Evaluation of Cutting Force for Two Different Graphite-Teflon Composites

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Graphite-based Teflon composites find various applications in many engineering fields. For certain applications, the use of composites rather than metals has in fact resulted in savings of both cost and weight. The usage in many fields demands several machining operations to be performed on engineering polymers. The paper deals with two different materials: polytetrafluoroethylene with regenerated graphite (PTFE GR) and polytetrafluoroethylene with 32% carbon and 3% graphite (PTFE CG 32-3). At the beginning of the study it was performed an advanced characterization for both materials that have been used: PTFE GR and PTFE CG 32-3. The chemical composition was determined using X-ray photoelectron spectroscopy (XPS). Complementary information about the chemical structure is obtained with Fourier transform infrared spectroscopy (FTIR). This combination of spectroscopic methods was used to establish individual differences between the chemical structures for the used materials. Second part of the present paper investigates the effect cutting parameters on the cutting force in the turning of PTFE GR and PTFE CG 32-3 materials. The effects of different parameters on cutting force are analyzed and presented in this study. This paper presents that the success of the machining operation is affected by the chemical structure of the work material.

Keywords: engineering polymers, spectroscopy analysis, cutting force, turning

Engineering polymers have found many industrial applications such as mechanical units, wear resistant low friction coatings for engine components, heat- and chemical-resistant storage units, electrical parts, building and construction industry and many others. The reason the polymers are so popular is that they may offer such advantages as transparency, self-lubrication, lightweight, flexibility, economy in fabricating, and decorating [1-5].

This category of polymers is extraordinary large and varied. Among engineering polymers, polytetrafluoroethylene (PTFE), first marketed under the DuPont trade name Teflon, is characterized by its extreme inertness to chemicals, very high thermal stability, low coefficient of friction, and ability to resist adhesion to almost any material. PTFE is a slippery thermoplastic polymer with similar properties to polystyrene except that it has a very wide temperature range and cannot be practically melted [6-8].

The type of fabrication process adopted depends on the properties and characteristics of the polymer and on the shape and form of the final product. There are, however, some fairly broad and basic approaches that can be followed when designing or fabricating a product out of polymers or, more commonly, polymer composites (fillers, reinforcing agents, and/or chemical additives embedded in a continuous polymeric matrix).

The present paper deals with graphite-based Teflon composites. The usage of this composites demands several machining operations to be performed. Although some efforts have been made to understand the machinability of the polymeric materials, any evaluation of machining characteristics must allow for the particular properties of the material being used. Each category of engineering polymers demands different tool geometries for a great acting and productivity.

Materials and methods

The aim of this study was to compare the cutting force in the turning of two materials: polytetrafluoroethylene with regenerated graphite (PTFE GR) and polytetrafluoroethylene with 32% carbon and 3% graphite (PTFE CG 32-3). Fundamental characteristics of PTFE GR and PTFE CG 32-3 are presented in table 1.

At the beginning of the study it was performed an advanced characterization for both composites that have been used: PTFE GR and PTFE CG 32-3. The chemical composition was determined using X-ray photoelectron spectroscopy (XPS). Complementary information about the chemical structure is obtained with Fourier transform infrared spectroscopy (FTIR). Second part of the present paper investigates the effect of the cutting force in the turning of PTFE GR and PTFE CG 32-3 materials. The effect

Table 1
MAIN PROPERTIES FOR THE STUDIED COMPOSITES

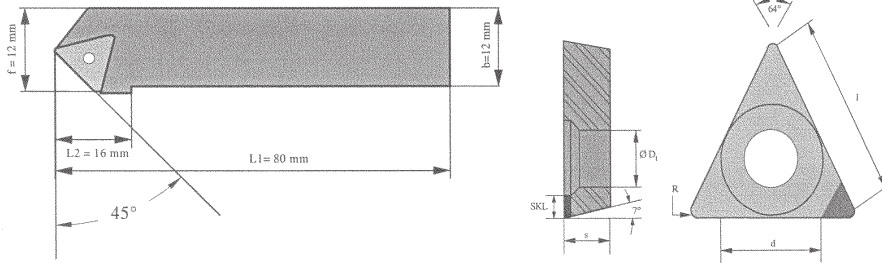| Code	Reinforcing agents	Density [kg/cm^3]	Hardness Rockwell M	Stretch resistance [kgf/cm^2]	Elongation [%]
PTFE GR	regenerated graphite	1.98÷2.08	58÷65	50	30
PTFE CG 32-3	32% carbon + 3% graphite	2.05÷2.12	64÷69	60	30

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Fig. 1. The geometry of the cutting tool

of different parameters on cutting force are analyzed and presented.

