Experimental Study on the Cutting Forces in PTFE Orthogonal Cutting

DANIEL VLAD[1], CATALIN FETECAU[1]*, CRISTIAN DOICIN[2], LIVIU IULIAN PALADE[3]

[1]Dunarea de Jos University of Galati, Faculty of Mechanical Engineering, Deparment of Manufacturing Robotics and Welding Engineering, 111 Domenasca Str., 800201, Galati, Romania

[2]University Politehnica of Bucharest, IMST Faculty, 313 Spaliul Independentei, 060042, Bucharest, Romania

[3]Université de Lyon, CNRS, Institut Camille Jordan UMR5208, INSA-Lyon, Pôle de Mathématiques, Bât. Léonard de Vinci, 401, 21 Avenue Jean Capelle, F-69621 Villeurbanne, France

The study aims at analysing the effect of the glass microfiber content on the variation of the cutting forces in the orthogonal turning process of two types of polytetrafluoroethylene: PTFE and PTFE S25 (25 [wt%] glass microfibers) with a polycrystaline diamond (PCD) tool. The influence of the process parametres (cutting speed and feed rate), as well as that of the geometrical parametres of the cutting part of the tool (rake angle γ when the clearance angle α and the incidence angle χ are constant) on the two components of the cutting force (cutting force, F_z, and feed force, F_x). The values of the turning forces were recorded with a Kistler piezoelectric dynamometer (type 9257B). Experimental results indicated that the value of the cutting force decreases with the increase of the cutting speed. Moreover, the glass microfiber content influences the value decrease of the main cutting force component. A statistical mathematical model, determined by linear regression, was developed to analyze the influence of varying parametres on the cutting force components (F_z and F_x).

Keywords: PTFE, orthogonal cutting, cutting force, PCD tool

The mechanical cutting of polymeric materials has been increasingly used to obtain single or small-scale products, or certain forms, surfaces and tolerances for parts that cannot be obtained by pressing, turning or injection [10, 12, 14, 20].

Few research studies are available in the literature concerning the machining of polymeric materials or their behaviour under cutting.

Roy and Basu [4] investigate the effects of process parametres on the main cutting force component, on roughness, and on the determination of a model by multiple linear regression for the two elements. One of the authors' final findings was that the cutting depth is the main parameter influencing the cutting force components, followed by the feed rate. Instead, they noticed that the influence of the cutting speed on the value of the cutting force is insignificant.

Davim and Mata, [1], used a polycrystaline diamond (PCD) cutting tool to run turning tests on glass fibre reinforced plastics (GFRPs), in order to identify the optimal cutting mode for surfaces that observe ISO 7 and ISO 8. This optimal cutting mode was determined by linear regression and the conclusion is that surface roughness increases with the increase of the feed rate and decreases with the cutting speed.

The experimental work by Wang and Zhang, [7], investigates the orthogonal cutting of an carbon fibre reinforced epoxy resin. One of the conclusions is that the orientation of the carbon fibres highly influences the value of the cutting forces (measured with a Kistler piezoelectric dynamometer, type 9257B), as well as surface roughness.

Davim and Mata, [3] achieved an experimental study on the cutting process for polyamides PA 6 and PA 66-GF30. The aim was to evaluate the influence of glass fiber reinforcement on chip compression ratio, friction angle, shear angle, normal stress, and shear stress. Using the Merchant model of shear angle, the two authors concluded that the effect of glass fibres in the under prefixed cutting parametres (cutting velocity and feed rate), glass fibres on the PA 66-GF30 composite is an increase of the values of the cutting forces (for friction angle and normal stress), whereas, for the PA 6 composite, the values of the chip deformation and the shear stress are higher.

Silva et al., [8], studied the variation of the forces F_x (axial), F_y (radial), and F_z (the main cutting force component) during the micro-turning of the PA 66-GF30 composite, using cutting tools with CVD (diamond coated carcarbide), K15 (metalic carbide) and PCD (poly-crystalline diamond) plates. The machining with the PCD plate cutting tool resulted in lower numerical values for the main cutting force component, in comparison with the values for the turning with the other plates.

Davim et al. [22], investigated the cutting forces involved in the turning of two polymers (PA 6 and PA 66-GF30) with two types of plates: polycrystalline diamond (PCD) and cemented carbide (K 15). The cutting forces were measured with a Kistler piezoelectric dynamometer, type 9121, and the tubes samples used were 113 mm of diameter and thickness of wall of 6 mm. The results indicated that cutting tools with PCD plates lead to the lowest values of the cutting force and the finest roughness.

In his study, Wyeth [9] examines the validity of existing cutting theories (Merchant, Lee-Shaffer, and Atkins) using orthogonal cutting for Nylon 66. The author determined the cutting forces and compared the values of the shear angle analytically obtained from theory with experimental data.

Machining by cutting of turned composites was the object of study of Mata et al. [11]. The results regarding the cutting forces, the wear of the cutting tool, the temperature and quality of the surface after turning were analyzed and compared in terms of the influence of filling material

* email: catalin.fetecau@ugal.ro; Tel.: 0744276267

(carbon fibres). A mathematical model was realized based on linear regression, which can predict very precisely the values of the cutting forces for the turning of PEEK polymeric materials additivated with carbon fibres, with a correlation ratio between 0.9 and 0.99%.

