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Surface Roughness, Flatness Error and Material Removal Rate Optimization in End Milling Operation Using Taguchi Method

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ABSTRACT

Taguchi design of experiments and analysis of variance (ANOVA) are introduced to investigate the effect of the end milling parameters on surface quality. Spindle speed, feed rate, number of flutes of end mill are selected as the control parameters. An aluminum silicon (Al-Si) alloy reinforced with different volume fraction of MWCNTs was used as a workpiece material. The machining responses were surface roughness, flatness error and material removal rate of the machined workpieces. An orthogonal array L27 of the Taguchi technique and S/N ration were selected to investigate and analyze the effect of the different control parameters on the process responses. The results of the study indicated that feed rate is the most significant factor on MRR, followed by number of flutes. Feed rate is the most significant factor on surface roughness followed by spindle speed. Number of flutes is the most significant factor on flatness error followed by spindle speed. The optimal levels of control parameters are determined from main effects plot for SN ratios for different responses, for maximum MRR (277.1363 mm^3/min) at the optimal levels are A_3 $B_2C_1D_3$, for minimum surface roughness (0.492um) at level $A_2B_2C_3D_1$and minimum flatness error (0.064 um) at $A_3B_3C_2D_1$.

Keywords: End milling**,** Nanocomposites, Surface roughness, Flatness error- Design of experiments

1. INTRODUCTION

Surface quality influences the performance of the machined components and the total manufacturing costs. This is due to their effect on lubricant, friction and geometric tolerance. The main factors that influence surface quality are type of cutting tool, workpiece material properties and cutting conditions. In milling operation, for example, the surface roughness depends on spindle speed, feed rate, depth of cut in addition tool materials and its number of cutting edges. Therefore, it is important for the researchers to model and quantify the relationship between surface roughness, and the control variables affecting on its value.

Kumar et al. [1] was investigated the modeling and optimization of face milling parameters on Al-6061 Alloy by using multi- objective genetic algorithm . It has been found that feed rate was the most influence parameter on material removal rate, followed by depth of cut and the spindle speed most influence on surface roughness. The same technique was used on different materials and the same results were observed [2-4]. Singh et al. [5] studied the effect of machining parameters on surface roughness and material removal rate in milling of Ti-6Al-4V Alloy material by using Taguchi method and gray relation analysis GRA . Spindle speed, feed rate and depth of cut were selected as control process parameters. They found that spindle speed was the most significant parameter on surface roughness, material removal rate and depth of cut followed by feed rate. Similar techniques were applied on Al-Cu-Zn alloy matrix composites in CNC and face milling results were also reported [6,7]. Abd El-Rahman et al. [8] applied Artificial neural networks (ANNS)of implementation of neural network for monitoring and prediction of surface roughness in a virtual end milling process of a CNC vertical milling. The workpiece tested is 60/40 Brass. They found that spindle speed was most significant parameters on material removal rate (MRR), followed by depth of cut. The effects of cutting tool geometry and processing parameters on the surface roughness of brass by using ANN. ANN technique was also applied for similar studies [9-11].

Thus, the determination of the relationship between control variables on surface quality for end milling process is an open field of investigation. Therefore, the aim of the work presented is to evaluate the machinability of Al-Si/ MWCNTs in end milling operation.

2. EXPERIMENTAL PROCEDURES

2.1. Materials

In this work an aluminum silicon (Al-Si) alloy was selected as a base material with the chemical compositions listed in Table 1. The MWCNTs has an average diameter of 20-40 nm and purity of 99.8% was used as a reinforcement material.

