	0.088
15	0.25	1000	24	0.50	1.136	600	0.080
16	0.25	1600	12	0.75	1.287	450	0.070
17	0.25	1600	12	0.75	1.274	450	0.077
18	0.25	1600	12	0.75	1.259	450	0.078
19	0.50	640	24	0.75	1.343	900	0.078
20	0.50	640	24	0.75	1.469	900	0.070
21	0.50	640	24	0.75	1.320	900	0.077
22	0.50	1000	12	1.00	1.598	600	0.078
23	0.50	1000	12	1.00	1.510	600	0.070

24	0.50	1000	12	1.00	1.601	600	0.077
25	0.50	1600	17	0.50	0.725	425	0.071
26	0.50	1600	17	0.50	0.738	425	0.064
27	0.50	1600	17	0.50	0.887	425	0.070

3.1. Effect of the cutting Parameters on Material Removal Rate

Figure 4 shows the main effects plots for S/N ratio for MRR. The main effects plot is plotted between the S/N ratio and the values of the input parameters. According to Fig. 4, the feed rate (parameter C) exhibited the most significant influence on MRR followed bydepth of cut (parameter D) has a effect on MRR. The optimal process parameter combination that yields individual maximum mean S/N ratio and thus the same for maximum MRR is $A_3B_3C_3D_3$. Table 5 lists the ANOVA results for MRR of MWCNTs . The last column in Table 4 shows the percentage contribution (P_c) of each of the parameters. The feed rate (parameter C) has the most significant influence on MRR (P_c = 49.29%) followed bydepth of cut (parameter D) was significant (P_c = 47.05%)

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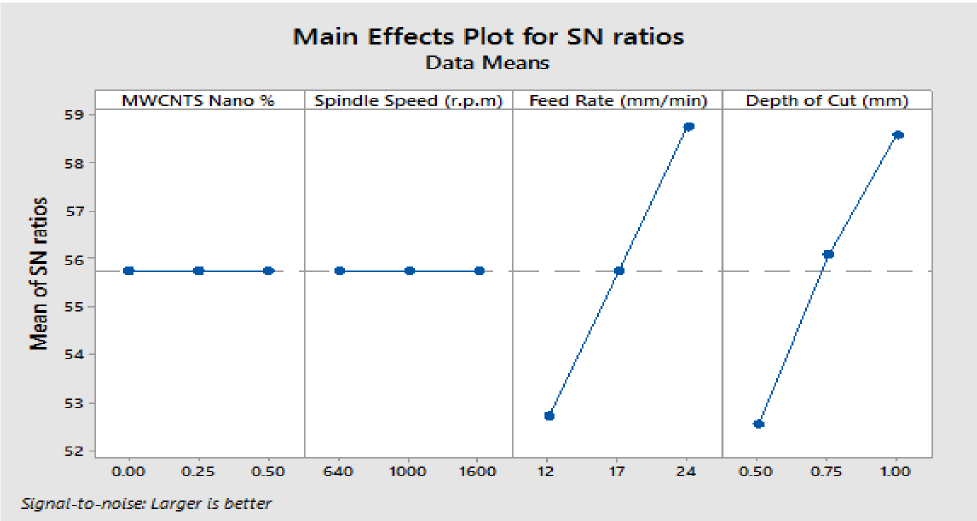

Fig 4. Main effects plot for mean S/N ratios for MRR.

Table 5. The results of ANOVA for MRR.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	contribution
MWCNTs Nano %	2	34062	17031	9647.59	0.000	1.825769
Spindle Speed (r.p.m)	2	34063	17031	2662.53	0.000	1.825822
Feed Rate (mm/min)	2	919688	459844	93419.60	0.000	49.29651
Depth of Cut (mm)	2	877813	438906	60910.54	0.000	47.05195
Error	18	0	0			0
Total	26	1865625				100%

3.2. Effect of the cutting Parameters on Surface Roughness

The main effects plots for S/N ratio for surface roughness (Ra) is shown in Fig. 5. Table 6 lists the ANOVA results for the surface roughness. The results revealed that depth of cut (parameter D)is found to be the most significant factor which affectsthe roughness while followed be feed rate(parameter C).The depth of cut and feed rate parameters showed percentage contribution (P_c) of 41.32% and 36.75%, respectively.The optimal process parameter combination that yields minimum surface roughness was found to be $A_2B_2C_3D_3$.