The present paper will study the influence of the content of glass microfibres and of the cutting mode parametres, speed and feed rate, as well as of the angle of the rake tool on the cutting forces during orthogonal turning of two PTFE types: unfilled and reinforced with 25% glass microfibres. The numerical values of the cutting force have been obtained using a Kistler piezoelectric dynamometer (type 9257B), based on a Taguchi statistical experiment plan, with three 3-level factors. Experimental data were analyzed in terms of the signal-to-noise ratio, and the ANOVA variance analysis method. Consequently, a mathematical model based on linear regression was performed to estimate the numerical values of the cutting force and to study the influence of the cutting speed, the feed rate and the rake angle on the components of the resulting cutting force, F_z and F_x.

Experimental part

Materials and experiment methodology

PTFE is a semi-crystalline polymer of the group of Fluoropolymers $(F2\text{-}C{=}C\text{-}F2)_n$, known under the name of Teflon, with applications in almost all activity domains [11, 13, 17, 19]. It is a thermoplastic material containing carbon and fluorine atoms, and the atomic bonds are very strong [13]. Due to its high melt temperature (approximately 327°C), its viscosity is also very high (in the order of 1010 Pa s), which results in parts made of PTFE composites being prepared by compression molding and free sintering [15, 17]. In order to enhance properties like wear resistance, compression resistance, hardness, electric and thermal conductivity, PTFEs are reinforced with glass or carbon fibres, graphite, sulphur, molybdenum, bronze, metal oxides [16, 18, 19]. Glass and carbon fibres are commonly used fillers for thermoplastics with multiple applications [10, 11, 14, 16, 18, 22].

Orthogonal cutting experimental tests have been conducted on two types of PTFE, PTFE (100% polytetrafluoroethylene), and PTFE S25 (25 [wt%] glass micro-fibres), in order to determine the values of the cutting force components.

The mechanical and thermal characteristics of the materials used are listed in table 1.

The purpose of conducting these tests was to study the influence of glass micro-fibres addition, of process parametres (feed rate and cutting speed), and that of the angle of the rake tool γ on the cutting forces, as well as to develop a model that can predict, with minimum error, the value of the forces involved in PTFE orthogonal turning process.

The experimental work was conducted at the Faculty of Engineering and Management, "Stefan cel Mare" Technical University of Suceava, on a universal lathe, type SN 320x750, without cooling, at ambient temperature (23°C). The bar samples were 250 mm long, with a φ50 mm outer diameter and a φ42 mm inner diameter.

The cutting scheme used in this experiment (free orthogonal turning), the cutting force components, the cutting tool and the sample are presented in figure 1. The cutting force component Fy is zero in orthogonal turning.

The cutting tool has been provided with a PCD plate with different rake angles (γ = 6°, -6° and 0°), and a constant clearance angle (α=7°). This way, the width (7 mm) of the PCD plate is greater than that of the sample (4 mm).

To achieve the study on the variation of the cutting forces, an experiment plan was devised (table 2), which included three values for each rake angle, cutting speed and feed rate, resulting in 27 combinations.

For each of these combinations, three tests have been carried out, and three values of the cutting forces were recorded when the orthogonal turning process became steady, and then their average was calculated.

A Kistler piezoelectric dynamometer (type 9257B) measured the cutting force components, a 5070 amplifier and a PC equipped with the Dynoware software achieved data acquisition at an acquisition frequency of approximately 3kHz. The general scheme is presented in figure 2: the main cutting force component F_z (axis *Z*), and the force corresponding to the feed rate F_x, measured transversally, in the sense of the cutting direction (axis *X*).

Table 1
THE MECHANICAL AND THERMAL CHARACTERISTICS OF THE MATERIALS [26]

Material	Density [kg/m^3·10^{-3}]	Elongation, [%]	Hardness, Shore D	Strength stress, [MPa]	Melting point, [°C]
PTFE	2,12÷2,18	300	55÷58	30	329,52
PTFE S 25	2,18÷2,24	210	63÷66	15	330,81

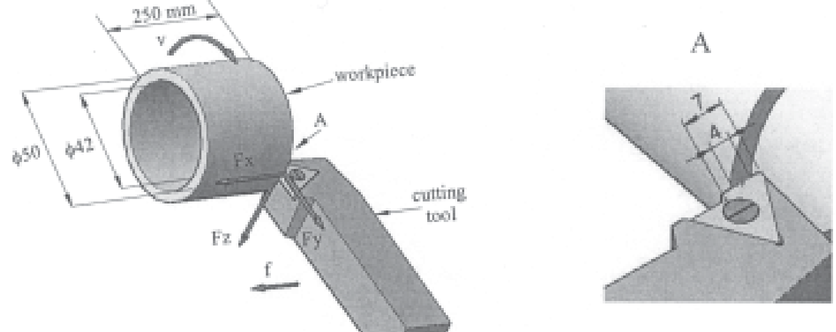

Fig. 1. Schematic representation of orthogonal turning process

Table 2
EXPERIMENTAL PLAN

Geometrical and process parameters	Low level (-1)	Center level (0)	High level (1)
Rake angle, *γ*, [°]	-6	0	6
Feed, *f*, [mm/rev]	0.08	0.14	0.28
Cutting speed, *v*, [m/min]	60	95	155

