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Effect of Machining Parameters on the Machining Characteristics of Epoxy/Tin Nanocomposites using Taguchi Design of Experiments Approach

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Abstract. : The present work represents an experimental study of the machinability of epoxy/TiN nanocomposites during turning. The effect of the cutting speed, feed rate, depth of cut and the cooling condition on the machining characteristics, typically, the surface roughness (Ra), the material removal rate (MRR) and roundness error (Er) of the machined epoxy/TiN nanocomposites specimens were investigated. The machining experiments were designed using Taguchi approach. The results revealed that the cooling condition showed no or slight influence on the MRR, Ra and Er of epoxy/TiN nanocomposites. The other machining parameters exhibited significant influences on the MRR, Ra and Er of epoxy/TiN nanocomposites.

Keywords: Machinability, Nanocomposites, Design of Experiments, Taguchi, Epoxy, TiN.

1. INTRODUCTION

The polymer matrix composites (PMCs) are widely used in industry for manufacturing a diverse type of products such as sporting goods, aerospace components and automobiles due to their high strength-to-weight ratios [1,2]. However, itis more difficult to machine these composites into the desired shape by the machining methods, and, therefore, limiting their widespread applications [3]. The machining of the PMCs may be employed by traditional and non-traditional machining techniques. These machining methods have been applied to PMCs with varying degrees of success. Specific method may be good for machining one polymer/matrix system, but it may be unsuitable for another polymer/matrix system. So, it is difficult to make at decision for specific machining process in a generalize manner [4].

The knowledge and understanding of manufacturing process, particularly the machining of the epoxy containing nano particles are not well developed [5].Very limited investigations, especially using turning machining, were reported in the machining of polymer-based composites [6,7].

In the present investigation, epoxy polymer-based nanocomposites reinforced with 50 nm TiN nanoparticles was fabricated using mechanical stirring method. The machining of epoxy/TiN nanocomposites were studied using conventional turning lathe using different machining conditions, typically, cutting speed, feed rate, and depth-of-cut, and cooling condition. The influence of the aforementioned machining parameters on the surface roughness (R_a), materials removal rate (MRR) and roundness error (Er) of the TiN nanocomposites were evaluated.

2. EXPERIMENTAL PROCEDURES

2.1. Materials

The commercial epoxy resin KEMAEPOXY-150 manufactured by the Chemicals for Modern Buildings (CMB) Company, Egypt was used as a matrix. The TiN nanoparticles, having average size of 50 nm, were used as reinforcing agent. The TiN were added to the epoxy matrix by 0.5 and

1% by volume (vol.-%). Figure 1 shows scanning electron microscope (SEM) micrograph of the TiN nanoparticles. Figure 2 shows an energy dissipative x-ray (EDX) analysis for the TiN nanoparticles.

2.2. Fabrication of Epoxy/TiN Nanocomposites

The epoxy/TiN nanocomposites were fabricated using mechanical stirring technique. The TiN nanoparticles were dispersed in the epoxy resin and mixed together using mechanical stirrer in a plastic mould. The stirring speed and mixing time were 200 rpm and 5 minutes, respectively. After mixing, the hardener solution was added to the epoxy/TiN mixture (1:2 vol.-%) and the mixing process was prolonged for about 5 minutes. After complete mixing, the mixture was poured into a plastic mould and left to be hardened at room temperature. The final epoxy/TiN nanocomposite work pieces have 50 mm diameter and 150 mm length.

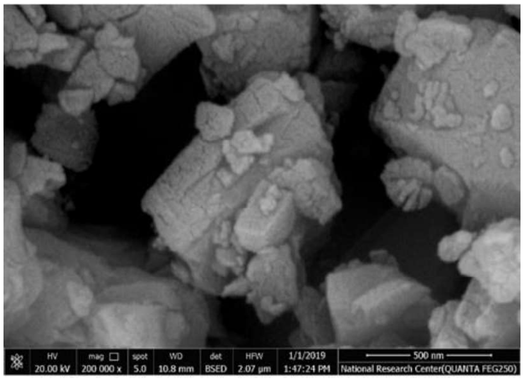

Fig1. SEM micrograph of the TiN nanoparticles.

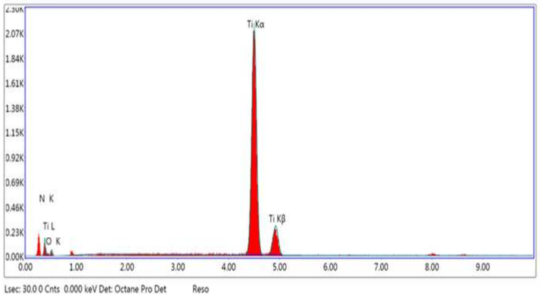

Fig 2 . EDX analysis of the TiN nanoparticles.

