ENGINEERING RESEARCH JOURNAL (ERJ)

Vol. 1, No. 41 July. 2019, pp. 26-30

Journal Homepage: www.feng.bu.edu.eg

Machinability of EPOXY/MWCNTs NANOCOMPOSITES during Turning Operation

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Abstract. The machinability of the epoxy resin reinforced with multi-wall carbon nanotubes (MWCNTs) was evaluated during turning. The experiments were designed and performed using Taguchi design of experiment approach. The independent factors were the volume fraction of the MWCNTs, the cutting speed, feed rate and the depth-of-cut. The dependent (machining characteristics) factors were the surface roughness of the machined surface, the roundness error and the material removal rate (MRR). The results revealed that volume fraction of MWCNTs has slight influence on the MRR, surface roughness and roundness error of epoxy/MWCNTs nanocomposites. The cutting speed has the most significant influence on the MRR of epoxy/MWCNTs nanocomposites. While the feed rate is the most influential factor on both surface roughness and the roundness error of epoxy/MWCNTs nanocomposites.

Keywords: Machining, Turning, Epoxy, Design of Experiments, Nanocomposites, Surface roughness, Material Removal Rate, Roundness error.

1. INTRODUCTION

Polymer-reinforced nanocomposites are new class of advanced engineering materials. Such materials exhibit high specific strength (strength-to-weight ratio) and specific stiffness (stiffness-to-weight ratio). These high specific strength and stiffness of nanocomposites make them also attractive for both military and civilian aircraft components [1]. For example, common components, in military aircrafts, include wing skins and substructures, rudders, flaps, rotors and blades.

Epoxy resins is widely used as a matrix material for nanocomposites owing to their excellent mechanical properties, low cost, ease of processing, and good chemical resistance to corrosion [2]. Nanofibers, nanotubes, particulates, and whiskers. have been used as fillers in epoxy for improving the mechanical performance of the materials. Several investigations were reported on the mechanical and tribological characteristics of epoxy matrix reinforced with nanoparticles or tubes such as Al_2O_3, carbon nanotubes (CNTs), multiwall carbon nanotubes (MWCNTs), SiC …etc [2-4]. The results show that nanocomposites have better mechanical and tribological characteristics when compared with the neat epoxy matrix.

Unfortunately, very few investigations were reported on the machinability of polymeric matrix composites (PMCs) [1,5,6]. Machining of PMCS can be conducted using conventional or nonconventional material removal techniques [7]. The conventional techniques include turning, milling, drilling, and grinding processes. While the nonconventional machining techniques include abrasive waterjet and laser beam cutting processes. Generally, the machinability of the nanocomposites is greatly affected bythe physical properties and volume fraction of their constituents (i.e. the reinforcements and the matrix). For instance, the tool wear is greatly influenced by the type and volume fraction of the nano-reinforcement [1]. Also, the quality of machined surfaces (i.e. the geometric features and surface roughness) can be affected by the aforementioned parameters as well as the machining conditions [8].

The present investigation studies the machinability during turning for epoxy/MWCNTs nanocomposites. The influence the MWCNTs volume fraction as well as the machining parameters, typically, the cutting speed, depth of cut and the feed rate on the machining characteristics, typically, the surface roughness, roundness error and material removal rate (MMR)were evaluated.

2. EXPERIMENTAL PROCEDURES

2.1. Materials

In the present investigation, the KEMAEPOXY-150 epoxy resin made by Chemicals for Modern Buildings (CMB) Company, Egypt, was used as a matrix material. Multi-walled carbon nanotubes (MWCNTs) was used as a reinforcement. The MWCNTs were dispersed by 0.5% and 1% (vol.-%) in the epoxy resin. Figure 1 shows high resolution transmission electron microscope(TEM) micrograph and energy dissipative x-ray (EDX) analysis for MWCNTs, respectively.

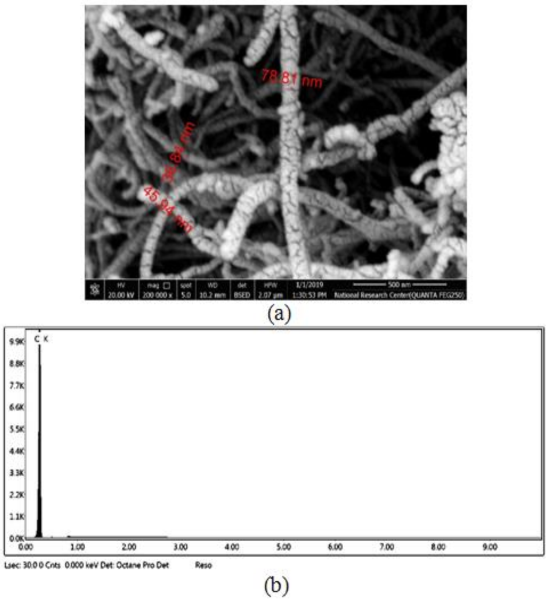

Fig 1. (a) High magnification SEM micrograph; (b) EDX analysis for MWCNTs.