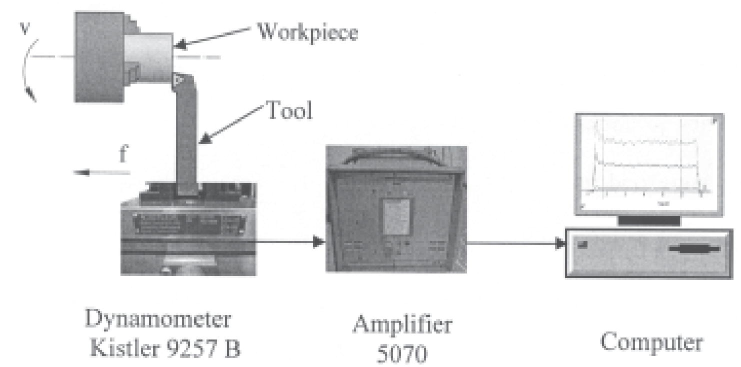

Fig. 2. Experimental setup

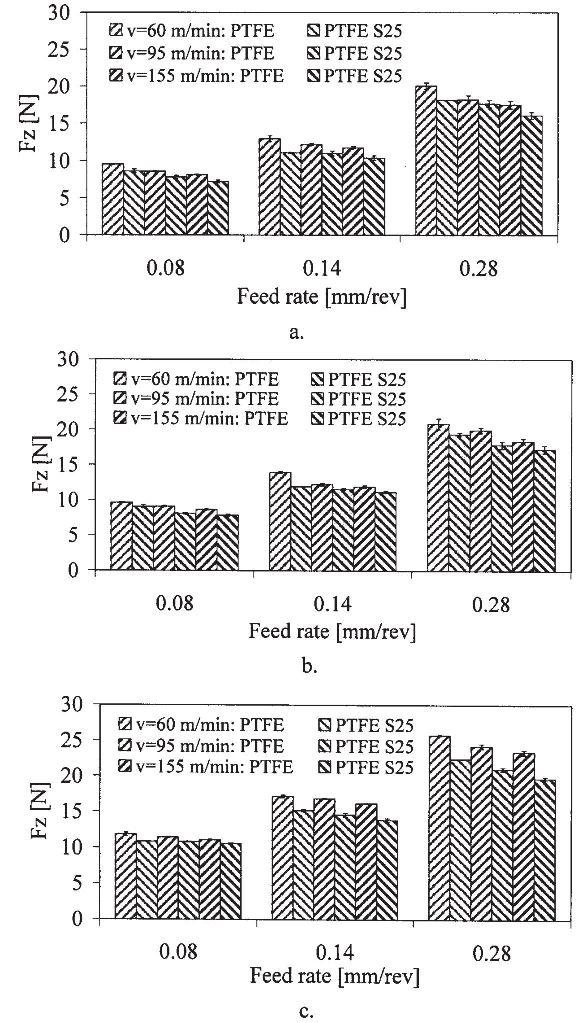

Fig. 3. Comparison of cutting force F_z as a function of feed rate and cutting speed, for: a.$\gamma=+6°$; b. $\gamma=0°$; c. $\gamma=-6°$.

Dynamometer measurements can be used within ± 5kN, with a sensitivity of approximately -7.5 pC/N for F_x and F_y, and about -3.7 pC/N for F_z.

Results and discussion

During orthogonal cutting it is assumed that the cutting is uniform along the rake face [2, 5, 24, 25]. Cutting forces act only in the directions of the cutting speed and the feed rate. The third component, F_y, acting in the direction of the tool, is zero. Same type cutting plates were used, with a clearance angle α=ct=7°, and the seats of the plates were cut so as to obtain the three different rake angles (γ=6°/0°/ -6°).

For the study of the influence of the cutting speed on the cutting force components, the experimental tests were carried out at three different speeds: v=60m/min, v=95m/min, and v=155 m/min. The comparison results of the two materials regarding the variation of the cutting force F_z with the feed rate at the three rake angles are presented in figure 3.

Figure 3 shows that the 25% glass microfibre content reduces the values of force F_z when compared with those for the PTFE. The lower hardness and the higher elongation of glass micro-fibres causes a decrease in resistance of the sample machined by cutting when compared with not reinforced PTFE samples, with a higher resistance. It is also observed that the main cutting force component F_z increases with the increase of the feed rate and decreases with the increase of the cutting speed.

Figure 4 is a comparative presentation of the values recorded for F_x in relation to the feed rate, for the two materials tested. Increasing the feed rate determines the increase of the numerical values of the cutting force component F_x. Glass microfibre reinforcement leads to a value increase of force F_x for the same cutting mode in orthogonal turning with different rake angles of the tool. Higher values are recorded for the PTFE S25 material.

