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Optimization of the Machining Parameters for Surface Roughness and Flatness of Aluminum Silicon Alloy reinforced by Aluminum Oxide Nano Particulates in End Milling Using Taguchi and ANOVA Approaches.

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Abstract. In this paper, Taguchi method has been used to identify the optimal combination of influential factors in the end milling process. The experiments have been performed on aluminum silicon (Al-Si) alloy reinforced by aluminum oxide nanoparticles. A Taguchi orthogonal array L27 was selected for various combinations of different controllable factors (number of flutes of end mill, volume fraction of nanoparticles, spindle speed and feed rate). The process responses, i.e. surface roughness, material removal rate(MRR) and flatness error are measured and recorded for each experiment. The results are analyzed by Taguchi S/N ratio and then the optimal combination of controllable factors and their contributions are identified. The results showed that, minimum surface roughness(Ra= 0.736um) was obtained at optimal parametric combination is $A_2B_2C_3D_1$, for maximum (MRR= 291.97080mm^3/min), optimal levels are A_3 $B_2C_1D_3$while minimum flatness error(0.080µm) was obtained at level $A_2B_3C_2D_3$.The result from ANOVA showed that feed rate was the most significant parameter on surface roughness. Feed rate was the most significant parameter on MRR followed by volume fraction of nanoparticles. The most significant parameter on flatness error was number of flutes followed by volume fraction of Al_2O_3 nanoparticles.

average Nusselt number and Fanning friction factor are presented. The results showed that the conica

Keywords: End milling- Nanocomposites- Surface roughness- Flatness error- ANOVA

1. INTRODUCTION

Roughness and flatness of flat surfaces are considered a good predictor for performance of mechanical components. Since irregularities and flatness error in the surface may form nucleation site for cracks. Therfore decreasing surface roughness and flatness error will usually have interested important objectives for machining studies.

Harun etal. [1] applied Taguchi method and ANOVA to analyze and optimize the cutting parameters in CNC end milling. Cutting speed and feed rate were selected as a control process parameter. The surface roughness was selected as a process response. They found that the feed rate is more significant on surface roughness. Taguchi and ANOVA technique were also applied for similar studies [2,3,4]. Jignech . [5] predicted surface roughness for end milling process by applying ANN. They selected spindle speed, feed rate and depth of cut as control variables. The surface was only the process response. Their result indicated that depth of cut has most influence on surface roughness. Seref [6] used ANN for prediction surface roughness in machining cast mide material in CNC end milling. They found that the feed rate has more effect on surface roughness than other considered parameters. Kumbhar.et al. [7] applied Taguchi orthogonal array method and gray relation analysis (GRA) in their experiments. Cutting feed, spindle speed and depth of cut were selected as process parameters in CNC end milling of Stainless Steel 304. 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.Sakthivelu et al. [8] studied the multi–objective optimization of machining conditions on surface roughness and MRR during CNC end milling of aluminum by using Taguchi design of experiments. They found that cutting feed, spindle speed and depth of cut influence on surface roughness and material removal rate. Similar results were reported in reference [9-11].

2. Experimental Work

2.1 Workpiece Material

In this work, the Al-Si cast alloy was selected as base material with the chemical composition shown in Table 1. An aluminum oxide (Alumina, Al_2O_3)with an average diameter of 20 nm and purity of 99.8% was used as a reinforcement.

Table.1 The chemical composition of the Al-Si alloy (wt %)

Al	Si	Mn	Ni	Fe	Ti
93.2	5.50	0.014	0.62	0.221	0.14

2.2. Fabrication of Al-Si/Al_2O_3Nanocomposites

An Al-Si/Al_2O_3 nanocomposites were fabricated using stir casting route. The aluminum alloy was put into crucible and heated and melted 750°C in electric of furnace. Preheating of Al_2O_3nanoparticles was carried out at 400°C for ten minutes. A steel stirrer with three blades was used for stirring the melt mechanically. The stirrer was inserted into the crucible and started to stir the molten alloy. The nanoparticles were added gradually to the molten alloy during the stirring process. The stirring process was continued for 10 minutes for proper mixing of Nanoparticles in the matrix alloy. The metal matrix nanocomposites were kept in the crucible for 30 second, and then, the melt was poured into a preheated rectangular mold with dimensions of 30cm (length), 10 cm (width) and 2.5 cm (height). The surface of specimens was prepared using milling machine to the final work piece dimensions.