2.2. Manufacturing of the epoxy/MWCNTs Nanocomposites

The epoxy/MWCNTs nanocomposites were fabricated mechanical stirring technique as follows: first, the epoxy resin and a specified volume fraction of the MWCNTs were mixed together in mold made of plastic. After that the mixture was mechanically stirred at 200 rev/min for about 10 minutes. When the mixing process is completed, the hardener was added to the mixture by ratio 1:2 by volume and then the mixture was again stirred mechanically for 3 minutes. Finally, the epoxy/MWCNTs mixture was poured in a plastic mold having a cylindrical shape with 50 mm diameter and 150 mm length and allowed to fully harden at room temperature.

2.3. Turning Process of Epoxy/MWCNTs Nanocomposites

In the present investigation, coated cutting tool were used for turning the epoxy/MWCNTs nanocomposites. The turning process was carried out usingCNMG 120408-VM (KORLOY Inc. Code System) rhombic coated carbide inserts (see Fig. 2a). Table 2 shows the dimensions and specifications of the carbide inserts. The inserts were mounted on a tool holder of MCLNR2525M12 giving an approach angle of 95°. The turning process was carried out using the center lathe shown in Fig. 3. The selection of the insert was chosen according to KORLOY manufacturing catalog according to workpiece material [9].

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

ISO catalog number	Tip	Dimension (mm)		
		d	t	d1
CNMG 120408-VM	Coated carbide	12.70	4.76	5.16

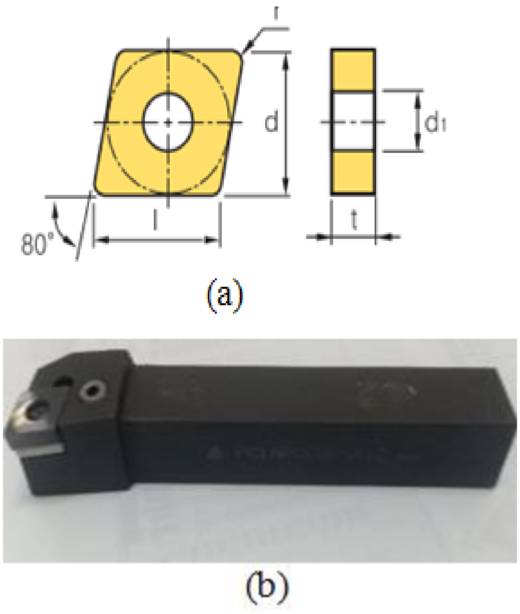

Fig 2. (a) the NC5330 carbide insert;
(b) the carbide inserts mounted
on a tool holder of MCLNR2525M12.

Fig 3. The turnining process curried out on epoxy/MWCNTs nanocomposites.

2.4. Design of Experiments

The influences of the machining factors during turning, viz, the cutting speed, feed rate and depth-of-cut, and the volume fraction of MWCNTs, on the machining characteristics of epoxy/MWCNTs nanocomposites, viz, material removal rate (MRR), surface roughness (Ra) and roundness error (Er) of epoxy/MWCNTs were investigated. The experiments were designed using Taguchi method. A L9 orthogonal array(OA)was selected for conducting the experiments. Table3 summarizes the investigated factors with the corresponding levels.

Table 3. The factors and their levels.

Parameter	Unit	Level 1	Level 2	Level 3
MWCNTs % (A)	Vol.-%	0	0.5	1
Cuttingspeed (B)	rev/min	142	410	712
Feed rate (C)	mm/rev	0.096	0.12	0.168
Depth of cut (D)	mm	0.5	1	1.5

The S/N (signal-to-noise) ratio was calculated using the mean values by considering the quality characteristics of the following: the larger-the-better for the MMR and the smaller-the-better for the surface roughness and roundness error.

2.5. Surface Roughness and Roundness Error Measurements

The Ra surface roughness parameter was measured using Mitutoyo Surftest SJ-310 surface roughness tester. The roundness error (Er) was measured using Taylor-Hobson talyrond 73 roundness tester.

3. RESULTS AND DISCUSSION

3.1. Effect on Material Removal Rate (MMR)

Figure 4 shows the main effects plot for the averages of MRR of the epoxy/MWCNTs nanocomposites. The results showed that increasing the MWCNTs volume fraction reduces the MRR of epoxy/MWCNTs nanocomposites. While increasing the cutting speed, feed rate and the depth-of-cut increased the MRR of the epoxy/MWCNTs nanocomposites.