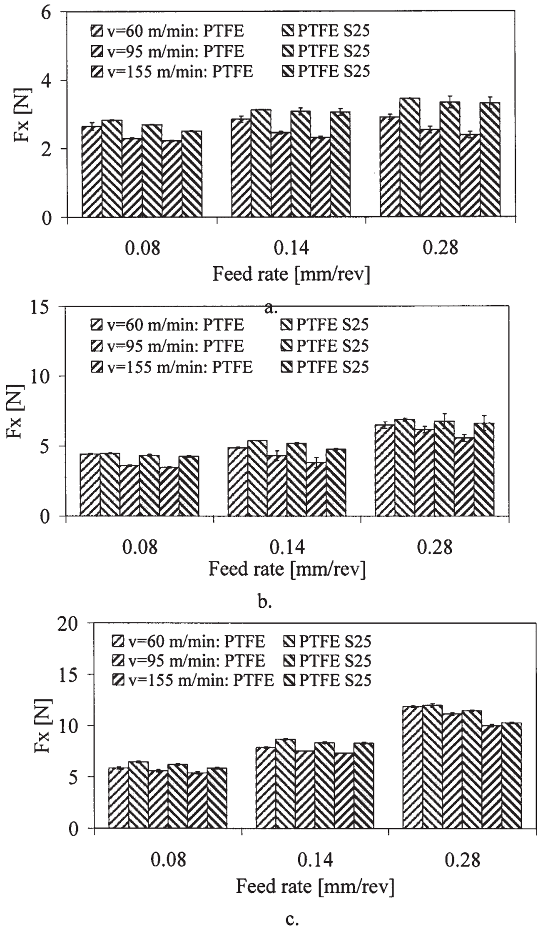

Fig. 4. Comparison of cutting force F_x as a function of feed rate and cutting speed for: a. $\gamma=+6°$; b. $\gamma=0°$; c. $\gamma=-6°$.

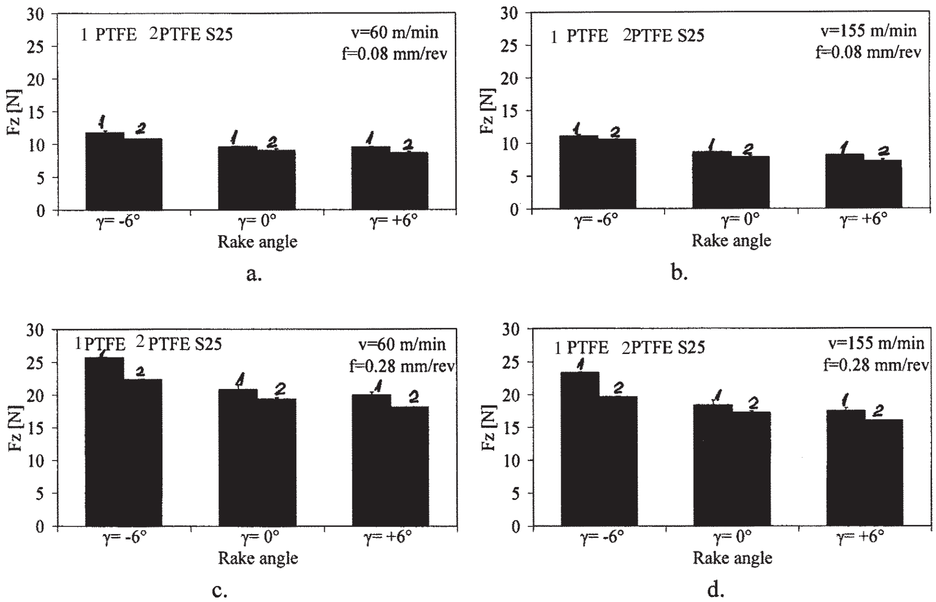

Fig. 5. The comparison of two materials for cutting force Fz as a function of rake angle at different cutting regime

A comparison of the results obtained for the main cutting force component depending on the three rake angles is shown in figure 5. The numerical values of the cutting force decrease with the increase of the rake angle. The explanation is that at a small rake angle (close to zero or negative), the deformation of the material is higher. Adding filler material causes a decrease of the cutting force component F_z, in the same cutting mode, and the lowest values are obtained for the PTFE S25 sample.

Analysis of variance ANOVA

The ANOVA test was performed to calculate the effects of all factors and their interactions, as well as to determine the influence of cutting parameters and their interactions, in percentages, taking into account freedom degrees and residues [11, 23]. The analysis was performed using the Minitab 16 programme.

ANOVA analysis of PTFE

Conducting orthogonal cutting tests on the PTFE sample as planned resulted in values for the two forces.

The diagrams in figure 6 present the impact of the feed rate, the cutting speed and the rake angle on the two cutting force components F_z and F_x, as well as the signal/noise ratio.

As can be easily noticed, an increase in the feed rate increases the main cutting force component F_z and the feed rate component F_x, which is due to the fact there is an increasing cutting effort which also increases the specific cutting pressure. When the cutting speed increases, the forces remain almost constant. When the value of the rake angle increases, the numerical values of the force decreases, as confirmed by experimental results (fig. 5).

To obtain an optimal mode, the signal-to-noise ratio is determined. The Taguchi method allows for the calculation of the S/N ratio, and the selection of the performance characteristic between "smaller is better", "large is better" or "normal is better" [20, 23]. The S/N ratio is the ratio between the value wanted and the one unwanted, both being exit characteristics

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \text{ [dB]}, \qquad (1)$$

where:

n is the number of measurements;

y_i – the measured values for every i test.

This method allows for the selection of the best values of the cutting forces in the orthogonal cutting of PTFE. In the case under analysis, the value wanted is the smallest.

The "smaller is better" criterion was selected to calculate the average of the responses for the S/N ratio, both for F_z and for F_x. In order to find the minimal value of the cutting force, the level of the factors must be selected so as their effect is the minimization of the force. In the case of the PTFE sample under analysis, it has been established that the minimal value is reached when the factors are: minimal feed rate (level 1, f=0.08 mm/rot), rake angle (level 3, +6°), and maximal cutting speed (level 3, 155 m/min). These values are valid for both force components.

To obtain the statistical significance of process variables and their interactions on the cutting forces in PTFE orthogonal turning, the ANOVA procedure was applied.