2.3 Tool Material and Machine Specifications

Designed for highly hardened materials up to HRc 55 theta very good abrasion resistance for wear and hardness at high cutting temperatures than other suitable high speed steels. Coated carbide tip of aluminum titanium nitride (AlTiN) material of ISO designation of ZE506160, ZE504160 and ZE502160shown in Fig.1and the cutting diameter tolerance is +.003/-0.00 and50° left hand helix, left hand cut and the dimensions of tool show in Table 2.The selection of the tool material end mill was chosen according to the manufacturing catalog of WIDIN company catalogue considering workpiece material and the recommended other cutting parameters.

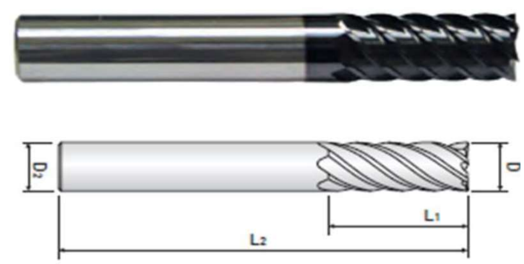

Fig 1 End mill tool for 6 flutes

Table.2 The specification of cutting tool

ISO catalog number	Tip	Series	Dimension (mm)			
			D	L1	L2	D2
ZE506160	coated carbid	ZE506	16	40	90	16

The experiments were carried out on vertical milling machine model "USM30S".The machine has specificationsof:range of speed (35 – 1600 r.p.m), range of feed speed (4-240 mm/min), range of power (0.75kw -1380rpm) and max. rotations angle of table45°ontable surface300 x 1150mm.

2.4 Measurement devices

The surface roughness parameter (R_a) of the workpiece after machining was measured with Surftest (MitutoyoSJ-310) instrument shown in Figure.2,The JENAGERMANYflatness testeris shown in figure.3.

Fig 2 The surface roughness tester

Fig 3 Flatness tester

3.Design of experiments

Design of experiments (DOE) based Taguchi method can be used for reducing the number of experiments. 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. The L27 OA has been selected for conducting the experiments for this work.In the presented work, the milling process parameters and their levels are indicated in Table 3.

Table 3. The milling process parameters levels

Parameter	Unit	Level 1	Level 2	Level 3
Number of Flutes (A)	-	2	4	6
Al2O3 nanoparticles (B)	Volume%	0.0	0.25	0.50
Spindle speed (C)	r.p.m	260	640	1000
Feed rate (D)	(mm/min)	12	17	24

4. Results and discussion

A statistical analysis was carried out for the experimental results obtained which are shown in Table 4 from the L_{27} experiments. By using minitab-17software, the average performance and S/N ratio were calculated for various responses. Analysis of variance (ANOVA) was performed to identify the most significant control parameter and to quantify their effects on the different responses.

Table 4. Central Composite Rotatable Design Different Controlling Parameters and Results

Run	No Flutes	Al_2O_3 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	2.213	144.5783	0.100
2	2	0.0	260	12	2.834	14.4023	0.109
3	2	0.0	260	12	1.711	144.4043	0.111
4	2	0.25	640	17	2.412	196.3993	0.089
5	2	0.25	640	17	2.523	195.4397	0.080
6	2	0.25	640	17	2.235	196.0784	0.087
7	2	0.50	1000	24	3.275	236.2205	0.130
8	2	0.50	1000	24	2.953	237.6238	0.144
9	2	0.50	1000	24	3.869	236.6864	0.142
10	4	0.0	640	24	2.905	273.9726	0.133
11	4	0.0	640	24	2.630	275.8621	0.131
12	4	0.0	640	24	3.721	273.3485	0.120