2.3. Turning of Epoxy/TiNNanocomposites

Figure 3 shows a photograph of the machining of epoxy/TiN nanocomposite specimens during turning using a conventional center lathe. The cutting process was carried out using coated carbide inserts (CNMG 120408-VM) made by KORLOY Inc. (see Figure 4) with specifications listed in Table 1.

Fig 3. The machiningof epoxy/TiN nanocomposite specimens during turning.

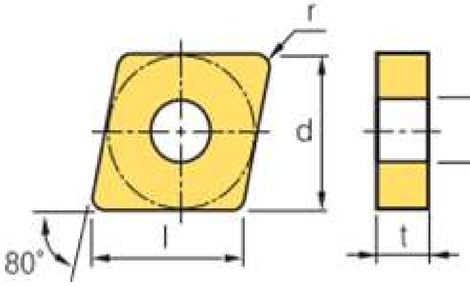

Fig 4. A schematic illustration of the CNMG 120408-VM carbide inserts.

Table 1 . The specifications of CNMG 120408-VM coated carbide inserts shown in Figure 4.

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

2.4. Design of Experiments

The machining experiments carried out in the present work were designed using Taguchi approach based on L9 orthogonal array (OA). Table 2 lists the investigated machining parameters and their corresponding levels. As shown from Table 2, the studied machining parameters (independent variables) are the cutting speed (V), feed rate (F), depth-of-cut (D) and cooling. The machining was carried out under both dry and emulation cooling conditions. In table 2 the dry machining was denoted by number (0) and the emulation cooling is denoted by number (1). The investigated material parameter is the volume fraction of MWCNTs (V_f). The studied machining characteristics (dependent variables) were the surface roughness (Ra),material removal rate (MRR) and roundness error (Er).Empirical models were developed to predict the effect of the aforementioned machining and materials parameters on the machining characteristics of epoxy/TiN nanocomposites. The empirical models and statistical analysis of the results was carried out using MiniTab commercial software.

Table 2. The turning machining parameters and their levels.

Parameter	Symbol	Unit	Level 1	Level 2	Level 3
Amount of TiN	V_f	vol.-%	0	0.5	1
Cutting speed	V	rpm	142	410	712
Feed rate	F	mm/rev	0.08	0.12	0.16
Depth-of-cut	D	mm	0.5	1	1.5
Cooling	-	-	Dry (0)	-	Cooling (1)

2.5. Surface Roughness and Roundness Error Measurements

The surface roughness and roundness error were measured using Mitutoyo Surftest SJ-310 roughness tester and Taylor-Hobson talyrond 73 roundness tester, respectively

3. RESULTS AND DISCUSSION

3.1. Effect of the Machining Parameters on the Material Removal Rate (MRR).

The main effects plot for the means of MRR of the epoxy/TiN nanocomposites is shown in Figure 5. The results indicate showed that increasing the volume fraction of the TiN nanoparticles, cutting speed, feed rate and depth-of-cut increase the material removal rate of the epoxy/TiN nanocomposite workpieces. The cooling has no significant effect on the MRR of the epoxy/TiN nanocomposites.

