Machining Operation Parameters in Drilling Process; Variation of Thrust Forces in Epoxy Based Nanocomposites

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Abstract
During the past decade, polymer nanocomposites have emerged relatively as a new and rapidly developing class of composite materials and attracted considerable investment in research and development worldwide.Direct machining of polymers can be an option for personalized products and for manufacturing product samples. To obtain high quality products and reduce machining costs, it is very important to understand the machining conditions so as to achieve enhanced machining performance. The influence of machining parameters (feed rate) and tool type (cemented carbide, HSS and coated HSS) on thrust force in drilling of epoxy, epoxy/clay and epoxy/TiO2nanocomposites are investigated. Variation of input parameters, feed rate and tool type affects the thrust force. The cemented carbide tool creates less thrust force than HSS and coated HSS tools. The thrust force in drilling process of epoxy/TiO2nanocomposite was more significant than epoxy resin and epoxy/nano clay. The minimum thrust force (13 N) was obtained in feed rate of 0.02 mm/tooth in neat epoxy with carbide tool.

Keywords
Drilling, Machining Parameters, Tool Type, Nanocomposites

1. Introduction

The advent of polymer based nanocomposite, with reinforcing phase, consisting of filler has been achieved great interest in industry and science. The epoxy polymers (resins), a thermosetting polymer, are basically a polyether. A large number of applications have been reported due to their remarkable chemical resistance and good adhesion. Epoxy resins are used in industrial flooring [1], foams [2], potting materials for electrical insulations [3], fiber-reinforced plastics [4]. However, the epoxy resins have some innate deficiencies such as mechanical properties in pristine form to be used as a widely acceptable material. To overcome it as mentioned drawbacks, many efforts have been made either by blending [5], co-polymerization [6] and nanocomposite formation [7]. Unfortunately, limited success has been achieved in blending and co-polymerization.

Various nanofillers are used to reinforce the epoxy resins like TiO_2 [7, 8] and clay [9-11]. Polymer containing clay and/or TiO_2 nanoparticles possess unique nanoscale properties in the matrix. As reported in literature, polymer-clay and polymer-TiO_2nanocomposites improved the mechanical properties [8, 12, 13], thermal stability [7, 14], gas permeability [15] and fire retardancy [16].

Apart of all above applications/properties, the knowledge and understanding of manufacturing process, particularly the machining of the novel epoxy containing nano particles are not well developed. A few reports in this area i.e. machining of polymer/clay and polymer/TiO2 (nano) composites have been investigated [17-19].

For assembling the (nano) composite parts, drilling tends to be the real challenge of machining operation [20]. In drilling process, the thrust force is a significant element in machine vibrations, chatter, and inaccuracy issues. Therefore, reducing the thrust force in drilling process can directly reflected into the quality of the drilled hole, diminution of vibration and chatter. Shape accuracy of component corresponds to machining accuracy [21].

In this study, an attempt has been developed to peruse the influence of machining parameters and tool type on thrust force in drilling process of pristine epoxy, epoxy/clay and epoxy/ TiO_2nanocomposites. Three types of drilling tools (HSS, coated HSS and cemented carbide) were used.

2. Materials and Methods

2.1 Materials

Epoxy resin (diglycidyl ether of bisphenol-A; ML-526; viscosity =1.2–1.4 Pa.S; specific gravity = 1.2 g/cm^3), and the curing agent (HA-41; viscosity=1.2–1.4 Pa.S; specific gravity = 1.2 g/cm^3, anhydride commercial hardener) were purchased from Mokarrar Engineering Material Co.(Iran). Titanium oxide (AEROXIDE® TiO_2 P25) nanoparticles with an average diameter of 21 nm and a specific surface area of 50±15 m^2/g and natural montmorillonite (MMT) modified with ammonium salt (cloisite 30B) were both supplied from Evonic Industries (Germani) and Southeren Clay Products (USA) respectively.

The dried nanoparticles i.e. TiO_2 and MMT with 1, 3 and 5 wt% (Table 1) were dispersed into 50ml of epoxy resin solution. The mixing process was carried out using a high shear mixer for 90 min in 1500 rpm. Dispersed nanocamposites solutions were degassed by placing the container in a vacuum oven at 80 ºC for 20 minutes, cool down, and the hardener was added by vigorous stirring for two minutes. The obtained solution was slowly poured into a silicon rubber mold. The prepared samples were pre-cured at 80˚C for 8 hours and were post-cured at 120 ºC for 10 hours.