13	4	0.25	1000	12	1.088	161.7251	0.120
14	4	0.25	1000	12	0.736	161.9433	0.133
15	4	0.25	1000	12	0.806	161.2903	0.131
16	4	0.50	260	17	2.453	147.9655	0.150
17	4	0.50	260	17	2.883	147.4201	0.164
18	4	0.50	260	17	2.734	147.7833	0.167
19	6	0.0	1000	17	2.075	190.1743	0.178
20	6	0.0	1000	17	2.226	189.8734	0.174
21	6	0.0	1000	17	2.465	190.4762	0.160
22	6	0.25	260	24	3.340	290.5569	0.167
23	6	0.25	260	24	3.187	291.9708	0.150
24	6	0.25	260	24	3.178	289.8551	0.164
25	6	0.50	640	12	1.487	144.7527	0.150
26	6	0.50	640	12	1.311	144.2308	0.164
27	6	0.50	640	12	1.269	144.4043	0.167

4.1. Effect of MachiningParameters on Surface Roughness

From Fig (4), for minimum surface roughness the optimal parametric combination is $A_1B_1C_1D_3$. Table (5) shows that the feed rate is the most significant factor on surface roughness followed by spindle speed, flutes and volume fraction of nanoparticlesrespectively. From ANOVA Table (6) it is clear that, feed rate is the most significant factor on surface roughness with 71.608% contribution, followed by spindle speed with 8.35% and finally by number offlutes with 5.679%.

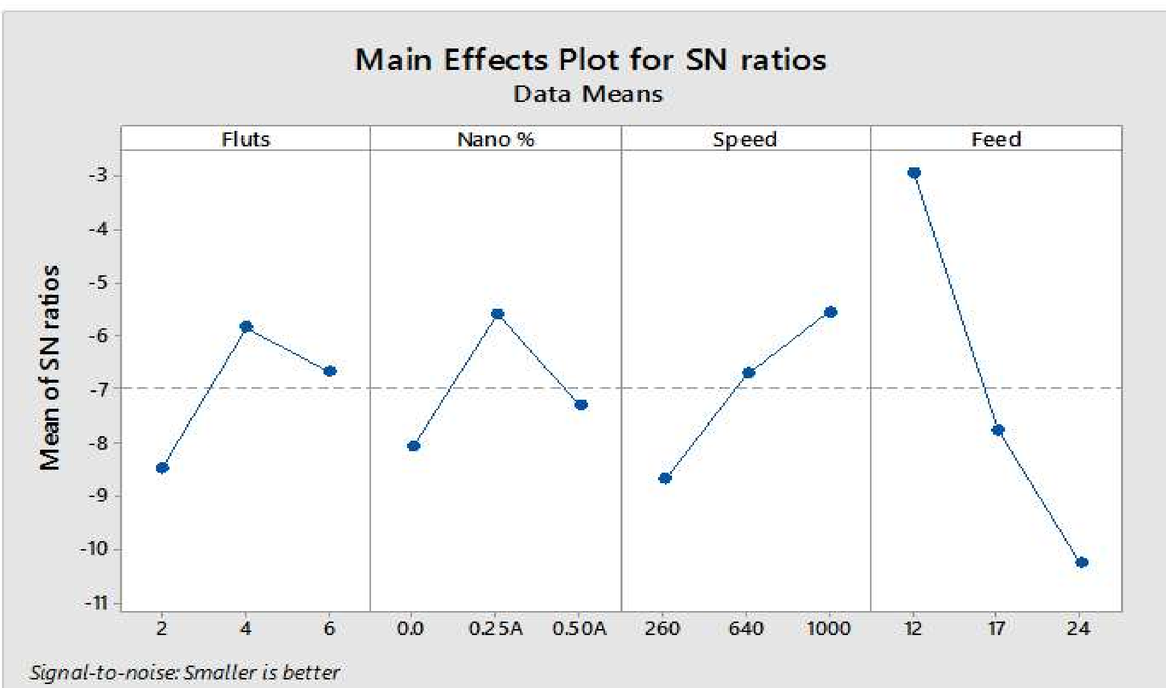

Fig.4 Main effects plot for SN ratios for Ra

Table 5. Response Table for Signal to Noise Ratios for Ra(Smaller is better)