X-ray photoelectron spectroscopy (XPS)

The XPS spectra were recorded on Thermo Scientific K-Alpha spectrometer, fully integrated, equipped with an aluminum anode monochromatic X-ray source. Pressure inside the ultra high vacuum chamber was maintained around 5×10^{-9} Pa during the course of analysis. Dimensions of the analyzed areas were typically 30 - 400 μm. Binding energies for all observed photopeaks were referenced to the value of the carbon-carbon/carbon-hydrogen bond at 285.0 eV. Atomic concentration calculations and curve fitting were carried out using Advantage software version 1.0.

Fourier transform infrared spectroscopy (FTIR)

FTIR analysis is an advanced technique that provides essential information about the chemical structure of the studied material due to the vibrational characteristics of various bonds from the molecule. The FTIR Spectra were recorded on a FT-IR Bruker Vertex 70 spectrometer using 30 scans with a resolution of 4 cm^{-1} in 400-4000 cm^{-1} region. The samples were run from KBr pellets.

Cutting force measurements

Orthogonal cutting experiments were performed using a CNC machine at a series of cutting speeds up to 163.28 m/min, different cutting depths 0.5, 1, 1.5 and 2 mm, and different feed rates 0.053, 0.106, 0.167 and 0.25 mm/rev. The geometry of the cutting tool is presented in figure 1. The cutting tool was a PCD (polycrystalline diamond) with nose radius r_ε = 0.4 mm, according to ISO 2004.

The cutting force during machining is measured based on Hottinger strain gauges [9]. The gauge is installed on the cutting tool at the point and direction where the strain is to be measured figure 2.
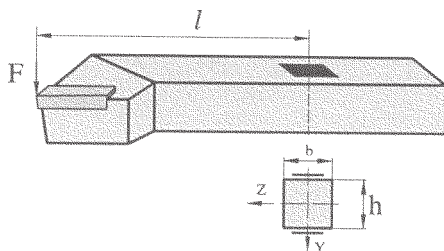

Fig. 2. The design of strain gauges

The strain gauge has the following characteristics: measuring grid length of 22.07 mm, nominal resistance of 120 Ω and bridge supply voltage of 4 V.

The force signals were captured and processed using the data acquisition system based on hardware SPIDER 8 which consists of eight digital amplifiers operation in frequency of 4.8 kHz [7, 8, 10]. Principle of cutting force measurements follows the equation of bending momentum:

$$\sigma_m = \frac{M_y}{W_y} = \frac{F \cdot l}{\dfrac{b \cdot h^2}{6}} = \frac{6 \cdot F \cdot l}{b \cdot h^2}; \, [Pa] \qquad (1)$$

where: σ_m – normal stress [Pa];
  F – cutting force [N];
  l = 22.07 [mm];
  $b = h$ = 12 [mm].

$$\varepsilon = \frac{\sigma_m}{2.1 \cdot 10^5}. \qquad (2)$$

where: ε – specific deformation [μm/m].

$$W_y = \frac{b \cdot h^2}{6}; \qquad (3)$$

$$M_y = F \cdot l. \qquad (4)$$

The measurement force is

$$F = \frac{2.1 \cdot \varepsilon \cdot 172.8}{132.42} [N]. \qquad (5)$$

Results and discussion

When working with polymers, the characterization represents an important step, because the macro-molecules structure and organization determine the mechanical, physical and chemical properties of the material.