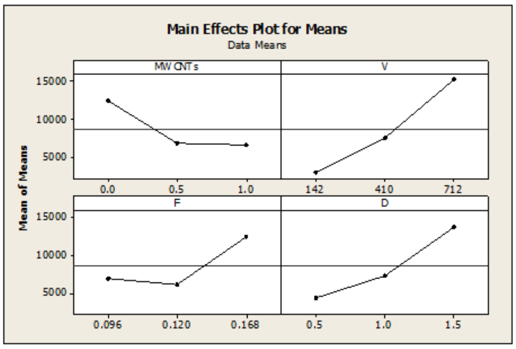

Fig (4). Main effects plots for averages MRR of epoxy/MWCNTs nanocomposites.

The response table by the factor level for the S/N ratios of MRR of epoxy/MWCNTs nanocomposites and the corresponding response graph are shown in Table 2 and Fig. 5, respectively. The results revealed that cutting speed has the most significant influence on the MRR of epoxy/MWCNTs nanocomposites. The depth-of-cut has lower influence on MRR than the cutting speed. The feed rate exhibited lower influence on MRR of epoxy/MWCNTs nanocomposites when compared with the cutting speed and the depth-of-cut. The MWCNTs volume fraction has no influence on the MRR of epoxy/MWCNTs nanocomposites. The maximum MRR can be obtained when the cutting speed is 712 rev/min (level 3), feed rate is 0.168 mm/rev (level 3) and depth-of-cut is 1.5 mm (level 3).

Table 2. Effect Response Table for S/N ratios of MRR for epoxy/MWCNTs nanocomposites

Level	MWCNTs (Vol.%)	Cutting speed (V)	Feed rate (F)	Depth-of-Cut (D)
1	12321	2943	7024	4395
2	6717	7467	6148	7400
3	6574	15203	12441	13817
Delta	5747	12260	6293	9423
Rank	4	1	3	2

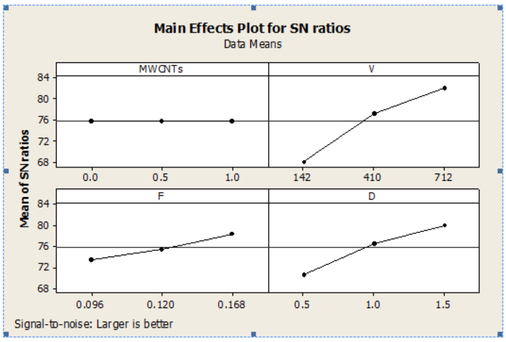

Fig (5). Main effects for S/N ratios of MRR of epoxy/MWCNTs nanocomposites.

3.2. Effect on Surface Roughness (Ra)

Figures 6 and 7 show the main effects plots for means and S/N rations of the surface roughness of epoxy/MWCNTs nanocomposites, respectively. Effect response for S/N ratios of Ra of epoxy/MWCNTs nanocomposites are listed in Table 3. The results showed that both of the MWCNTs volume fraction and the depth-of-cut have no practical influence on the surface roughness of the machined epoxy/MWCNTs nanocomposite surfaces. The feed rate and the cutting speed are the most influential factors on the surface roughness of epoxy/MWCNTs nanocomposites, respectively. The minimum surface roughness of the epoxy/MWCNTs nanocomposites was obtained when the feed rate and the cutting speed are 0.168 mm/rev (level 3) and 142 rev/min (level 1), respectively. It has been found that increasing the feed rate reduces the surface roughness of epoxy/MWCNTs nanocomposite specimens. In contrast, increasing the cutting speed increases the surface roughness of the epoxy/MWCNTs nanocomposites.

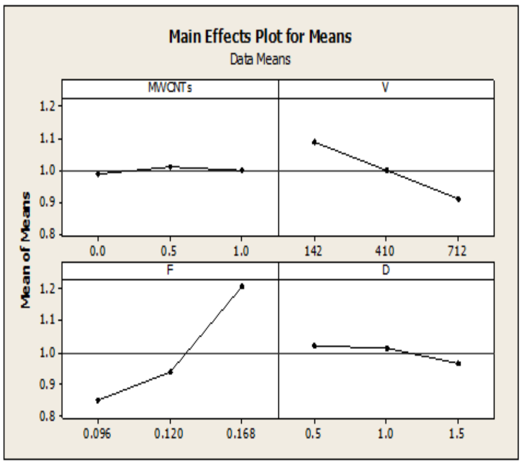

Fig (6). Main effects plots for averages Ra of epoxy/MWCNTs nanocomposites.