Level	no Flutes	Nano %	Spindle Speed	Feed Rate
1	-8.469	-8.067	-8.682	-2.960
2	-5.828	-5.588	-6.709	-7.760
3	-6.650	-7.291	-5.556	-10.226
Delta	2.641	2.479	3.126	7.266
Rank	3	4	2	1

Table6. ANOVA for Ra model

Source	DF	Adj SS	Adj MS	F-Value	P-Value	**Contribution %**
No Flutes	2	1.0761	0.5380	4.76	0.022	5.6799
Nano %	2	0.6841	0.3421	3.02	0.074	3.61
SpindleSpeed	2	1.5823	0.7912	6.99	0.006	8.351
Feed Rate	2	13.5668	6.7834	59.96	0.000	71.608
Error	18	2.0364	0.1131			10.748
Total	26	18.9457				100 %

4.2. Effect of The Machining Parameters on Material Removal Rate

The maximum MRR the optimal parametric combination is $A_3B_2C_2D_3$show in fig (5). Table (7) shows the signal to noise ratios for MRR, it is clear that feed rate is the most significant factor on material removal rate followed by volume fraction of nanoparticles, respectively. From ANOVA Table (8), it is clear that feed rate has the highest contribution percentage on metal removal rate with a contribution of 75.845% followed by volume fraction of nanoparticleswith 6.98% and finally number of flutes with 3.9153%.

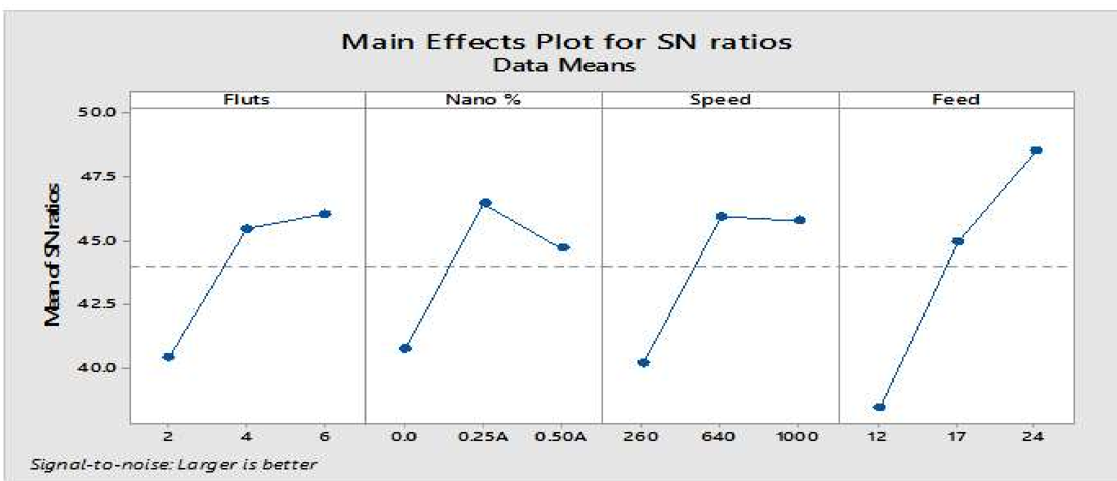

Fig.5 Main effects plot for SN ratios for MRR

Table 7. Response Table for Signal to Noise Ratios for MRRLarger is better

Level	No Flutes	Nano %	SpindleSpeed	Feed Rate
1	178.0	188.6	179.9	135.7
2	194.6	216.1	204.9	178.0
3	208.5	176.3	196.2	267.3
Delta	30.5	39.8	25.1	131.6
Rank	3	2	4	1