The molecular structure of the polymer determined by XPS and FTIR plays an essential role in linking the structure with material properties. This combination of spectroscopic methods was used to establish individual differences between the chemical structures for the used materials.

XPS survey spectra

Survey scans (0-1200 eV) were performed to identify constitutive elements. The survey spectra allow a rapid identification of the elements from the surface of the sample and their relative atomic concentration (At%).

Figure 3 reveals the survey spectrum for each material PTFE GR and PTFE CG 32-3. The XPS survey spectra illustrate that the composites surfaces are primarily composed of carbon C (1s) and fluorine F (1s), photopeaks indicative of Teflon. A small amount of oxygen O (1s) is also observed. The presence of oxygen is probably due to adsorption from residual atmosphere.

Table 2 lists relative atomic concentrations (At%) of carbon, fluorine and oxygen found in composites.

High resolution XPS spectra

High resolution C(1s) spectra were acquired from each sample and are shown in figure 4. There are no significant differences in the spectra of both materials PTFE GR respectively PTFE CG 32-3.

For the both samples, two C(1s) lines were detected at a binding energy of 283 eV and at 291 eV, which are assigned to C-C and respectively to C-F bonds.
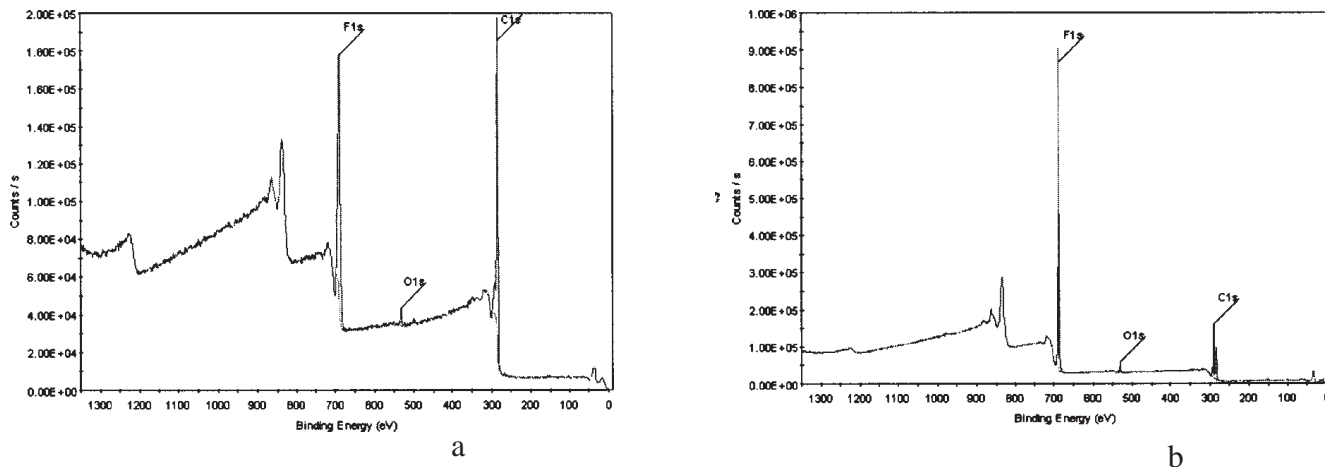
Fig. 3. XPS survey spectra for a) PTFE GR and b) PTFE CG 32-3