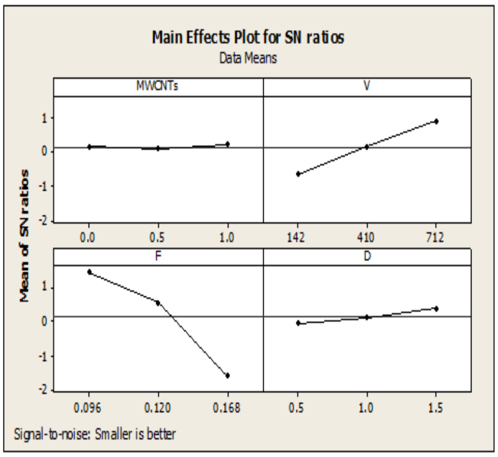

Fig (7). Main effects for S/N ratios of Ra of epoxy/MWCNTs nanocomposites.

Table 3. Effect Response Table for S/N ratios of Ra for epoxy/MWCNTs nanocomposites.

Level	MWCNTs (Vol.%)	Cutting speed (V)	Feed rate (F)	Depth-of-Cut (D)
1	0.9863	1.0890	0.8500	1.0197
2	1.0100	0.9980	0.9387	1.0120
3	0.9987	0.9080	1.2063	0.9633
Delta	0.0237	0.1810	0.3563	0.0563
Rank	4	2	1	3

3.3. Effect on Roundness Error (Er).

The plots for the main effects for the means and S/N rations for the roundness error (in µm) of the epoxy/MWCNTs nanocomposites workpieces are shown in Fig. 8 and Fig. 9, respectively. Table 4 lists the S/N ratios for each level of the investigated factors for roundness error of epoxy/MWCNTs nanocomposites. Again, the MWNCTs volume fraction has no significant influence on the roundness error. Both of the cutting speed and depth-of-cut have slight effect on the roundness error. Increasing the cutting speed slightly increases the roundness error. In contrast, increasing the depth-of-cut reduces slightly the roundness error. Increasing the feed rate increases significantly the roundness error.

According to the results listed in Table 4, the feed rate is the most influential factor that affects the roundness error of the epoxy/MWCNTs nanocomposites, followed by the feed rate. The depth-of-cut showed lower influence on the roundness error than the feed rate and the cutting speed. The MWCNTs volume fraction showed the least influence on the roundness error. The smallest roundness error can be obtained at MWCNTs volume fraction of 1 vol.-%, cutting speed of 712 rev/min, feed rate of 0.168 mm/rev and depth-of-cut of 1.5 mm.

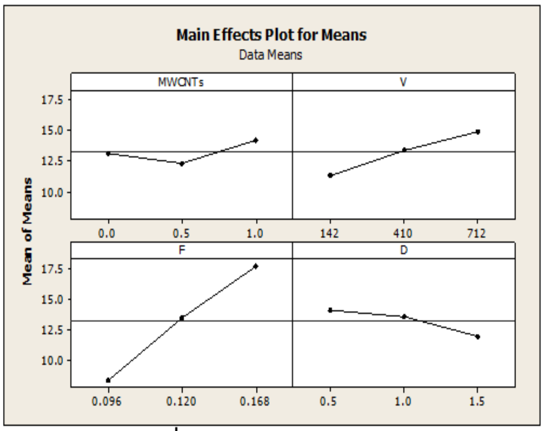

Fig (8). Main effects plots for averages Er of epoxy/MWCNTs nanocomposites.

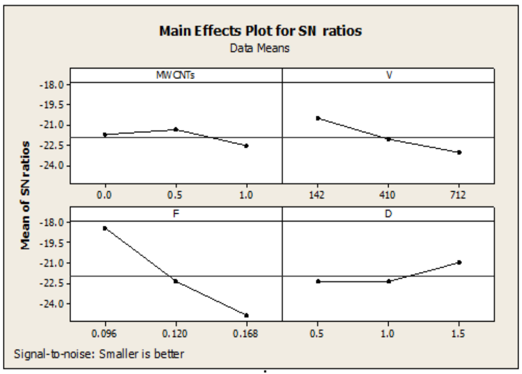

Fig (9). Main effects for S/N ratios of Er of epoxy/MWCNTs nanocomposites.

Table 4. Effect Response Table for S/N ratios of Erfor epoxy/MWCNTs nanocomposites.

Level	MWCNTs (Vol.%)	Cutting speed (V)	Feed rate (F)	Depth-of-Cut (D)
1	13.100	11.340	8.383	14.123
2	12.317	13.383	13.510	13.563
3	14.180	14.873	17.703	11.910
Delta	1.863	3.533	9.320	2.213
Rank	4	2	1	3

4. CONCLUSIONS

Based on the results obtained, the following conclusions have been drawn:

1. The volume fraction of MWCNTs is the least influence on the material removal rate, the surface roughness and roundness error of epoxy/MWCNTs nanocomposites.
2. The feed rate is the most significant factor, followed by the cutting speed,that influencing the surface roughness and the roundness error of epoxy/MWCNTs nanocomposites.
3. The cutting speed is the most significant factor, followed by the depth-of-cut, that influencing the material removal rate of epoxy/MWCNTs nanocomposites.

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