On the influence of Machining parameters on the surface characteristics and material removal rate of Epoxy/Bn Nanocomposites

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Abstract. : In the present investigation, the influence of machining parameters during turning on the surface characteristics and material removal rate of epoxy/BN nanocomposites. The influence of machining parameters, typically, the feed rate, cutting speed, and depth-of-cut on the surface characteristics of epoxy/BN nanocomposite workpieces, typically, the surface roughness (Ra) and roundness error (Er) were evaluated. Moreover, the influence of the aforementioned machining parameters on the material removal rate of epoxy/BN nanocomposites was investigated. Empirical regression models were developed to estimate influences of the aforementioned independent variables on the MRR, Ra and Er.

1. INTRODUCTION

The use of composite materials is increasing in several industries such as automotive, aerospace and sports equipment. This may attribute to their superior properties to metallic materials such as the high strength-to-weight ratio, good impact resistance, sound mechanical properties and they are also cheaper as compared to metal products [1,2].

Polymer matrix composites (PMCs) reinforced with ceramic nanoparticles are the most widely used composites due to their low cost and ease of fabrication [3,4].However, the machining of these materials is very difficult to achieve due to the existence of the hard-ceramic phases that accelerate the wear rate of cutting tools [5].

In the present investigation, epoxy/BN nanocomposites were fabricated using mechanical stirring route. The effect of the machining parameters during turning on the surface characteristics such as the surface roughness and roundness error as well as the material removal rate of epoxy/BN nanocomposites was evaluated.

2. EXPERIMENTAL PROCEDURES

2.1. Materials& Nanocomposites Fabrication

Figures 2 and 3 show scanning electron microscope (SEM) micrograph and energy dissipative x-ray (EDX) analysis for the BN nanoparticles. The BN nanoparticles have a size range from 50 nm to 100 nm. Commercial epoxy resin of type (KEMAEPOXY-150) produced by Chemicals for Modern Buildings Company (CMB), Egypt, was used as a matrix. The BN nanoparticles were dispersed in the epoxy matrix by 0.5 and 1 vol.-% using mechanical stirring method. In this technique the epoxy and BN nanoparticles were mixed together, at room temperature, using a mechanical stirrer rotating at 200 rpm for 5 minutes. After mixing, the epoxy/BN slurry was poured into a plastic mould and allowed to be cured at room temperature. The final epoxy/BN nanocomposite workpieces have 50 mm diameter and 150 mm length.
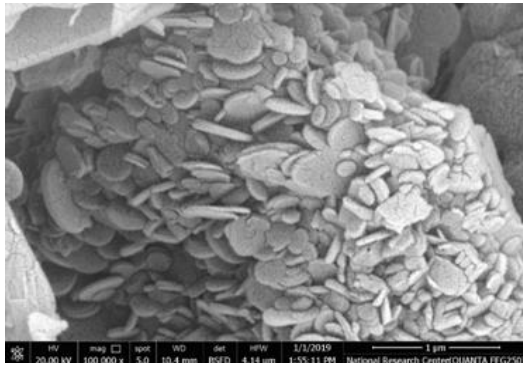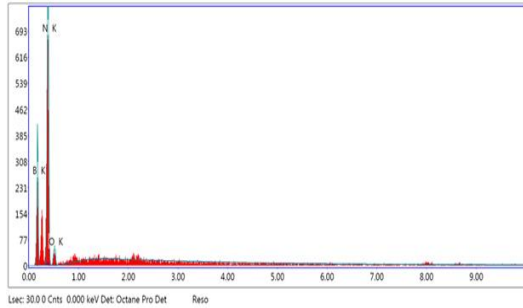
Fig.1. SEM micrograph of BN nanoparticles.

Fig. 2.EDX analysis ofBN nanoparticles.

2.2. Machining of Epoxy/MWCNTs

Nanocomposites

The turning machining process was implemented using a conventional lathe. Figure 3 shows a photograph of the used lathe. The cutting tool used to machine the epoxy/BN nanocomposite specimens were coated carbide inserts(CNMG 120408-VM) made by KORLOY Inc.The carbide inserts have the specifications listed in Table 1. The tool holder of MCLNR2525M12 was used to mount the carbide inserts giving an approach angle of 95°as shown in Figure 4. The selection of the insert was chosen as recommended by KORLOY catalog [6].

Fig. 3. The turnining of epoxy/BN nanocomposites

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Table 1. The coated carbide inserts specification.