Table 2
RELATIVE ATOMIC CONCENTRATIONS (At %) OF THE ELEMENTS FROM THE XPS SURVEY SPECTRA

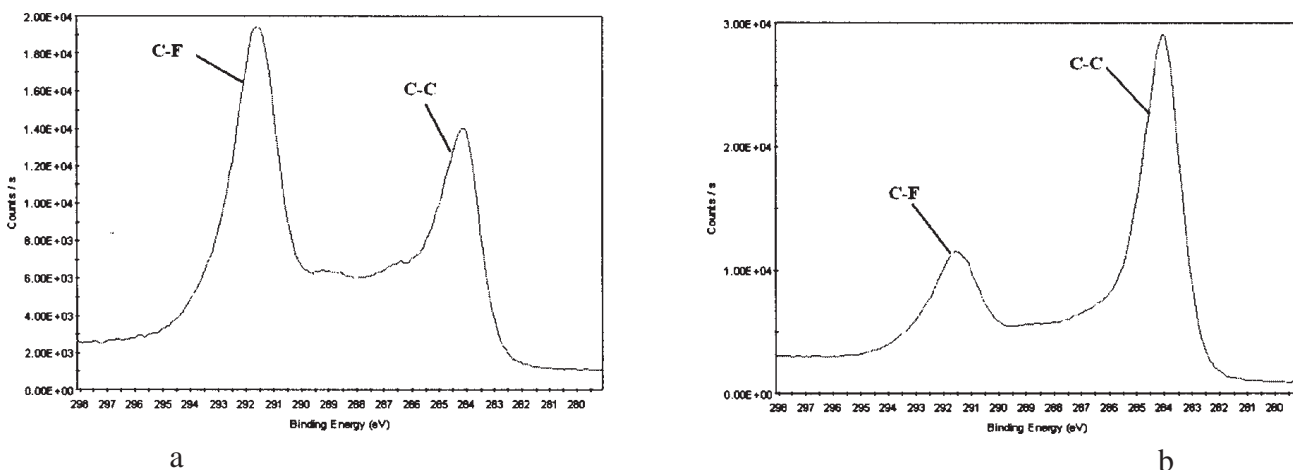| Sample	At% C 1s	At% F 1s	At% O 1s
PTFE GR	68.88	29.41	1.70
PTFE CG 32-3	45.01	52.58	2.41

Fig. 4. High resolution C(1s) XPS spectra for a) PTFE GR and b) PTFE CG 32-3

In the PTFE GR XPS spectrum, the peak located at a binding energy of 283.84 eV, is assigned to C-C bond. For PTFE CG 32-3 the corresponding peak is found at 283.99 eV.

The formation of C-F bond induces chemical shifts of binding energy that could be detected on higher energy levels 291.49 eV in PTFE GR and 291.68 eV in PTFE CG 32-3.

In the XPS spectrum of PTFE GR, C-F bonds have a higher contribution (At = 63%), in comparison with the proportion of C-F bonds (At = 26%) from the XPS spectrum of PTFE CG 32-3. This is probably due to the reinforcing agents incorporated in the PTFE CG 32-3, which replace a certain amount of fluorine.

FTIR spectroscopy
The two FTIR spectra are shown in figure 5. The results of FTIR analyses indicate the presence of only three important absorptions peaks at 1191, 1140, and 622 cm^{-1},
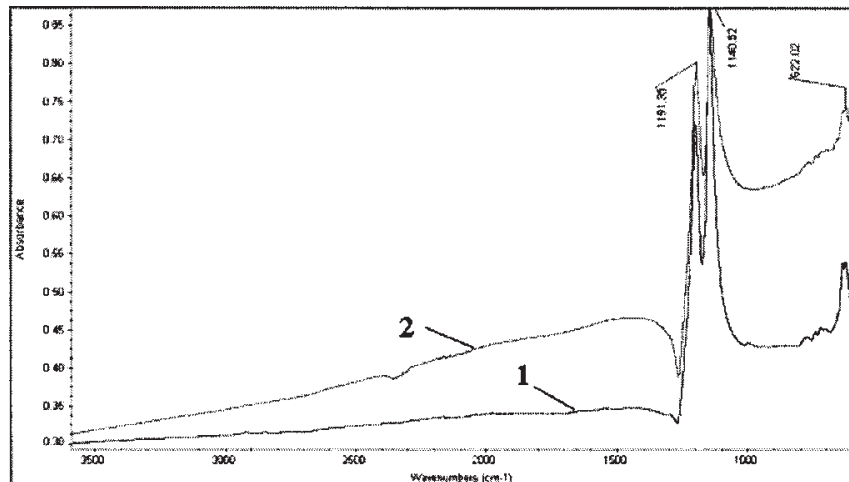
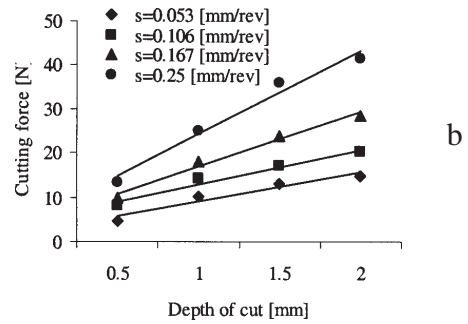