Table8. ANOVA for Material Removal Rate Model

Source	DF	Adj SS	Adj MS	F-Value	P-Value	**Contribution %**
No Flutes	2	4196	2098.0	3.34	0.058	3.916079
Nano %	2	7481	3740.3	5.96	0.010	6.981932
Spindle Speed	2	2913	1456.7	2.32	0.127	2.71867
Feed Rate	2	81268	40633.8	64.78	0.000	75.84649
Error	18	11290	627.2			10.53683
Total	26	107148				100%

4.3. Effect of the Machining Parameters on Flatness error

Table (9) showed that the number of flutes is the most significant factor on flatness followed by volume fraction of Al_2O_3 nanoparticles, spindle speed, feed rate and from fig (6) for minimum flatness error the optimal parametric combination is $A_3B_3C_3D_3$. From ANOVA Table (10), it is obvious that, the highest contribution percent on flatness is the number of flutes with a contribution of 62.59% followed by volume fraction of Al_2O_3 nanoparticleswith 18.17%.

Table 9. Response Table for Signal to Noise Ratios for Flatness error(Smaller is better).

Level	No Flutes	Nano %	Spindle Speed	Feed Rate
1	22.06	20.28	19.82	20.47
2	19.94	21.11	21.11	20.28
3	18.46	19.06	19.52	19.71
Delta	3.60	2.05	1.59	0.76
Rank	1	2	3	4

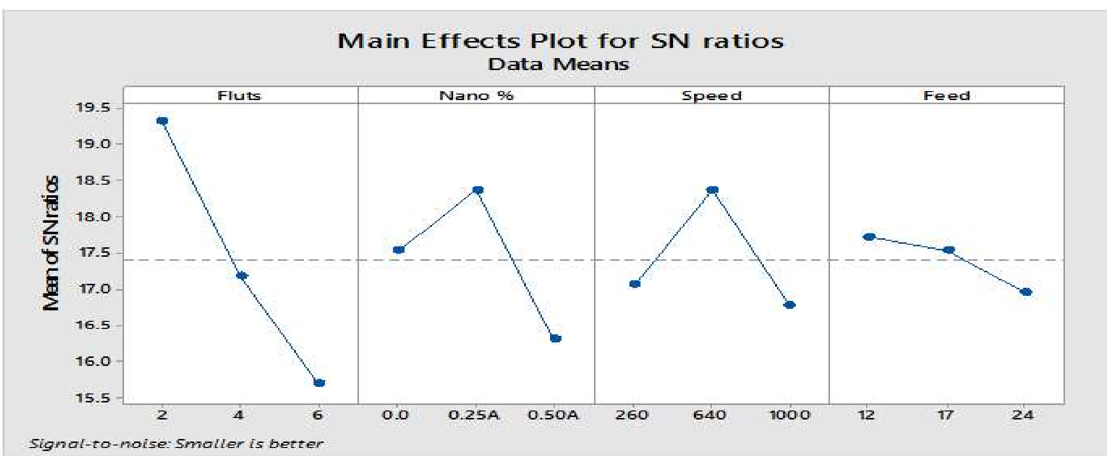

Fig .6. Main effects plot for SN ratios for flatness error

Table10. ANOVA for flatness Model

Source	DF	Adj SS	Adj MS	F-Value	P-Value	**Contribution %**
No Flutes	2	0.012926	0.006463	106.08	0.000	62.59261
Nano %	2	0.003753	0.001876	30.80	0.000	18.17345
Spindle Speed	2	0.002345	0.001172	19.24	0.000	11.35538
Feed Rate	2	0.000531	0.000265	4.36	0.029	2.571304
Error	18	0.001097	0.000061			5.312091
Total	26	0.020651				100%

5. CONCLUSION

On the basis of the experimental results during machining ofAl/Al $_2O_3$nanocomposites, the following conclusions are drawn:

(1) The feed rate has a most significant effect on surface roughness with 71.608 % contribution followed by spindle speed with 8.35 %.
(2) The feed rate has a most significant effect on material removal rate with 75.845% contribution followed by volume fraction of nanoparticles with 6.98 and number of flutes3.9153%.
(3) The number of flutes has a most significant effect on flatness error with 62.95 % contribution followed by volume fraction of Al_2O_3 nanoparticleswith 18.17 %.
(4) For surface roughness, the optimal parametric combination is $A_1B_1C_1D_3$, formaterial removal rate is at the parametric combination is $A_3B_2C_2D_3$ and finally for flatness error, the optimal parametric combination is $A_3B_3C_3D_3$.

References

[1] Harun Yaka, Halil Demir, Arif Gök, optimization of the cutting parameters affecting the surface roughness on free form surface for Al 7075-T6 in CNC End milling. Sigma J Eng & Nat Sci vol. 35 (2),pp. 323-331, 2017.

[2] João Ribeiro, Hernâni Lopes, Luis Queijo, Daniel Figueiredo, Optimization of Cutting Parameters to Minimize the Surface Roughness in the CNC End Milling Process Using the Taguchi Method. Periodica Polytechnica Mechanical Engineering, vol. 61(1),pp. 30-35, 2017.

[3] Shadab Anwar, Saleem Uz Zaman Khan, Optimization of End Milling Parameters for Improving Surface Roughness Using Taguchi Method. International Journal of Mechanical And Production Engineering, ISSN: 2320-2092, vol. 4, pp. 6-9, 2016.

[4] D. BAJI , design of experiment's application in the optimization of face milling process, of steel 52-3. METALURGIJA vol. 49, pp. 123-126, 2010.

[5] Chi-Hsiang Chen, Yung Cheng Wang, Bean Yin Lee. The Effect of Surface Roughness of End-Mills on Optimal Cutting Performance for High-Speed Machining cutting. Journal of Mechanical Engineering vol. 59, pp 124-134, 2013.

[6] Murat Sarýkaya, Hakan Dilipak, Akýn Gezgin, optimization of the process parameters for surface roughness and tool life of AISI D3 steel in face milling using the Taguchi analysis. Materials and technology vol. 49, pp. 139–147, 2015.

[7] Abhishek Kumbhar, Rohit Bhosale, Amit Modi, Shalaka Jadhav, Suresh Nipanikar, Aditya Kulkarni. Multi-objective Optimization of Machining Parameters in CNC End Milling of Stainless Steel 304,using KYOCERA; carbide insert LOMU 150508 ER-GH cutting tool. International Journal of Innovative Research in Science, Engineering and Technology Vol. 4, pp. 8419-8426, Issue 9. 2015.

[8] S. Sakthivelu T. Anandaraj M. Selwin, Multi–Objective Optimization of Machining Conditions on Surface Roughness and MRR during CNC End Milling of Aluminium Alloy 7075 using High Speed Steel (HSS) cutting tool Using Taguchi Design of Experiments. Mechanics and Mechanical Engineering Vol. 21, pp. 95–103, 2017.

[9] G.Guruvaiah Naidu, A.Venkata Vishnu, G.Janardhana Raju, Optimization Of Process Parameters For Surface Roughness In VERTICAL CNC Milling Of En-31 Steel Material Using Taguchi Robust Design Methodology. International Journal of Mechanical and Production Engineering, ISSN: 2320-2092, vol. 2, pp. 15-21, Issue-9.2014.

[10] Mahendra M S, B Sibin , Optimization of End Milling Parameters for Minimum Surface Roughness Using Taguchi Method. Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, pp. 01-05, 2016.

[11] Pooja A. Sutar , Study the effect of machining parameters on surface roughness in CNC End Milling of AISI 316L. International Journal of Engineering Research and Technology. ISSN 0974-3154, vol. 10, pp.801-804 ,2017.