Table 1. Chemical compositions 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 MWCNTs Nanocomposites

The MWCNTs reinforced Al-Si nanocomposite was fabricated by stir casting route. The shape of the workpiece was rectangular shape. The final dimension of the workpiece was 300x100x24mm. In order to produce Al-Si/ MWCNTs , the base alloy(Al-Si) was melted in a crucible at 750 ^{o}C in electric furnace. Then the MWCNTs was added gradually in the crucible according to the required volume fraction and stirred continuously for 10 minutes. A steel stirrer used that has three blades and fixed on a drilling machine with a variable speed controller. The nanocomposite was poured carefully on to a steel mold. The mold has a rectangular shape with 300 mm (length), 100 mm (width) and 25mm (height). The MWCNTs particles were preheated before adding them to the molten Al-Si to 400 ^{o}C. Also, the mold was preheated before the molten mixture was pureed on to it to avoid the common defects raised in such cases.

2.3 Milling machine

The specifications of the (USM30S) vertical milling machine are used to carry out experiments. Max rotations angle of table 45^{o} and table surface 300 x 1150mm. The range of speed (35 – 1600 rpm), range of feed speed (4-240 mm/min) and range of feed motor power (0.75Kw-1380rpm).

2.4 Tool Martial

The selection of the end mill material was chosen according to WIDIN manufacturing catalog. Coated carbide tip of aluminum titanium nitride (AlTiN) material of ISO designation of ZE504160, ZE502160 and ZE506160 shown in Fig.1. The designed to machine tool steel, alloy steel, mold steel and other high hardened materials that very good abrasion resistance for wear and hardness at higher milling temperatures than other high speed steels and deep flutes for chip evacuation and 30^{o} of left hand helix, left hand cut. The cutting diameter of tolerance is +0.003/-0.000 and the tool dimension show in Table 2

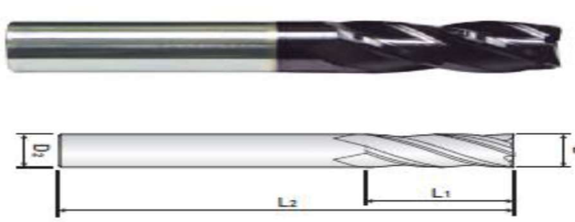

Fig 1 End mill tool of 4 flutes

Table.2 The specification of cutting tool

ISO catalog number	Tip	Series	Dimension (mm)			
			D	L1	L2	D2
ZE504160	coated carbide	ZE504	16	40	90	16

2.5 Measurement devices

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

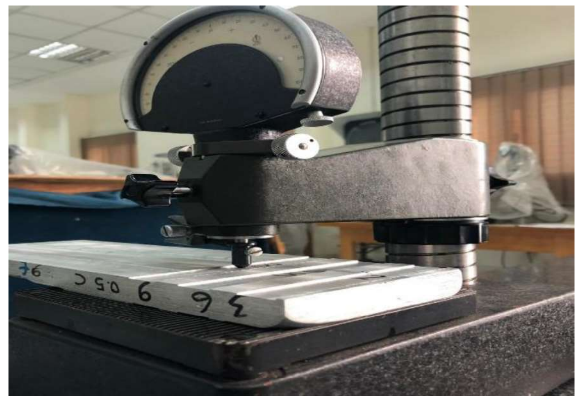

Fig 2 Flatness tester JENA

Fig 3 The surface roughness tester

2.6. Design of Experiments

In the present study, the effect of the milling process parameters, typically, the spindle speed, feed rate and depth of cut as well as the volume fraction of MWCNTs on the surface roughness, flatness and MRR was evaluated. Taguchi has been 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. Table 3 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 tester 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. The ANOVA and S/N ratio calculations were calculated using Minitab 18 commercial statistical software.

Table3. Parameters, codes, and level values used for orthogonal arra.