Table1. Sample synthesis

Symbol	Sample	TiO_2 (%wt)	Clay (%wt)	Epoxy resin (%wt)
ER	pristine epoxy resin	0	-	100
ET1	Epoxy/TiO_2 1%	1	-	99
ET3	Epoxy/TiO_2 3%	3	-	97
ET5	Epoxy/TiO_2 5%	5	-	95
EC1	Epoxy/clay 1%	-	1	99
EC3	Epoxy/clay 3%	-	3	97
EC5	Epoxy/clay 5%	-	5	95

2.2 Mechanical Testing and Morphology

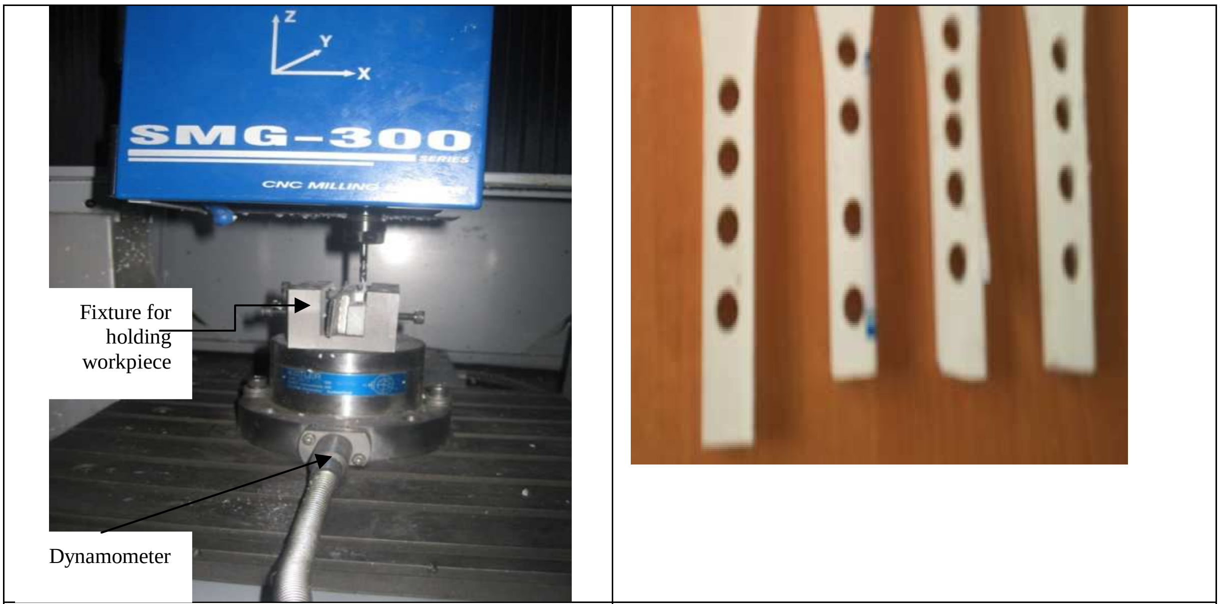
Tensile test has been performed using SANTAM (STM50 model) tensile test machine with a constant loading speed of 3 mm/min according to ASTM D638. At least 5 samples were tested for each condition. The ultimate stress, Young’s modulus and strain at break point were measured.

Transmission Electron Microscopy (TEM) is a powerful tool for the characterization of nanocomposites (the internal structure and dispersion of nanoparticles). In this paper, the XLC TEM operating at an acceleration voltage of 120 kV was used.

2.3 Machining

The drilling processes were performed on a vertical computer numerically controlled (CNC) milling machine (SMG-300) with a maximum spindle speed of 5000 rpm. The actual machining operation is illustrated in Figure 1. The experiments were carried out on nanocomposites plates, using cemented carbide, high speed steel (HSS) and coated HSS drills, with 5 mm diameter. In order to measure the axial thrust force, the workpiece was mounted on a Kistler 9272 (Switzerland) four-component piezoelectric dynamometer, which in turn was mounted onto the machine's table (Figure 1). Data acquisitions were made through the piezoelectric dynamometer by interface RS-232C to load three Kistler 5070A amplifiers and to the PC using the appropriate software DynoWare type 2825 A Kistler®.

The best samples from mechanical testing were selected for drilling process. Neat epoxy resin (blank sample), EC1and ET3, as will be discussed, nanocomposites with highest performances in UTS test were selected for further machinery operation. The results of drilling tests allowed evaluating of EC and ET nanocomposites, using cemented carbide, HSS and coated HSS drills. The machinability was evaluated by thrust force.