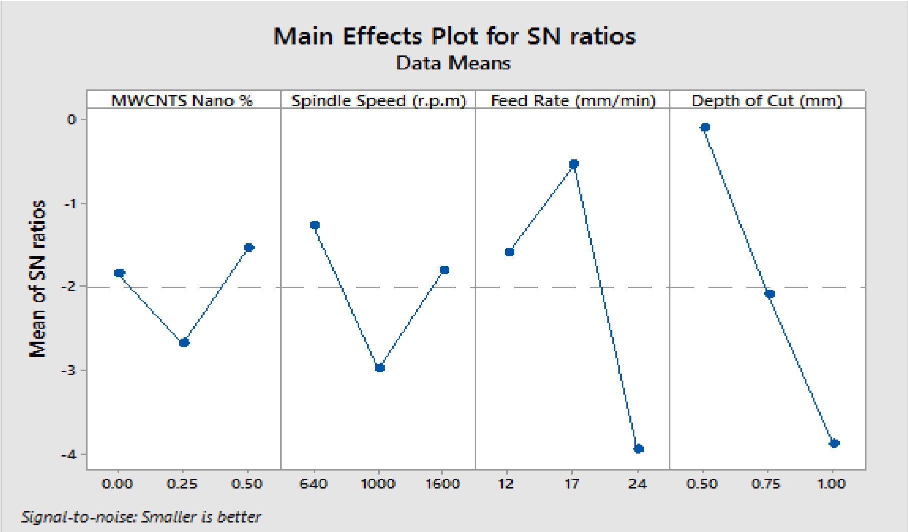

Fig 5. Main effects plot for mean S/N ratios for surface roughness (R_a).

Table 6. The results of ANOVA for R_a.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution
MWCNTs Nano%	2	0.05657	0.02828	1.30	0.297	1.814502
Spindle Speed (r.p.m)	2	0.23473	0.11736	5.39	0.015	7.529044
Feed Rate (mm/min)	2	1.14591	0.57296	26.30	0.000	36.75545
Depth of Cut (mm)	2	1.28827	0.64413	29.56	0.000	41.3217
Error	18	0.39218	0.02179			12.57931
Total	26	3.11766				100%

3.3. Effect of the cutting Parameters on Flatness Error

Figure 6 and Table 7 shows the main effects plots for S/N ratio and ANOVA results flatness, respectively. The results revealed that MWCNTs% (parameter A) showed the most significant factor (P_c = 61.73%) which affects the flatness followed by feed rate%(P_c = 15.10%). The optimal process parameter combination that yields minimum flatness is $A_1B_2C_2D_3$.

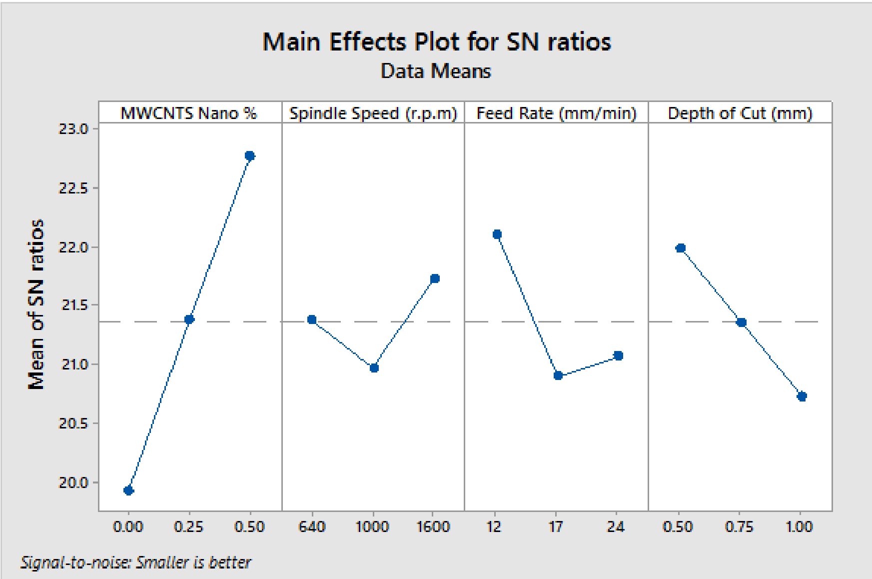

Fig 6. Main effects plot for mean S/N ratios for flatness.

Table 7. The results of ANOVA for flatness.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution
MWCNTS Nano %	2	0.003681	0.001840	85.97	0.000	61.73067
Spindle Speed (r.p.m)	2	0.000232	0.000116	5.42	0.014	3.890659
Feed Rate (mm/min)	2	0.000901	0.000451	21.05	0.000	15.10984
Depth of Cut (mm)	2	0.000763	0.000381	17.81	0.000	12.79557
Error	18	0.000385	0.000021			6.456482
Total	26	0.005963				100%

4. CONCLUSIONS

In the present investigation, conventional milling experiments were performed on carbon workpiece. The influences of carbon%, spindle speed, feed rate, and depth of cut were investigated on the machined surface roughness, flatness error and material removal rate (MRR). The influence of MWCNTs volume percentage was also studied. The analysis of variance (ANOVA) was performed based on Taguchi technique to determine the most influential parameter on the parameters of importance. Based on the results obtained, the following conclusions have been drawn:

1. The most significant factor on MRR is the feed rate with a percentage of contribution of 49.29% followed by depth of cut with 47.05%.
2. Depth of cut is the most significant factor that affects the surface roughness of MWCNTs with a percentage of contribution of 41.32 % followed by feed rate with a percentage of contribution of 36.755 % .
3. The MWCNTs nano% is the most significant parameter that effect the flatness error with a percentage of contribution of 61.73% followed by feed rate with 15.10%.
4. The optimal levels of process parameters are determined from main effects plot for S/N ratios for different responses, for material removal rate $A_3B_3C_3D_3$, for surface roughness the optimal levels are $A_2B_2C_3D_3$, flatness error $A_1B_2C_2D_3$.

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