Parameter	Unit	Level 1	Level 2	Level 3
Number Flutes (A)	-	2	4	6
MWCNTs nanoparticles fraction volume (B)	Vol %	0.0	0.25	0.50
Spindle Speed (C)	r.p.m	260	640	1000
Feed Rate (D)	mm/min	12	17	24

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 design

Run	Number Flutes	MWCNTs Volume	Spindle Speed (r.p.m)	Feed Rate (mm/min)	Ra um	MRR (mm^3/min)	Flatness error µm
1	2	0.0	260	12	1.281	144.2308	0.080
2	2	0.0	260	12	0.825	144.4043	0.084
3	2	0.0	260	12	0.716	144.0576	0.086
4	2	0.25	640	17	1.541	217.3913	0.100
5	2	0.25	640	17	1.868	218.1818	0.105
6	2	0.25	640	17	2.148	217.7858	0.108
7	2	0.50	1000	24	3.704	236.2205	0.100
8	2	0.50	1000	24	3.686	237.1542	0.105
9	2	0.50	1000	24	3.232	235.7564	0.108
10	4	0.0	640	24	3.989	267.2606	0.090
11	4	0.0	640	24	3.601	269.0583	0.095
12	4	0.0	640	24	4.143	267.8571	0.097
13	4	0.25	1000	12	0.492	149.4396	0.080
14	4	0.25	1000	12	0.522	149.8127	0.085
15	4	0.25	1000	12	0.716	149.0683	0.086
16	4	0.50	260	17	1.926	195.4397	0.070
17	4	0.50	260	17	1.921	195.7586	0.074
18	4	0.50	260	17	1.873	196.3993	0.075
19	6	0.0	1000	17	0.856	192.3077	0.070
20	6	0.0	1000	17	0.847	192.926	0.073
21	6	0.0	1000	17	0.954	193.2367	0.075

22	6	0.25	260	24	4.199	277.1363	0.071
23	6	0.25	260	24	4.889	275.2294	0.073
24	6	0.25	260	24	4.505	275.8621	0.075
25	6	0.50	640	12	0.792	144.9275	0.064
26	6	0.50	640	12	0.541	144.5783	0.067
27	6	0.50	640	12	0.643	144.4043	0.069

3.1. Effect of The Control 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. If the line for a parameter is near horizontal, it indicates that the parameter has no significant effect in the selected range of values. The plot indicates also that the parameter for which the line has the highest inclination will have the most significant effect. According to Fig. 4, the feed rate (parameter D) exhibited the most significant influence on MRR while the Nano % (parameter B) has a negligible effect on MRR. The optimal process parameter combination that yields individual maximum mean S/N ratio and thus the same for maximum MRR is A2B2C2D3. Table 5 lists the ANOVA results for MMR. The last column in Table 2 shows the percentage contribution (P_c) of each of the parameters. As shown earlier form the main effect plots, the same trend can be observed for the various parameters, i.e., the feed rate (parameter D) has the most significant influence on MRR (P_c = 93.88%) while parameter B (Nano-%) was not significant (P_c = 0.2422%) within the specific experimental range.