Table 3 shows the significant effect that the feed rate and the rake angle have on the main cutting force component F_z for P values smaller than 5%. The last column represents the percentage contribution of each factor in the total variance indicating its influence on each term of the model. The cutting speed, as well as the interactions between, on the one hand, the feed rate and the rake angle, and, on the other hand, between the feed rate and the cutting speed have a less than 2% contribution to the force F_z even if the P-value is smaller than 5%.

Table 3
ANOVA ANALYSIS OF F_z, FOR PTFE MATERIAL

Parameters	DOF	Seq SS	Adj SS	Adj MS	F-Test	P	Contrib %
Feed rate, f	2	571.92	571.92	285.96	3049.35	0.00	82.45
Rake angle, γ	2	98.29	98.29	49.14	524.03	0.00	14.17
Cutting speed, v	2	12.26	12.26	6.13	65.35	0.00	1.77
$f\cdot\gamma$	4	8.61	8.61	2.15	22.94	0.00	1.24
$f\cdot v$	4	1.59	1.59	0.40	4.23	0.04	0.23
$\gamma\cdot v$	4	0.26	0.26	0.07	0.70	0.62	0.04
Erorr	8	0.75	0.75	0.09			0.11
Total	26	693.67					100.00
R^2 = 99,89% ; R^2(adj) = 99,65%							

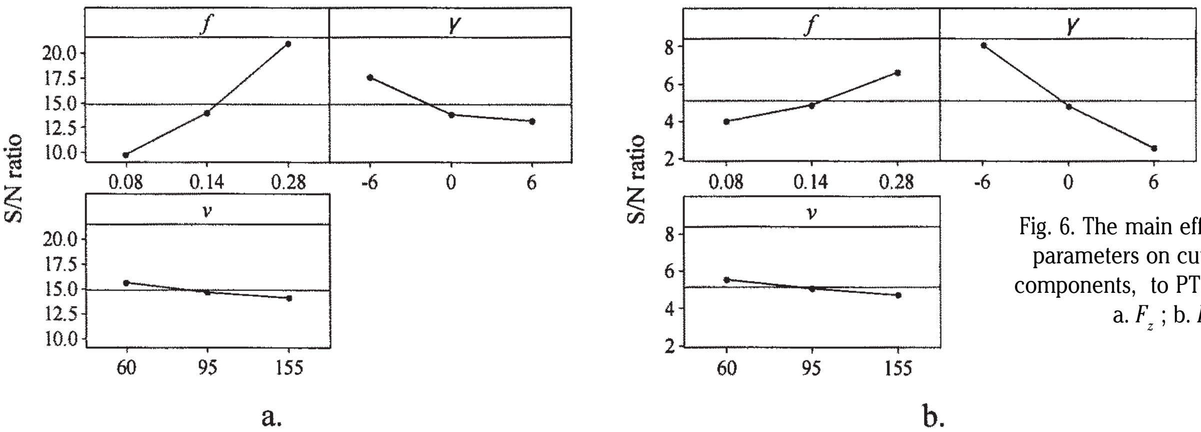

Fig. 6. The main effects plot of parameters on cutting force components, to PTFE material: a. F_z ; b. F_x

Table 4
ANOVA ANALYSIS OF F_x, FOR PTFE MATERIAL

Parameters	DOF	Seq SS	Adj SS	Adj MS	F-Test	P	Contrib %
Feed rate, f	2	32.36	32.36	16.18	281.67	0.00	16.30
Rake angle, γ	2	140.88	140.88	70.44	1226.17	0.00	70.95
Cutting speed, v	2	2.97	2.97	1.48	25.81	0.00	1.49
$f{\cdot}\gamma$	4	21.39	21.39	5.35	93.10	0.00	10.77
$f{\cdot}v$	4	0.26	0.26	0.07	1.13	0.41	0.13
$\gamma{\cdot}v$	4	0.26	0.26	0.06	1.11	0.42	0.13
Erorr	8	0.46	0.46	0.06			0.23
Total	26	198.57					100.00
R^2 = 99,77% ; R^2(ajustat) = 99,25%							

The statistical model of the main cutting force component F_z, based on the ANOVA linear regression, is

$$Fz = 6.197 + 62.202{\cdot}f - 0.152{\cdot}\gamma - 0.004{\cdot}v - 1.25{\cdot}f{\cdot}\gamma - 0.072{\cdot}f{\cdot}v \quad [N] \qquad (2)$$

Taking into account contributions larger than 2%, the model for F_z is

$$Fz = 6.197 + 62.202{\cdot}f - 0.152{\cdot}\gamma \quad [N] \qquad (3)$$

For this model, the correlation coefficient, R^2, is 96.96%, and the corelation coefficient adjusted with the freedom degrees is 96.24%.

To establish a linear regression model also for the feed component of the cutting force F_x, the ANOVA procedure was applied (table 4).

The linear regression model for the cutting force component F_x was devised considering the effects of the feed rate and the rake angle and their interaction. The contribution of the cutting speed is under 2% and has not been included in the model

$$Fx = 3.78 + 13.056{\cdot}f - 0.106{\cdot}\gamma - 2.144{\cdot}f{\cdot}\gamma \quad [N] \qquad (4)$$

For this model, the corelation coefficent, R^2 (used to stablished the quality of the model) is 97.35%, and the corelation coefficient adjusted with the freedom degrees is 96.86%.

