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Mach Inability OF Al-Si/MWCNTs Metal Matrix Nano Composites During Turning Operation

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Abstract. Multi-wall carbon nano-tubes (MWCNTs) have attracted great attention because their excellent mechanical properties. The aim of this investigation is to investigate the machinability of aluminum silicon alloys reinforced with various volume percentages of MWCNTs.The stir casting route was used to fabricate work piece materials reinforced with 0.5% and 1% vol.-% of MWCNTs. The effect of machining parameters, typically, the cutting speed, feed rate and depth of cut on the surface quality of Al-Si/MWCNTs metal matrix nanocomposites(MMNCs) was evaluated. The machinability of the Al-Si/MWCNTs nanocomposites was evaluated using the surface roughness (Ra), roundness error and metal removal rate (MRR). The analysis of variance (ANOVA) was carried out based on Taguchi L27 orthogonal array design of experiments techniqueto determine the most influential parameter on the aforementioned parameters. The ANOVA results showed that feed rate was the most significant parameter on surface roughness followed by cutting speed. The MWCNTsvol.-% was found to be the most significant parameter that affecting the roundness error followed by feed rate. While the most significant parameter on MRR was the cutting speed followed by feed rate.

Keywords : Machining, Turning, Analysis of Variance (ANOVA), Taguchi Method, Nanocomposites, Surface roughness, Roundness error.

1. INTRODUCTION

Traditional machining operations such as lathe turning, milling and drilling normally lead to the alterations of the machined surface. In order to avoid the undesirable alterations that may adversely affect the quality of the machined work piece, it is essential to optimize the cutting parameters and tool geometry that lead to high-quality machined components. Turning is the machining operation that produces cylindrical parts. The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material, the type and geometry of the cutting tool, and environmental conditions have a large influence on surface quality of the machined components [1,2].

Recently, the usage of metal-matrix nanocomposites (MMNCs) has increased in various areas of industry, especially, aerospace and automotive industries, due to their special mechanical and physical properties. MMNCs, particularly aluminum-based composites have a high strength-to-weight ratio, high stiffness, lower thermal expansion coefficient, high thermal conductivity as well as corrosion and wear resistances [3-5]. Due to the potential applications MMNCs, there exists a great need to understand the difficulties related to the machining of the secomposites. Machining of MMNCs is a relatively complex task owing to it is heterogeneity and to the fact that reinforcements are extremely abrasive and responsible for complex deformation behavior, high tool wear and poorer surface finish [6-8].

The present investigation studies the machinability of Al-Si/MWCNTs MMNCs during conventional turning operation. Several aluminum-based nanocomposites containing 0.5 and 1 vol.-% of MWCNTs were fabricated using stir casting technique. The controlled parameters being consider in this investigation are cutting speed, feed rate, depth of cut as well as the volume percentages (vol.-%) of MWCNTs. The machinability of the Al-Si/MWCNTs nanocomposites was evaluated using the surface roughness (Ra), roundness error and metal removal rate (MRR).Taguchi design of experiments methodology has been employed to determine the influence of the turning process parameters on the aforementioned machinability parameters. The optimum turning parameter combination was obtained using the analysis of signal-to-noise (S/N) ratio with machineability parameters as the response variable. The level of importance of the parameter son the machineability parameters determined by analysis of variance (ANOVA) statistical approach.

2 EXPERIMENTAL PROCEDURES

2.1. Materials

An 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 30 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 ,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 mould. The steel mould has a cylindrical shape cavity with 40 mm diameter and 220 mm height.

2.3. Turning Process

CNMG 120408-HA (ISO designation) uncoated carbide tip inserts were used to machine the fabricated Al-Si/MWCNTs nanocomposites (see Fig. 1).Table 2 lists the specifications of the carbide inserts. The carbide inserts were mounted on a tool holder of MCLNR2525M12 giving an approach angle of 95º. The selection of the insert tip was chosen according to KORLOY manufacturing catalog according to work piece material, the range of speed (290 – 2133 mm/sec), range of feed (up to 0.40 mm/rev), range of depth of cut (up to 3.50 mm) according to tool material. The cutting experiments were carried out using a conventional center lathe machine shown in Fig. 2.