(a) (b)

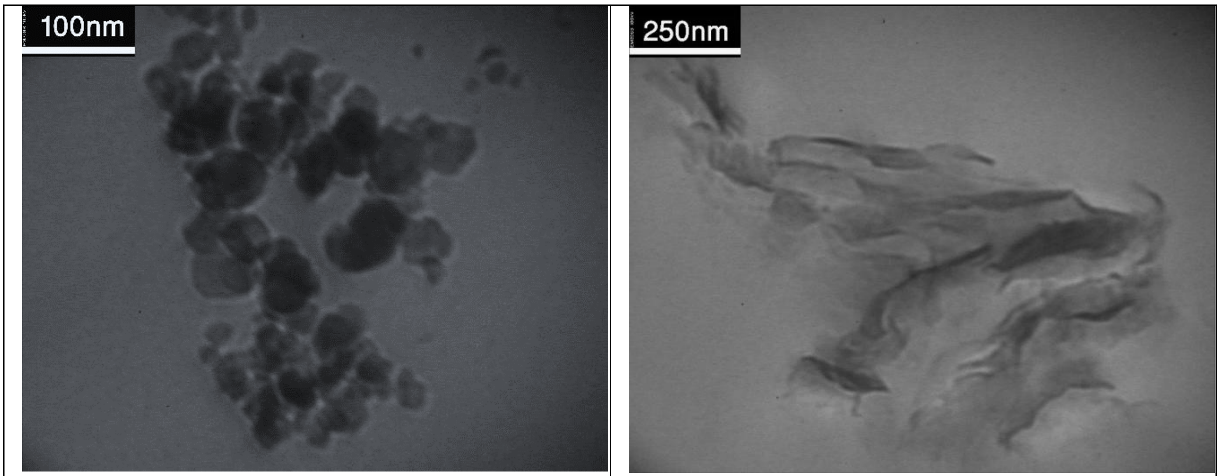
Figure1. a)Actual machining operation, b)Drilled work-pieces

3. Results and discussion

3.1 Mechanical properties and Morphology

The ultrathin TEM samples with a thickness of 60 nm were cut by means of a microtome at room temperature. Figure 2 shows TEM images for nanocomposites with 3 wt% of TiO_2 and 3 wt% of clay nanoparticles respectively.

The state of TiO_2 and clay nanoparticle dispersion in the VE matrix, and the presence of the particles under 100 nm in diameter and thickness can be seen.



ET3 EC3

Figure2. TEM micrographs of ET3 and EC3

In order to study the effect of nanoparticles concentration on tensile properties of ER and its respective nanocomposites, un-axial tensile test was conducted. The tensile properties of ER and ER/TiO_2nanocomposites (ET1, ET3 and ET5) including ultimate tensile strength and Young’s modulus are presented in Table 2.It is obvious that the Young’s modulus of nanocomposites depends on nanoparticle concentration. Upon increasing the nanoparticles, either MMT or TiO_2, the Young’s modulus increases gradually. It must be mentioned that the modulus of $TiO_2$is about 200-400 GPa [12] and clay is 170 GPa [27].The ultimate tensile strengths results indicate that the epoxy/TiO_2samples achieved higher values as compared to pristine ER and EC. Moreover, the ET sample containing 3 wt% TiO_2 shows the highest value (~41.5 MPa). This is due to the homogenous distribution of TiO_2 particles within polymer matrix. In general, the superior indication of mechanical properties of epoxy/TiO_2 nanocomposites can be related to the nano scale properties of this filler.

3.2 Influence of feed rate and tool type on thrust force

The evaluation of thrust forces versus feed rates are shown in Figure 3. It is obvious that there is a direct relation between the feed rate, the chip cross-section and the thrust force (increasing feed rate→ increasing chip cross section→ increasing trust force). It can be observed that the cemented carbide creates less thrust force than HSS and coated HSS tools. The hardness and the friction coefficient in cemented carbide tool have an opposite function on HSS and coated HSS tools (the former has superior effect). As a result, the sharpness of cemented carbide tool achieves higher values as compared to HSS and coated HSS tools. Direct decrements relations of friction coefficient, friction work, and the trust force can be observed. The friction coefficient in HSS tool is higher than coated HSS tool; hence, the coated HSS tool creates less thrust force than HSS tool.