Differences between measured and estimated values of the cutting force components were analysed by means of the residue charts in figure 7, the residue representing the difference between experimental values and values estimated by the model at each stage of the experiment. The confidence interval is 95% and the level of significance is 5%. The charts show that there is a normal distribution of the residues and P-values are 0.228 for F_z and 0.478 for F_x, both higher than 5%.

The relative error of the two models of cutting forces was calculated using the relation

$$\varepsilon = \frac{Val_{exp} - Val_{mod}}{Val_{exp}} * 100, \qquad (5)$$

where:

ε is the relative error;

Val_{exp} –experimental value of the cutting force;

Val_{mod} –calulated value of the cutting force through linear regression model.

For the PTFE sample, the maximal relative errors registered for the two models were between 0.4142 and 10.81% for F_z, and between 0.088 and 14.6 for F_x.

ANOVA analysis for PTFE S25

Following the orthogonal cutting of PTFE S25, the values of the two cutting force components have been obtained, and the S/N ratio has been calculated.

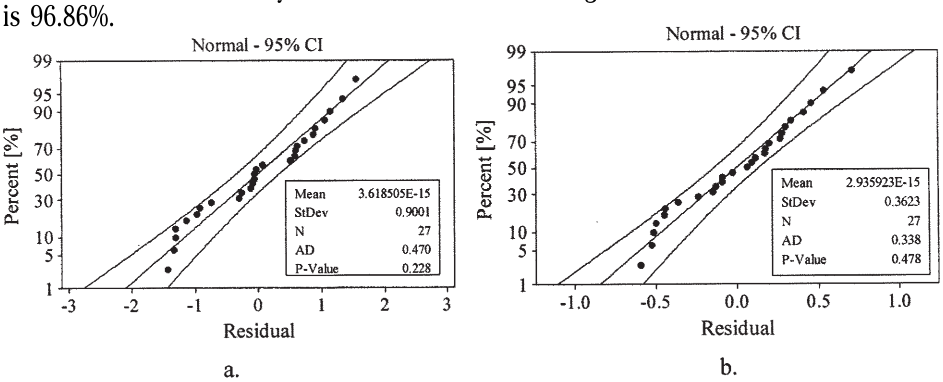

Fig. 7. Normal probability plot of residuals for cutting force components: a. Fz; b. Fx

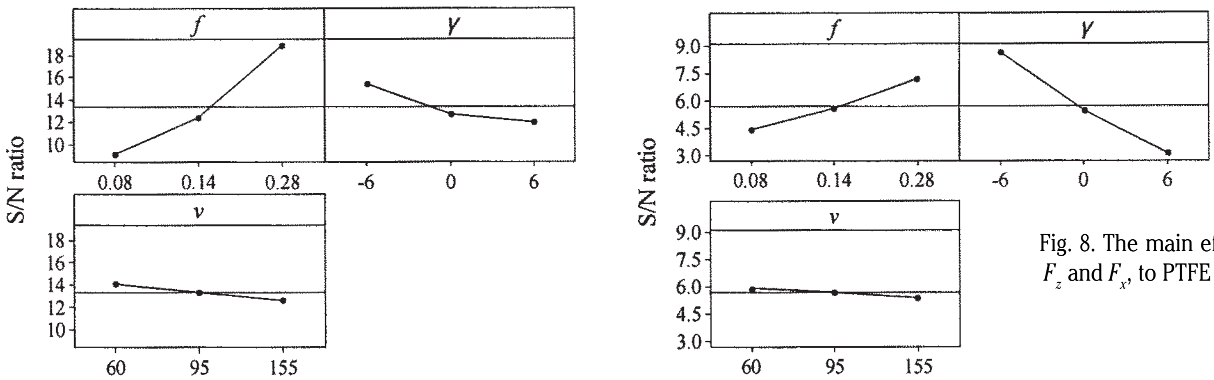

Fig. 8. The main effects plot for F_z and F_x, to PTFE S25 material

Table 5
ANOVA ANALYSIS FOR F_z, TO PTFE S25 MATERIAL

Parameters	DOF	Seq SS	Adj SS	Adj MS	F-Test	P	Contrib %
Feed rate, f	2	450.33	450.33	225.17	2265.60	0.00	86.17
Rake angle, γ	2	59.58	59.58	29.79	299.72	0.00	11.40
Cutting speed, v	2	8.85	8.85	4.42	44.51	0.00	1.69
$f\cdot\gamma$	4	0.81	0.81	0.20	2.04	0.18	0.16
$f\cdot v$	4	1.96	1.96	0.49	4.92	0.03	0.37
$\gamma\cdot v$	4	0.27	0.27	0.07	0.67	0.63	0.05
Erorr	8	0.80	0.80	0.10			0.15
Total	26	522.58					100.00
R^2 = 99,85% ; R^2(ajustat) = 99,51%							

Table 6
ANOVA ANALYSIS FOR F_x, TO PTFE S25 MATERIAL

Parameters	DOF	Seq SS	Adj SS	Adj MS	F-Test	P	Contrib %
Feed rate, f	2	33.84	33.84	16.92	263.28	0.00	17.59
Rake angle, γ	2	141.32	141.32	70.66	1099.57	0.00	73.46
Cutting speed, v	2	1.05	1.05	0.52	8.16	0.01	0.54
$f\cdot\gamma$	4	15.10	15.10	3.78	58.74	0.00	7.85
$f\cdot v$	4	0.12	0.12	0.03	0.46	0.76	0.06
$\gamma\cdot v$	4	0.43	0.43	0.11	1.67	0.25	0.22
Erorr	8	0.51	0.51	0.06			0.27
Total	26	192.37					100.00
R^2 = 99,73% ; R^2(adj) = 99,13%							