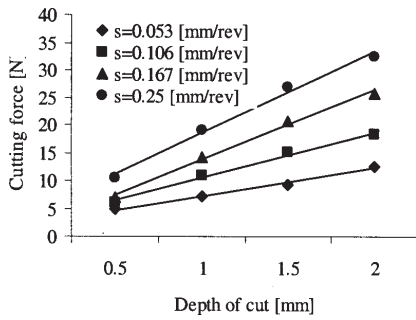Fig. 5. FTIR spectra for PTFE GR (1) and PTFE CG 32-3 (2)

Fig. 6. Effect of the depth of cut and feed rate on the cutting force;
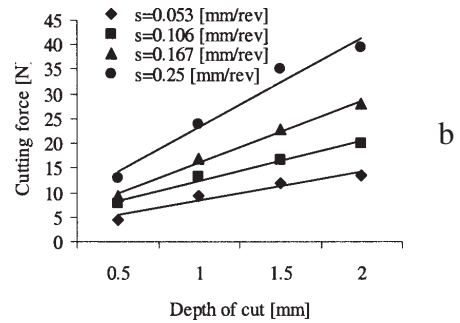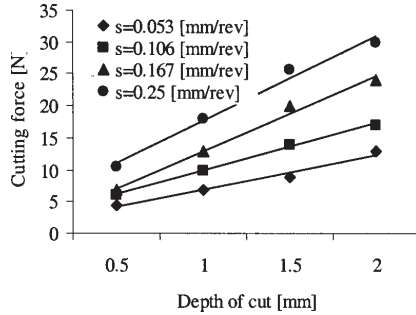a)PTFE GR, b) PTFE CG 32-3, v=51.02 m/min

Fig. 7. Effect of the depth of cut and feed rate on the cutting force;
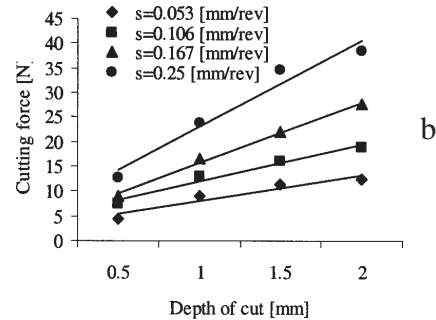a)PTFE GR, b) PTFE CG 32-3, v=102.05 m/min

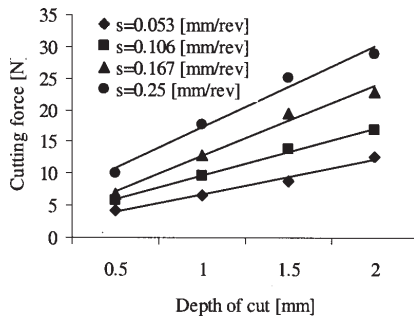

Fig. 8. Effect of the depth of cut and feed rate on the cutting force;
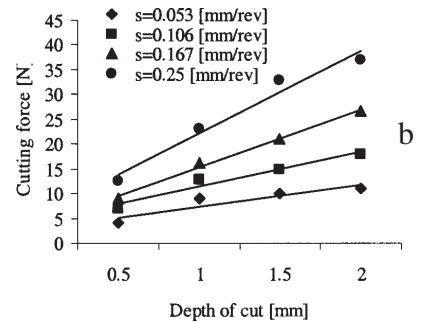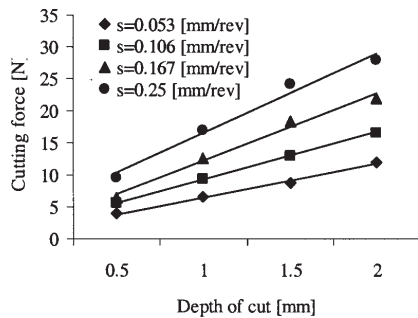a)PTFE GR, b) PTFE CG 32-3, v=128.58 m/min

Fig. 9. Effect of the depth of cut and feed rate on the cutting force;
a)PTFE GR, b) PTFE CG 32-3, v=163.28 m/min

due to the simple structure of the polymer. The characteristic peak for teflon appears at 622 cm^{-1} and is assigned to C-F stretch.