Table2. Tensile properties of neat polymer and nanocomposites

Materials	Ultimate tensile strength (MPa)	Young's modulus (GPa)
ER	39.12± 1.53	2.15 ± 0.19
EC1	40.61± 2.76	2.21 ± 0.12
EC3	32.58± 3.15	2.45 ± 0.18
EC5	28.85± 4.25	2.72 ± 0.21
ET1	33.38± 2.04	2.34 ± 0.14
ET3	41.51± 2.36	2.66± 0.21
ET5	39.35±1.84	2.94± 0.12

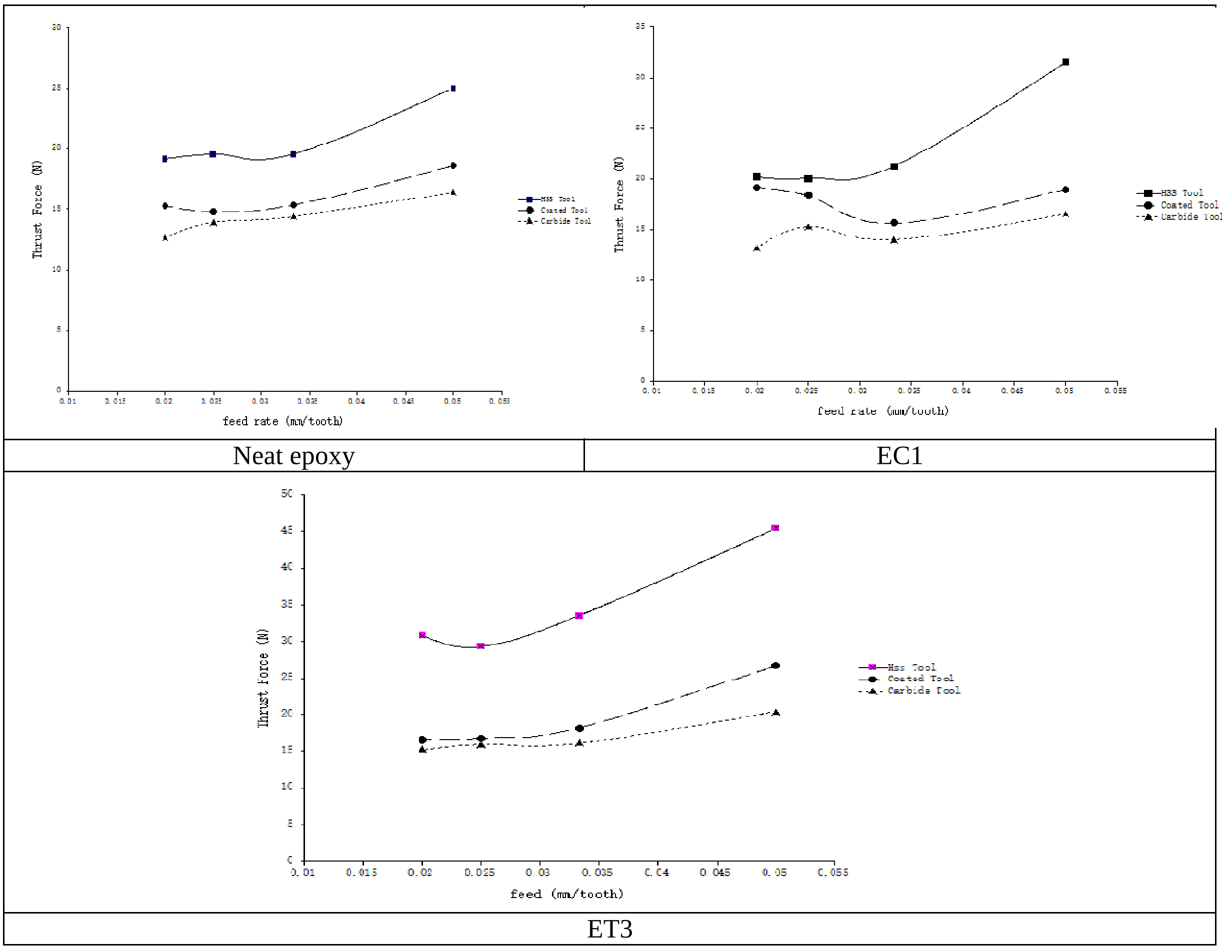


Figure3. Thrust force as function of feed rate and tool type for neat epoxy, EC1 and ET3 (Spindle speed=2000 rpm)

3.3 Influence of nanoparticles on thrust force

The effect of clay and TiO_2 nanoparticles on thrust force in HSS tool, coated HSS tool and cemented carbide tool is shown in Figure 4, respectively. In the mentioned tools, the thrust forces were recorded during the drilling process of ET nanocomposites, because it was shown a highest value. This behavior can be justified due to superior strength and modulus of ET nanocomposites (41.51 MPa in strength, 2.66 GPa in Modulus) as compared to ER (39.12 MPa in strength, 2.15GPa in Modulus) and EC (40.61 Mpa in strength, 2.21GPa in Modulus) nanocomposites. The results indicate that the thrust forces in drilling process of ER and EC nanocomposites are close to each other as a function of strength and Modulus.