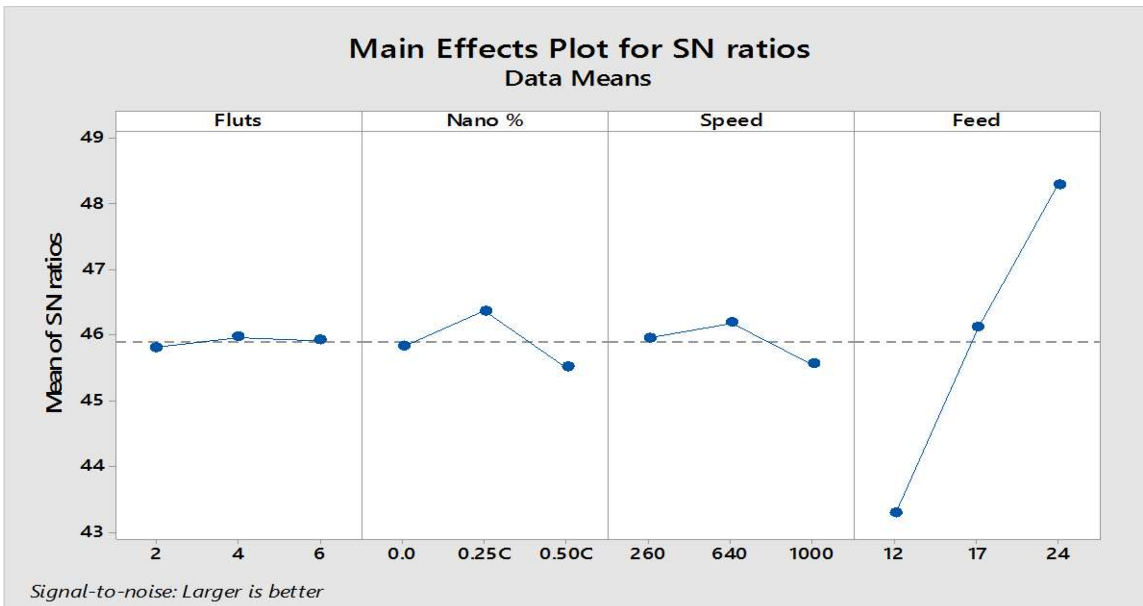

Figure 4. Main effects plot for mean S/N ratios for MRR.

Table 5. The results of ANOVA for MRR.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contrubition
No Flutes	2	2222.5	1111.3	3178.15	0.000	3.563355
Nano %	2	151.1	75.6	216.13	0.000	0.24226
Spindle Speed	2	1433.6	716.8	2050.06	0.000	2.298504
Feed Rate	2	58557.4	29278.7	83735.88	0.000	93.88562
Error	18	6.3	0.3			0.010101
Total	26	62371.0				100%

3.2. Effect of The Control 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 parameter D (feed rate) is found to be the most significant factor which affects the roughness while parameter C (spindle speed) has the minimum effect on the roughness of MWCNTs .The feed rate and the spindle speed parameters showed percentage contribution (P_c) of 91.75% and 5.03%, respectively. The nano%(parameter B) exhibited higher significance on the roughness than the MWCNTs. The optimal process parameter combination that yields minimum surface roughness was found to be A1B2C1D3.

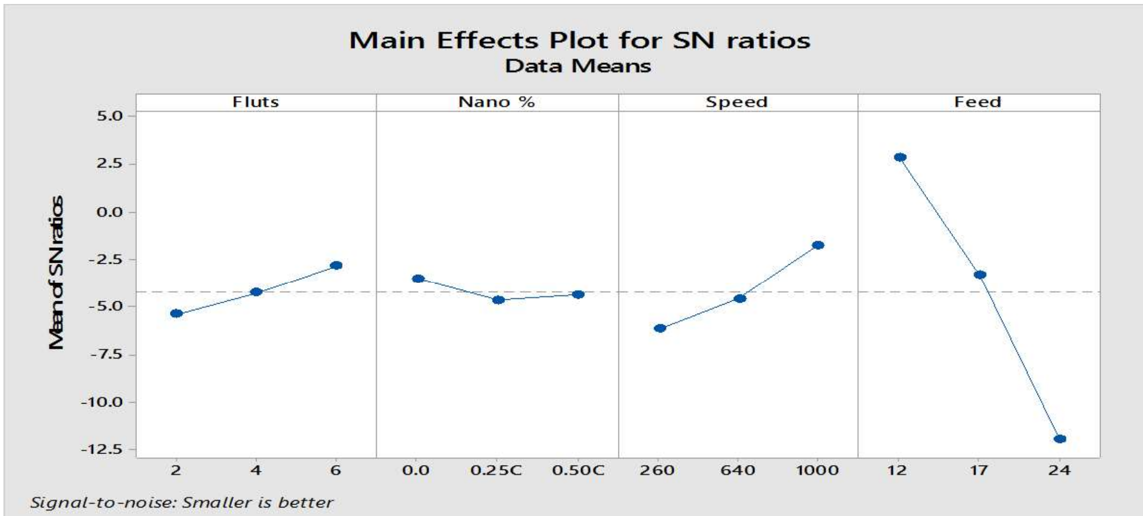

Figure 5. Main effects plot for mean S/N ratios for surface roughness (R_a).