2.4. Design of Experiments

In the present investigation, the effect of the turning process parameters, typically, the cutting speed, feed rate and depth of cut as well as the MWCNTs vol.-%, on the surface roughness, roundness error and MRR of Al-Si/MWCNTs nanocomposites were investigated.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 roundness error (RE) was measured using Taylor-Hobson talyrond 73 roundness tester. 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 turning process parameters on the surface roughness, roundness error and MRR of Al-Si/MWCNTs nanocomposites. 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 RE. The ANOVA and S/N ratio calculations were calculated using MiniTab commercial statistical software.

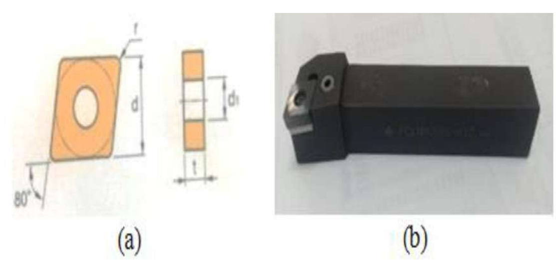

Fig 1. (a) the CNMG 120408-HA carbide inserts; (b) a carbide insert mounted on a tool holder of MCLNR2525M12.

Table 2. The CNMG 120408-HA carbide inserts specification.

ISO catalog number	Tip	Grade	Dimension (mm)			
			d	t	Re	d1
CNMG 120408-HA	Uncoated carbide	H01	12.70	4.76	0.8	5.16

Fig 2. The turnining process curried out on Al-Si/MWCNTs nanocomposites.

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

Parameter	Unit	Level 1	Level 2	Level 3
MWCNTs % (A)	**Vol.-%**	0	0.5	1
Cutting speed (B)	**mm/sec**	895	1253	1790
Feed rate (C)	**mm/rev**	0.09	0.12	0.16
Depth of cut (D)	mm	0.25	0.50	0.75

3.RESULTS AND DISCUSSION

3.1. Effect of the Parameters on Material Removal Rate

Figure 3 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. 3, the cutting speed (parameter B) exhibited the most significant influence on MRR while the MWCNTs vol.-% (parameter A) 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 A3B3C3D2. Table 4 lists the ANOVA results for MMR of Al-Si/MWCNTs nanocomposites. The last column in Table 4 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 parameter B (Cutting speed) has the most significant influence on MRR (P_c = 55.51%) while parameter A (MWCNTs vol.-%) was not significant (P_c = 5.19%) within the specific experimental range. The parameters C (feed rate) and D (depth of cut) exhibited lower significant influence (each P_c = 19.65%) on MRR when compared with the parameter B (Cutting speed).

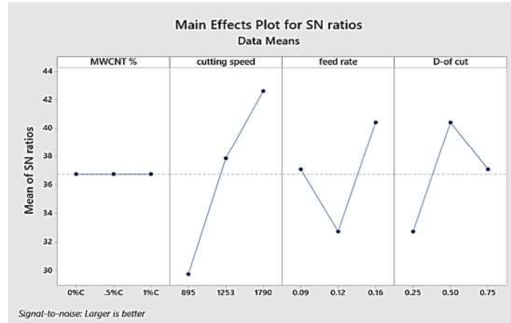

Fig 3. Main effects plot for mean S/N ratios for MRR.

Table 4. The results of ANOVA for MRR.