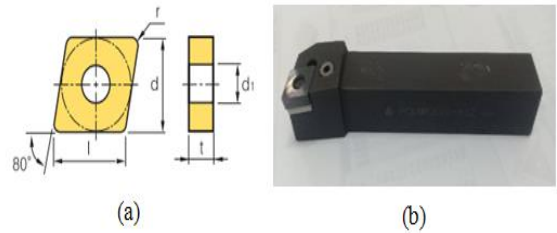| ISO catalog number	Tip	Dimension (mm)		
		d	t	d1
CNMG 120408-VM	Coated carbide	12.70	4.76	5.16

Fig. 4. (a) A schematic illustration of the carbide inserts; (b) photograph of the carbide inserts mounted on the tool holder.

2.3. Design of Experiments

The machining experiments were designed using Taguchi technique based on L9 orthogonal array (OA). The cutting speed (V), feed rate (F), and depth-of-cut (D) are considered as the machining variables (independent variables).The volume fraction (V_f) of the BN nanoparticles dispersed into the epoxy matrix is considered as a material variable (also an independent variable). The influences of the aforementioned independent variables on the material removal rate (MRR), surface roughness (Ra) and roundness error (Er) of the epoxy/BN nanocomposites were evaluated. Table 2 lists the independent parameters under investigation and their levels. Moreover, regression models were developed to estimate influences of the aforementioned independent variables on the MRR, Ra and Er.The regression and statistical calculations were carried out using *MiniTab* commercial software.

Table 2. The materials and machining variables and their levels.

Parameter	Symbol	Unit	Level 1	Level 2	Level 3
BN%	V_f	Vol.-%	0	0.5	1
Cutting speed	V	rev/min	142	410	712
Feed rate	F	mm/rev	0.096	0.12	0.168
Depth-of-cut	D	mm	0.5	1	1.5

2.4. Surface Roughness and Roundness Error Measurements

The surface roughness measurents were carried out using Mitutoyo Surftest SJ-310 roughness tester. While, the roundness error (Er) measurements were carried out using Taylor-Hobson talyrond 73 roundness tester shown in Figure 5.

Fig. 5. Photograph of Taylor-Hobson talyrond 73 roundness tester.

3. RESULTS AND DISCUSSION

3.1. Effect onthe Material Removal Rate

Figure 6 shows main effects plot for the means of the MRR of epoxy/BN nanocomposites. The results revealed that increasing the cutting speed, feed rate and depth-of-cut increase the MRR of the epoxy/BN nanocomposites. In contrast, increasing the volume fraction of the BN nanoparticles reduces the MRR of the epoxy/BN nanocomposites. This may attribute to the increase of the amount of the hard BN nanoparticles which resist the cutting process and hence reduces the MRR.

Table 3 lists response for means of MRR for epoxy/BN nanocomposites. The results revealed that cutting speed is the most influential variable that affect the MRR. The depth-of-cut and feed rate showed lower statistical significance than the cutting speed, respectively. The volume fraction of the BN nanoparticles exhibited the least statistical influence on the MRR for epoxy/BN nanocomposites.

Equation (1) shows an empirical relation resulted from the regression analysis of the MRR results:

$$MRR = -15235.7 - 5747.46\ BN + 21.5949\ V + 67714.1\ F + 9422.51\ D \qquad …(1)$$

Where: MRR is the material removal rate (mm^3/min), BN is the volume fraction of the BN nanoparticles, F is the feed rate (mm/rev), V is the cutting speed in rpm, and D is the depth-of-cut in mm. Equation (1) exhibits R-sq value of 90.18%.
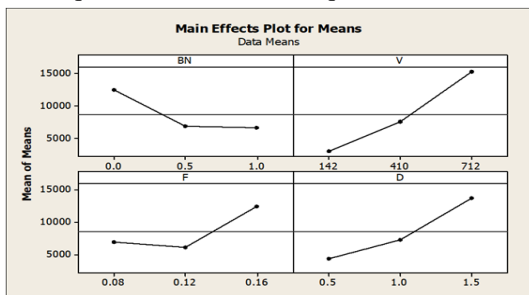

Fig. 6. Main effects plot for the means of the MRR of epoxy/BN nanocomposites.

Table 3. Response Table for Means of MRR for epoxy/BN nanocomposites.

Level	BN (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

3.2. Effect on the Surface Roughness

Figure 7 shows main effects plot for the means of the surface roughness (Ra) of epoxy/BN nanocomposite workpieces. The results revealed that increasing the feed rate and depth-of-cut increase the Ra of the epoxy/BN nanocomposites. Moreover, increasing the volume fraction of the BN nanoparticles reduces the Ra of the epoxy/BN nanocomposites. While increasing the cutting speed from 142 rpm to 410 rpm increases the Ra, further increase in the cutting speed from 410 rpm to 712 rpm tends to reduce the Ra of the epoxy/BN nanocomposites. The response for means of MRR for epoxy/BN nanocomposites is listed in Table 4. The results showed that volume fraction of the BN nanoparticles is the most influential parameter that affect the Ra, followed by the cutting speed, feed rate and depth-of-cut, respectively.