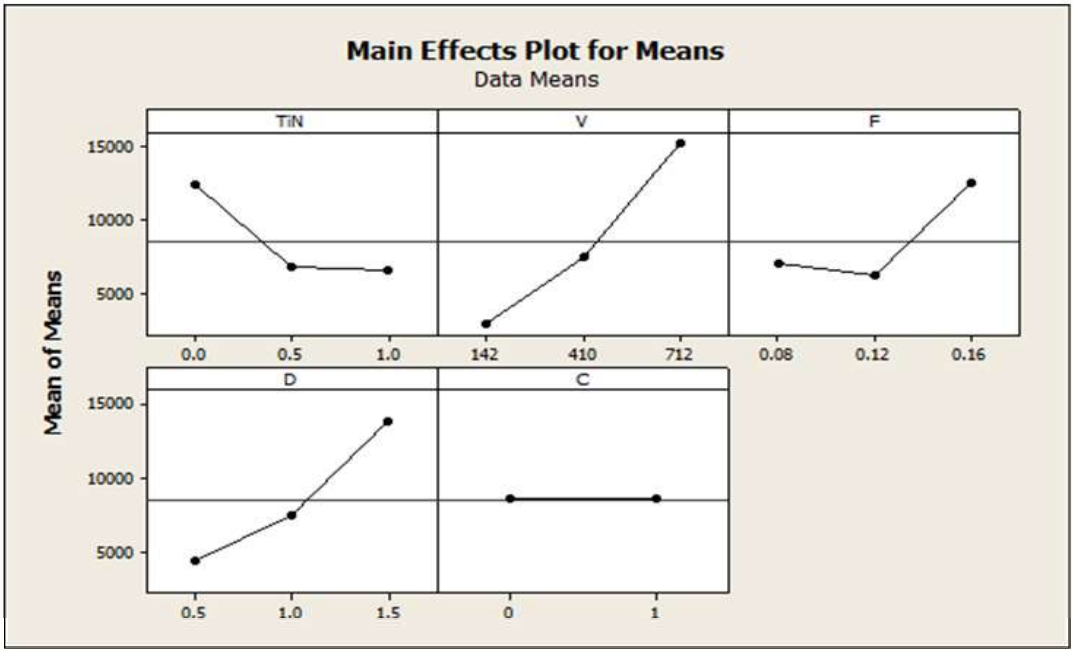

Fig 5. Main effects plots for means MRR of epoxy/TiN nanocomposites.

Table 3 lists the response table for means of MRR for epoxy/TiN nanocomposites. The Table indicates that the cutting speed has the most significant effect on the MRR of epoxy/TiN nanocomposites. The depth-of-cut, feed rate and TiN vol.-% showed lower influence on the MRR when compared with cutting speed, respectively. The cooling showed the least effect on the MRR of epoxy/TiN nanocomposites.

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

Level	TiN (Vol.%)	Cutting speed (V)	Feed rate (F)	Depth-of-Cut (D)	Cooling (C)
1	12321	2943	7024	4395	8537
2	6717	7467	6148	7400	8537
3	6574	15203	12441	13817	
Delta	5747	12260	6293	9423	
Rank	4	1	3	2	5

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

$$MRR = -15235.7 - 5747.46\, TiN + 21.5949\, V + 67714.1\, F + 9422.51\, D + 1.12914\times10^{-12}\, C \quad \ldots(1)$$

Where: MRR is the material removal rate (mm^3/min), TiN is the volume fraction of the TiN nanoparticles, F is the feed rate (mm/rev), V is the cutting speed in rpm, D is the depth-of-cut in mm and the cooling condition (0 for the dry machining and 1 for emulation cooling). Equation 1 has R^2 value of 90.18%.

3.2. Effect of the Machining Parameters on the Surface Roughness (Ra).

Figure 6 shows main effects plot for the means of Ra of the epoxy/TiN nanocomposites. The results indicate showed that increasing the feed rate increases the surface roughness of the epoxy/TiN nanocomposite specimens. Increasing the volume fraction of the TiN nanoparticles up to 0.5 vol.-% reduces the surface roughness of the nanocomposites, while increasing the volume fraction of the TiN nanoparticles above 0.5 vol.-% increases the surface roughness of the nanocomposites. The same behavior was observed for the depth-of-cut. Increasing the depth-of-cut up to 1 mm reduces the surface roughness of the nanocomposites, while increasing the depth-of-cut above 1 mm increases the surface roughness of the nanocomposites. Increasing the cutting speed from 142 rpm to 410 rpm increases the surface roughness of the TiN nanoparticles, while increasing the cutting speed from 410 rpm to 712 rpm tends to reduce the surface roughness. Again, the cooling has no significant effect on the Ra of the epoxy/TiN nanocomposites.

Table 4 lists the response table for means of Ra for epoxy/TiN nanocomposites. The table indicates that the feed rate has the most significant effect on the Ra of epoxy/TiN nanocomposites. The TiN vol.-%, depth-of-cut, and cutting speed showed lower influence on the Ra when compared with feed rate, respectively. The cooling showed again the least effect on the Ra of epoxy/TiN nanocomposites. Equation 2 shows an empirical relation resulted from the regression analysis of the Ra results:

$$Ra = 0.677212 - 0.0135\, BN + 4.69646\times10^{-5}\, V + 8.58958\, F - 0.110667\, D - 0.0445556\, C \quad \ldots(2)$$

Equation 2 has R^2 value of 63.72%.