Table 7
RELATIONS BETWEEN THE TWO COMPONENTS OF CUTTING FORCE

	PTFE	PTFE S25
γ= -6°	F_x=(0,5...0,6)·F_z	F_x=(0,51...0,63)F_z
γ= 0°	F_x=(0,32...0,48)F_z	F_x=(0,35,,,0,49)F_z
γ= +6°	F_x=(0,14...0,29)F_z	F_x=(0,18,,,0,36)F_z

The charts in figure 8 present the influence of the three parameters on the two cutting force components. The increasing influence of the feed rate and the decreasing one of the rake angle are easily noticeable. A minimal reduction, almost insignificant, is represented by the effect of the cutting speed on the two forces, F_z and F_x.

The optimization criterion chosen was also "smaller is better". and the average of the response parameters for the S/N ratio was calculated. It is observed that the minimum is reached when the factors are as follows: minimal feed rate (level 1, f = 0.08 mm/rev), rake angle (level 3, +6°), and maximal cutting speed (level 3, 155 m/min). These values apply to both forces, F_z and F_x.

ANOVA analysis to PTFE S25 material is given in table 5

Looking at table 5, a value of P less than 5% was recovered from the three parameters of the process and the interaction between the speed and the feed. These interaction are incorporated into the regression model which is written as

$$F_z = 5.408 + 56.638 \cdot f - 0.286 \cdot \gamma - 0.001 \cdot v - 0.077 \cdot f \cdot v \text{ [N]} \quad (6)$$

Taking into account the same observation concerning the elimination of the factors with a lower than 2% contribution, the model for F_z is

$$F_z = 5.408 + 56.638 \cdot f - 0.286 \cdot \gamma \quad \text{[N]} \quad (7)$$

For this model, the corelation coefficent, R^2 (used to establish the quality of the model) is 98.19%, and the corelation coefficient adjusted with the freedom degrees is 97.87%.

The linear regression model for the cutting force F_x during the orthogonal turning of PTFE S25 considered the effects of the feed rate and the rake angle, as well as their interaction, both with a smaller than 5% value; the effect of the cutting speed, with a contribution of 0.54% to F_x (see Table 6), being eliminated. The model for the F_x component is determined by the relation

$$F_x = 3.999 + 13.242 \cdot f - 0.168 \cdot \gamma - 0.005 \cdot v - 1.782 f \cdot \gamma \text{ [N\}} \quad (8)$$

For this model, the corelation coefficent, R^2 (used to establish the quality of the model) is 98.26%, and the corelation coefficient adjusted with the freedom degrees is 97.94%.

As in the case of PTFE S25, figure 9 shows a normal distribution of the residues for the two cutting forces, the P-values being 0.474 for F_z, and 0.389 for F_x. Both values are higher than the 5% level of significance.

The relative error of the two models of cutting forces for the PTFE S25 sample was determined using equation (4). Errors reported for the two models are in the range 0.37 ÷ 14.7% for model F_z, and 0.22 ÷ 9.23% for model F_x.

Following the analysis of experimental results, relations of dependence between the two components of the

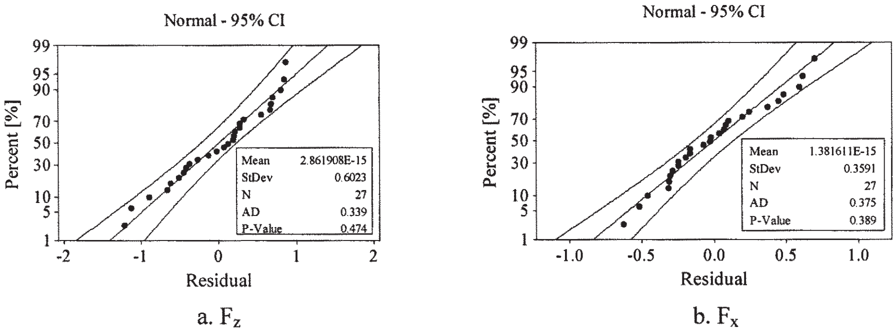

Fig. 9. The residual graphs of cutting forces model: a. Fz; b. Fx

cutting force F_z and F_x for each sample tested have been established. It is known from the literature [21] that the dependence between the cutting force components in metal turning is in the form of

$$F_x = (0{,}15\ ,,,\ 0{,}3)\cdot F_z \quad [\mathrm{N}] \qquad (9)$$

Consequently, for each of the two PTFE samples, relations between the two components of the cutting force were determined (table 7).