Equation (2) shows an empirical relation resulted from the regression analysis of the Ra results. Such equation exhibits R-sq value of 52.58%.

$$Ra = 0.817655 - 0.328667\ BN - 0.000167956\ V + 2.225\ F + 0.043\ D \qquad …(2)$$
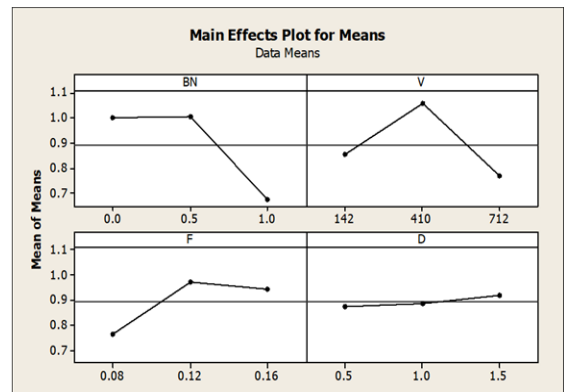
Where: Ra is surface roughness in μm.

Fig. 7. Main effects plot for the means of the Ra of epoxy/BN nanocomposites.

Table 4. Response Table for Means of Ra for epoxy/BN nanocomposites.

Level	BN (Vol.%)	Cutting speed (V)	Feed rate (F)	Depth-of-Cut (D)
1	1.0013	0.8530	0.7640	0.8743
2	1.0037	1.0577	0.9717	0.8860
3	0.6727	0.7670	0.9420	0.9173
Delta	0.3310	0.2907	0.2077	0.0430
Rank	1	2	3	4

3.3.   Effect on the Roundness Error

Figure 8 shows main effects plot for the means of the Er of epoxy/BN nanocomposites. The results revealed that increasing the cutting speed and/or the feed rate increase(s) the Er of the epoxy/BN nanocomposite workpieces. While, increasing the volume fraction of the BN nanoparticles and/or depth-of-cut has/have no practical influence on the Er of the epoxy/BN nanocomposite workpieces.
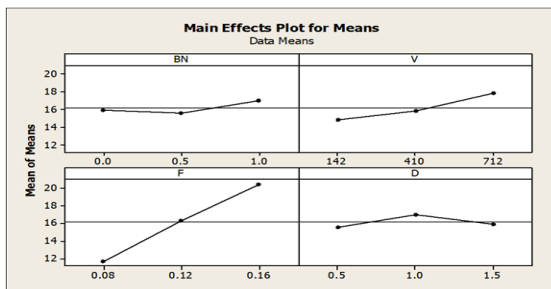

Fig. 8. Main effects plot for the means of the Er of epoxy/BN nanocomposites.

Table 5 shows the response for means of Er for epoxy/BN nanocomposites. The results showed that feed rate is the most influential variable that affect the Er of the epoxy/BN nanocomposite workpieces. The cutting speed and the depth-of-cut exhibit lower statistical significance than the feed rate, respectively. The volume fraction of the BN nanoparticles showed the least statistical influence on the Er for epoxy/BN nanocomposites.

Table 5. Response Table for Means of Er for epoxy/BN nanocomposites.

Level	BN (Vol.%)	Cutting speed (V)	Feed rate (F)	Depth-of-Cut (D)
1	15.86	14.80	11.71	15.57
2	15.59	15.83	16.29	16.99
3	16.99	17.81	20.45	15.89
Delta	1.41	3.01	8.74	1.41
Rank	4	2	1	3

Equation (3) shows an empirical relation resulted from the regression analysis of the Er. The equation has R-sq value of 96.33%.

$$Er = -0.0801578 + 1.13111\ BN + 0.00531113\ V + 109.264\ F + 0.313334\ D \quad \dots(3)$$

Where: Er is the roundness error in µm.

4.   CONCLUSIONS

1. Increasing the cutting speed, feed rate and depth-of-cut increase the MRR of the epoxy/BN nanocomposites. However, increasing the volume fraction of the BN nanoparticles reduces the MRR of the epoxy/BN nanocomposites.

2. Increasing the feed rate and depth-of-cut increase the Ra. However, increasing the volume fraction of the BN nanoparticles reduced the Ra of the epoxy/BN nanocomposites. Moreover, increasing the cutting speed to a certain value increases the Ra, further increase in the cutting above this value reduced the Ra of the epoxy/BN nanocomposites.

3. Increasing the cutting speed and the feed rate increase the Er of the epoxy/BN nanocomposite workpieces. Moreover, increasing the volume fraction of the BN nanoparticles and depth-of-cut have no practical influence on the Er of the epoxy/BN nanocomposite workpieces.

ACKNOWLEDGEMENTS

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