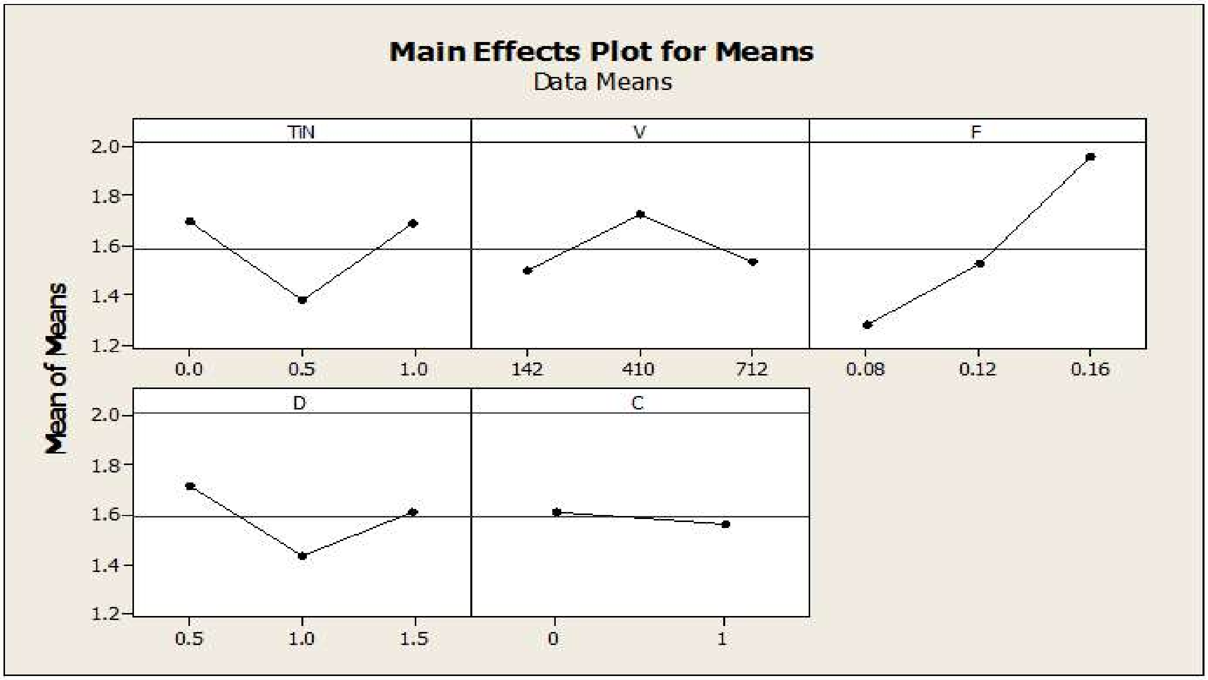

Fig 6. Main affects plots for means Ra of epoxy/TiN nanocomposites.

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

Level	TiN (Vol.%)	Cutting speed (V)	Feed rate (F)	Depth-of-Cut (D)	Cooling (C)
1	1.700	1.502	1.276	1.722	1.610
2	1.377	1.726	1.525	1.431	1.566
3	1.687	1.537	1.963	1.611	
Delta	0.323	0.224	0.687	0.291	0.045
Rank	2	4	1	3	5

3.3. Effect of the Machining Parameters on the Roundness Error (Er).

Figure 7 shows main effects plot for the means of Er of the epoxy/TiN nanocomposites. The results indicate showed that increasing the feed rate, cutting speed and volume fraction of TiN nanoparticle increase the roundness error of the epoxy/TiN nanocomposite workpieces. Increasing the depth-of-cut from 0.5 mm to 1 mm increases the Er of the epoxy/TiN nanocomposite workpieces, further increase in the depth-of-cut up to 1.5 mm reduces the Er of the epoxy/TiN nanocomposite workpieces. The cooling condition has slightly significant effect on the Er of the epoxy/TiN nanocomposite workpieces. The workpieces machined under dry conditions exhibited slightly higher Er values when compared with those machined under emulation solution cooling condition.

Table 5 lists the response table for means of Er for epoxy/TiN nanocomposites. The table indicates that the feed rate has the most significant effect on the Er of epoxy/TiN nanocomposite workpieces. The cutting speed, TiN vol.-%, and depth-of-cut showed lower significant influence on the Er when compared with feed rate, respectively. The cooling showed again the least effect on the Er of epoxy/TiN nanocomposites.