Cutting force results

The variations of the cutting force as a function of feed rate (*s*) and depth of cut, the cutting speed is constant 51.02 m/min, are plotted in figure 6 a) for PTFE GR and b) for PTFE CG 32-3.

Figure 7 shows the variation of cutting force function of cutting parameters feed rate and depth of cut at constant

cutting speed 102.05 m/min for the same polymeric materials a) for PTFE GR and b) for PTFE CG 32-3.

The effect of depth of cut and feed rate on cutting force, for a constant cutting speed 128.58 m/min is presented in figure 8.Figure 9 presents the evolution of cutting force function of two varying parameters, with the cutting speed value of 163.28 m/min.

From the experimental results, it is observed that the increase of feed rate produce higher cutting force values. The depth of cut plays a minor role on polymeric machining process. Comparing the cutting force materials at different
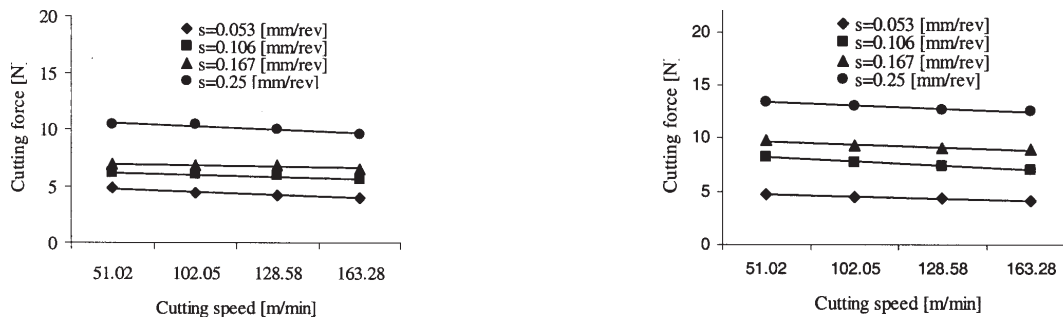
Fig. 10. Influence of cutting speed on cutting force; a) PTFE GR, b) PTFE CG 32-3, depth of cut = 0.5 mm

cutting speeds, for depth of cut 0.5 mm it can be observed that the force values are between 3÷11 N. According to the graphs, for PTFE GR material are necessary smaller force values comparing with PTFE CG 32-3.

The comparison between force results for different cutting speeds 51.02, 102.05, 128.58, 163.28 m/min, depth of cut constant 0.5 mm, at different feed rate 0.053, 0.106, 0.167, 0.25 mm/rev, for PTFE GR and PTFE CG 32-3 polymeric materials is presented in figure 10.

Unlike the variations of forces with feed rate and depth of cut discussed above, in this case, cutting force can be seen to decrease approximately linearly with increase in speed.

Conclusions

Correlative X-ray photoelectron spectroscopy (XPS) and Fourier transform infrared (FT-IR) studies of the complex heterogeneous structure of graphite-based Teflon composites are presented. The results of the XPS investigations show only two photopeaks, carbon C (1s) and fluorine F (1s), indicative of Teflon. The obtained FTIR spectra confirm the chemical structure obtained by XPS.

After polymeric materials machining the following conclusions can be drawn:
- the increase of feed rate produces higher cutting force values for PTFE CG 32-3 and lower for PTFE GR polymeric materials;
- the depth of cut plays a minor role on orthogonal cutting of polymeric materials;
- the cutting force decrease approximately linearly with increase in cutting speed.

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