Table 6. The results of ANOVA for R_a.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contrubition
Nano %	2	0.7867	0.3934	7.28	0.005	1.387219
No Flutes	2	0.0574	0.0287	0.53	0.597	0.101216
Spindle Speed	2	2.8568	1.4284	26.43	0.000	5.037506
Feed Rate	2	52.0371	26.0185	481.52	0.000	91.75904
Error	18	0.9726	0.0540			1.715023
Total	26	56.7106				100%

3.3. Effect of The Control Parameters on Flatness error

Figure 6 and Table 7shows the main effects plot for S/N ratio and ANOVA results flatness, respectively. The results revealed that number of flutes (parameter A) showed the most significant factor (P_c = 64.007%) which affects the flatness followed by the spindle speed (P_c = 15.036%), followed by feed rate with 14.29%.

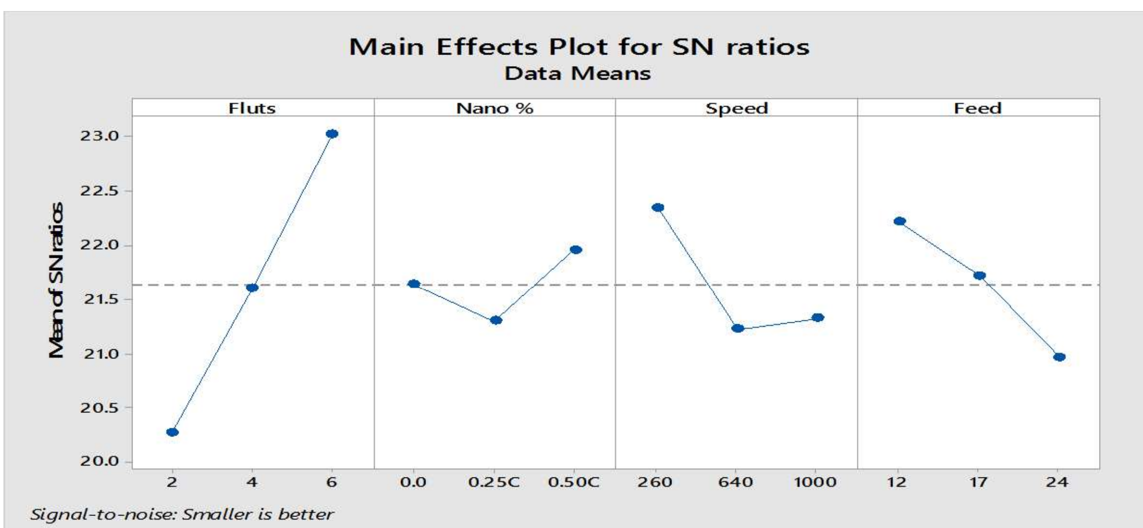

Figure 6. Main effects plot for mean S/N ratios for flatness error.

Table 7. The results of ANOVA for flatness error.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contrubition
Nano %	2	0.000150	0.000075	7.33	0.005	2.9994
Flutes	2	0.003201	0.001601	156.58	0.000	64.0072
Spindle Speed	2	0.000752	0.000376	36.76	0.000	15.03699
Feed Rate	2	0.000715	0.000357	34.96	0.000	14.29714
Error	18	0.000184	0.000010			3.679264
Total	26	0.005001				100%

4. CONCLUSIONS

In the present investigation, conventional milling experiments were performed on Al-Si/MWCNTs workpiece. The influences of number of flutes, 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 93.88%.
2. Feed rate is the most significant factor that affects the surface roughness of MWCNTs with a percentage of contribution of 91.75 %.
3. The number of flutes in end mill is the most significant parameter that affect the flatness error with a percentage of contribution of 64.007%, followed by spindle speed with contribution 15.036% and feed rate 14.29714 %.

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