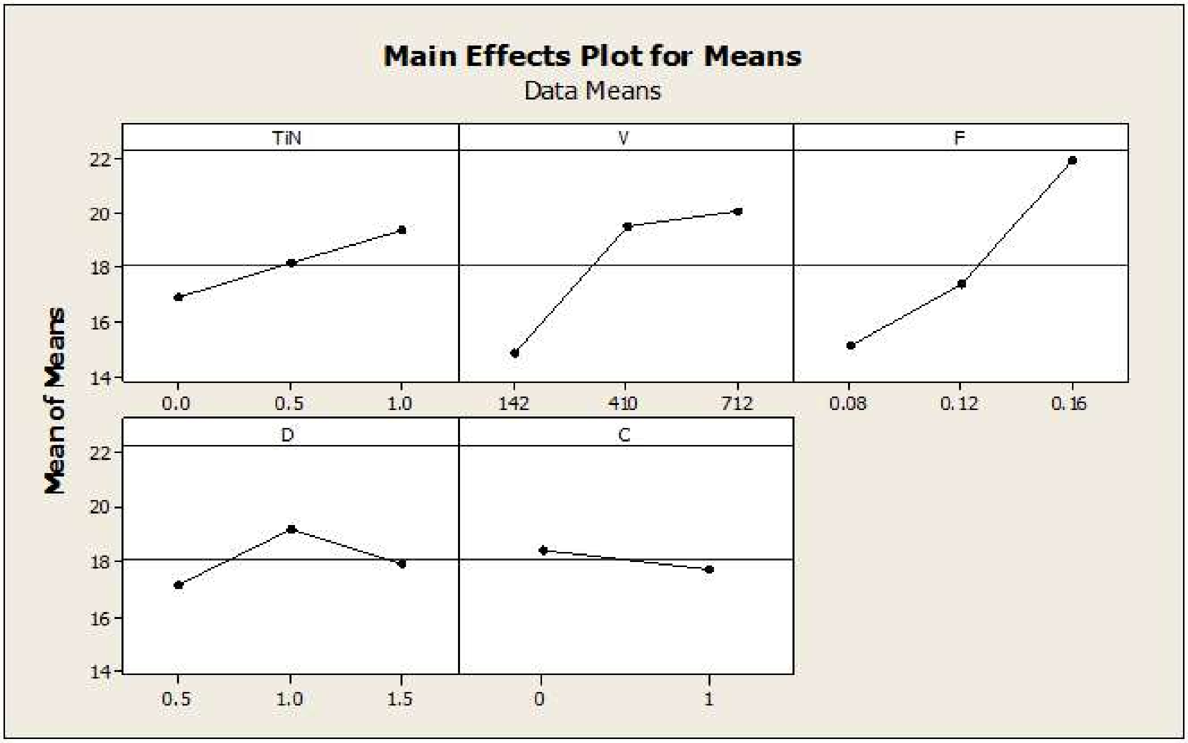

Fig 7. Main effects plots for means Er of epoxy/TiN nanocomposites.

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

Level	TiN (Vol.%)	Cutting speed (V)	Feed rate (F)	Depth-of-Cut (D)	Cooling (C)
1	16.91	14.81	15.10	17.16	18.48
2	18.11	19.46	17.35	19.24	17.74
3	19.31	20.06	21.89	17.93	
Delta	2.40	5.25	6.79	2.08	0.74
Rank	3	2	1	4	5

Equation 3 shows an empirical relation resulted from the regression analysis of the Er results:

$$Er = 2.50403 + 2.40389\ TiN + 0.00905427\ V + 84.8958\ F + 0.770555\ D - 0.737777\ C \ldots(3)$$

Equation 3 has R^2 value of 86.33%.

4. CONCLUSIONS

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

1. Increasing the volume fraction of the cutting speed, feed rate and depth-of-cut increase the MRR of the epoxy/TiN nanocomposites. Moreover, increasing the volume fraction of TiN nanoparticles increases the MRR.

2. Increasing the feed rate increases the Ra of the epoxy/TiN nanocomposites. Increasing the volume fraction and/or depth-of-cut to a certain value reduce the Ra of the nanocomposites. Further increase above these values increase the Ra of the nanocomposites. Increasing the cutting speed from 142 rpm to 410 rpm increases the Ra of the TiN nanoparticles, while increasing the cutting speed from 410 rpm to 712 rpm tends to reduce the Ra.
3. Increasing the feed rate, cutting speed and volume fraction of TiN nanoparticle increase the Er of the epoxy/TiN nanocomposite workpieces. Increasing the depth-of-cut from 0.5 mm to 1 mm increases the Er of the epoxy/TiN nanocomposite workpieces, further increase in the depth-of-cut up to 1.5 mm reduces the Er of the epoxy/TiN nanocomposite workpieces.
4. Within the range of the investigated machining parameters, the cooling condition has slightly or no significant effect on the Er, MRR and Ra of the epoxy/TiN nanocomposite workpieces.

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