Source	DF	Adj SS	Adj MS	F-Val	P-Val	Contr. (P_c)%
MWCNTs vol.-%	**2**	**6697**	**3348.6**	**-**	**-**	**5.19 %**
Cutting speed	**2**	**71579**	**35789.5**	**-**	**-**	**55.51 %**
Feed rate	**2**	**25335**	**12667.4**	**-**	**-**	**19.65 %**
Depth of cut	**2**	**25335**	**12667.4**	**-**	**-**	**19.65 %**
Error	**18**	**0**	**0.0**			**0 %**
Total	**26**	**128946**				**100 %**

3.2. Effect of the Parameters on Surface Roughness

The main effects plots for S/N ratio for surface roughness (Ra) is shown in Fig. 4. Table 5 lists the ANOVA results for the surface roughness. The results revealed that parameter C (feed rate) is found to be the most significant factor which affectsthe roughness while parameter D (depth of cut)
has the minimum effect on the roughness of Al-Si/MWCNTs nanocomposites. The feed rate and the depth of cut parameters showed percentage contribution (P_c) of 57.76% and 1.49%, respectively. The cutting speed (parameter B) exhibited higher significance on the roughness than the MWCNTs vol.-% (parameter A). The cutting speed and the MWCNTs vol.-% parameters showed percentage contribution (P_c) of 18.25% and 15.21%, respectively. The optimal process parameter combination that yields minimum surface roughness was found to be A2B1C3D2.

Fig 4. Main effects plot for mean S/N ratios for surface roughness (R_a).

Table 5. The results of ANOVA for R_a.

Source	DF	Adj SS	Adj MS	F-Val	P-Val	Contr. (P_c)%
MWCNTs vol.-%	2	3.9883	1.9941	18.78	0.00	15.21 %
Cutting speed	2	4.7876	2.3938	22.55	0.00	18.25 %
Feed rate	2	15.1442	7.5721	71.33	0.00	57.76 %
Depth of cut	2	0.3906	0.1953	1.84	0.188	1.49 %
Error	18	1.9108	0.1062			7.29 %
Total	26	26.2214				100 %

3.3. Effect of the Parameters on Roundness Error

Figure 5 and Table 6 shows the main effects plots for S/N ratio and ANOVA results for roundness error, respectively. The results revealed that MWCNTs vol.-% (parameter A) showed the most significant factor (P_c = 50.96%) which affects the roundness followed by the feed rate (P_c = 27.53%). The depth of cut show no influence on the roundness error. It showed a percentage contribution (P_c) of about 0.79%. The optimal process parameter combination that yields minimum roundness error is A2B1C3D2.

Fig 5. Main effects plot for mean S/N ratios for roundness error.

Table 6. The results of ANOVA for roundness error.

Source	DF	Adj SS	Adj MS	F-Val	P-Val	Contr. (P_c)%
MWCNTs vol.-%	2	417.137	208.568	80.20	0.00	50.96 %
Cutting speed	2	122.666	61.333	23.58	0.00	14.99 %
Feed rate	2	225.265	112.632	43.31	0.00	27.53 %
Depth of cut	2	6.521	3.261	1.25	0.309	0.79 %
Error	18	46.811	2.601			5.73 %
Total	26	818.401				100 %

CONCLUSIONS

In the present investigation, conventional turning experiments were performed on Al-Si/MWCNTs nanocompositesworkpiece. The influences of cutting speed, feed rate, and depth of cut were investigated on the machined surface roughness, error of roundness 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 followingconclusions have been drawn:

1. The most significant factor on MRR is the cutting speed with a percentage of contribution of55.51% followed by depth of cut and feed rate with an equal percentage of contribution of 19.65 %. The MWCNTs vol.-% has no influence on MRR.
2. Feed rate is the most significant factor that affectsthe surface roughness of Al-Si/MWCNTs nanocompositeswith a percentage of contribution of 57.76 % followed by cutting speedand MWCNTs vol.-% with a percentage of contribution of 18.25 % and 15.1%, respectively.

   The volume fraction of MWCNTs dispersed into the Al-Si alloy is the most significant parameter that affect the roundness error with a percentage of contribution of 50.96%. The feed rate and cutting speed showed percentages of contribution of 27.53% and 14.99%, respectively.

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