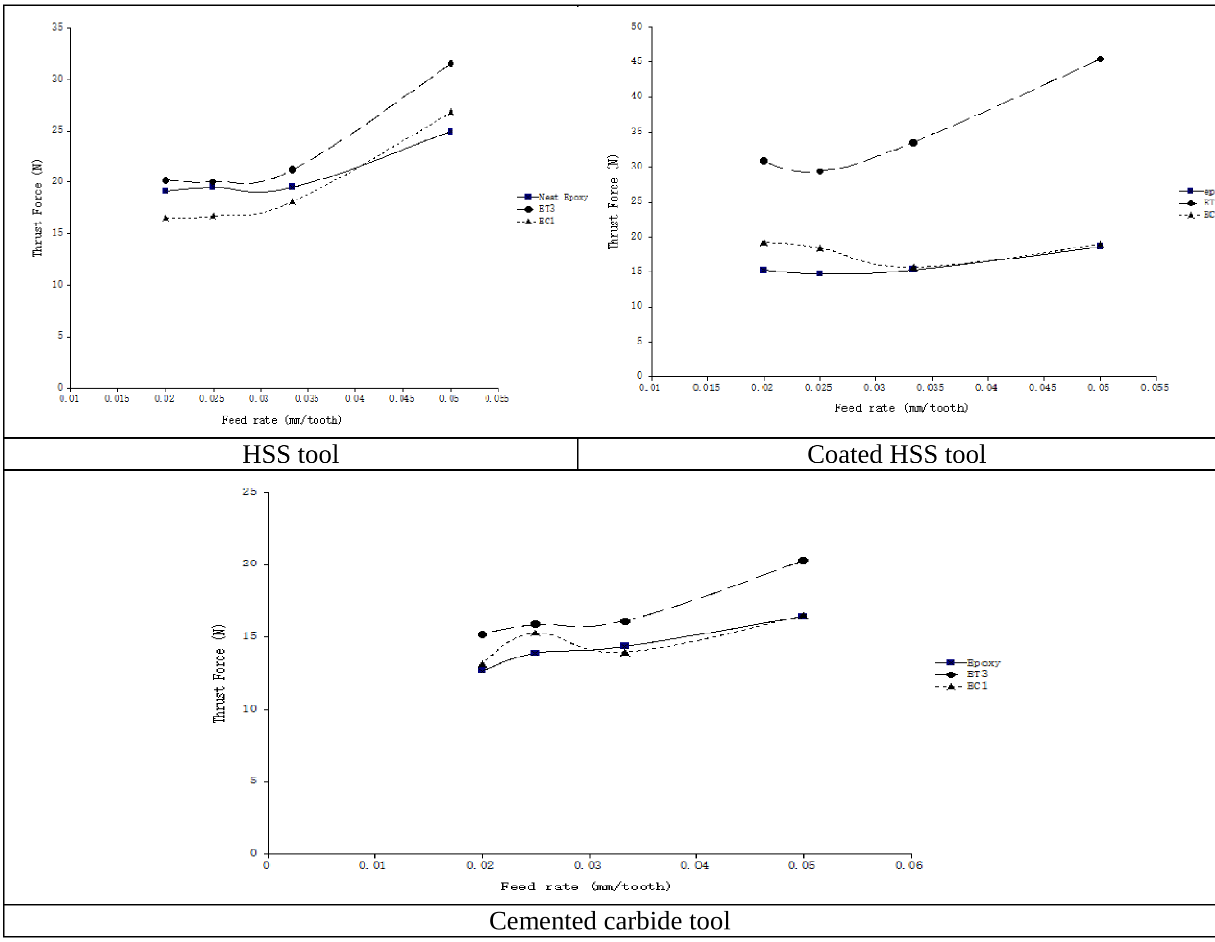


Figure4. The effect of nanoparticles on thrust forces for different tools

4. Conclusion

In this study, the machining operation factors in drilling process of epoxy resin, epoxy/clay and epoxy/TiO_2nanocomposites were successfully investigated.

Linear relation between the trust force and the feed rate was observed. Minimum and maximum thrust forces (TF=12.7 N and 45.44 N) achieve at 0.02 mm/tooth and 0.05 mm/tooth feed rates using a cemented carbide tooland coated HSS tool in drilling process of ER and ET nanocomposites, respectively. The cemented carbide creates less thrust force than HSS and coated HSS tools especially in low spindle speed. The thrust forces in drilling process of ET achieved higher values as compared to EC and ER.

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