Conclusions

The present experimental investigations shows the influence of the glass micro-fibre filler and parameters such as, feed rate, cutting speed and rake angle on the cutting force components, F_z and F_x, during the orthogonal turning process of the two PTFEs, also developing a mathematical model based on linear regression for each material. This study aims to complement the knowledge about the behavior of polytetrafluoroethylene (PTFE) during orthogonal turning. The two components of the cutting force have been analyzed using the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA). Based on orthogonal turning tests, some conclusions can be drawn:

-the F_z and F_x cutting forces are significantly influenced by the feed rate (as resulted from the statistic data recorded), the latter's increase causing the increase of the two components during orthogonal turning of PTFE based materials;

-the cutting speed has a smaller than 2% contribution to the values of the cutting forces F_z and F_x, in both cases. Given that the maximal value of the forces is 30N, it can be concluded that the cutting speed does not influence the cutting forces during the turning of the two PTFEs;

-the numerical values of the cutting force components F_z and F_x decrease with the increase of the rake angle in both cases;

-the minimal value of the main cutting force component, F_z, is recorded in a mode where the feed rate is minimal, the cutting speed is maximal, and the rake angle γ is -6° (f=0,08 mm/rev and v =155 m/min) for each of the two materials, which is also confirmed by the signal-to-noise ratio;

-the glass micro-fibres reinforced in the PTFE determine the decrease of the values for the F_z component of the cutting force, in all modes tested. The fact that the glass micro-fibres have low hardness and high elongation determines a decrease in the resistance of the material machined by turning, in comparison with the non-reinforced PTFE material;

-the reinforcement with glass fibers determines the increase of the numerical values for the feed rate cutting force component F_x;

-statistical results show that the factor significantly influencing the main cutting force component F_z is the feed rate (between 82.45% for the PTFE, and 86.17% for the PTFE S25);

-the factor significantly influencing the feed rate component of the cutting force F_x is the rake angle, for both materials (minimum 70.95% for the PTFE, and maximum 73.46% for the PTFE S25);

-the models obtained by linear regression for the two cutting force components can predict, with slight errors, values of the cutting forces in the orthogonal turning of the two PTFEs.

References

1. DAVIM J.P., MATA F., 2005, Optimisation of surface roughness on turning fibre-reinforced plastics (FRPs) with diamond cutting tools, Int J Adv Manuf Technol, 26, p 319-323,

2.MAMALIS A.G., LAVRZNENKO S.N., 2007, On the precision single-point diamond machining of polymeric materials, Journal of Materials Processing Technology, 181, p, 203–205,

3.DAVIM P.J., MATA F., 2007, A comparative evaluation of the turning of reinforced and unreinforced polyamide, International Journal Advanced Manufacturing Technology, Vol. 33, p.911-914;

4. ROY P. K., BASU S. K., 1997, Evaluation of processing factors on turning of thermoplastic Polymer Engineering and Science, 17, p.751–757

5.SAGLAM H., UNSACAR F., YALDIZ S., 2006, Investigation of the effect of rake angle and approaching angle on main cutting force and tool tip temperature, Int J of Machine Tools&Manuf, 46, p.132-141

6.RAO G.V.G., MAHAJAN P., BHATNAGAR N., 2007, Micro-mechanical modeling of machining of FRP composites –Cutting force analysis, Composites Science and Technology, 67, p. 579–593;

7. WANG X.M., ZHANG L.C., 2003, An experimental investigation into the orthogonal cutting of unidirectional fibre reinforced plastics, International Journal of Machine Tools & Manufacture, 43, p.1015–1022

8. SILVA L., DAVIM P.J., FESTAS A., ABRAO A.M., 2009, Machinability aspects concerning micro-turning of PA66-GF30-reinforced polyamide, International Journal Advanced Manufacturing Technology, Vol.41, p.839-845.

9. WYETH, D.J., 2008, An investigation into the mechanics of cutting using data from orthogonally cutting Nylon 66, International Journal of Machine Tools & Manufacture, 48, p.896–904

10. QUADRINI F., SQUEO E. A., TAGLIAFERRI V., 2007, Machining of glass fiber reinforced polyamide, eXPRESS Polymer Letters Vol.1, No.12, p.810–816

11. MATA, F., BEAMUD, E., HANAFI, I., KHAMLICHI, A., JABBOURI, A., BEZZAZI, M., 2010, Multiple regression prediction model for cutting forces in turning carbon reinforced PEEK CF30, Advances in Materials Science and Engineering

12. XIAO K.Q., XIAO L.C., ZHANG, 2002, The role of viscous deformation in the machining of polymers, International Journal of Mechanical Sciences, 44, 2317–2336

13. PATIL P.D., FENG J.J., HATZIKIRIAKOS S.G., 2006, Constitutive modeling and flow simulation of polytetrafluoroethylene (PTFE) paste extrusion, J. Non-Newtonian Fluid Mech, 139, 44–53

14. BRIA, V., CIRCIUMARU, A., BIRSAN, I., G., 2011, Mat. Plast., **48**, no. 2, p. 189
15.ZHAO Z.H., CHEN J.N., 2011, Preparation of single-polytetrafluoroethylene composites by the processes of compression molding and free sintering, Composites Part B: Engineering, 42, Issue 5, p. 993-1336
16. STAN F., 2008,, Mat. Plast., **54**, no.1, p. 8
17. Huang R, Hsu PS, Kuo CY, Chen AC, Lai JY, Lee LJ, 2007, Paste extrusion control and its influence on pore size properties of PTFE Membranes, Adv Polym Technol, 26(3), p.163–72,
18. Poitou B, Dore F, Champomier R, 2009, Mechanical and physical charactersations of polytetrafluorethylene by velocity compaction, Int J Mater Form, 2, p.657–60,
19. Zhao J., 2007, α Transition of polyamide 6 in chemically bonded polyamide 6/polytetrafluoroethylene compounds studied by dynamic mechanical thermal analysis and dielectric thermal analysis, J Mater Science, 42(13), p.4757–62,
20. COSMA C., ROTAR D., CIOANA C., Mat. Plast., **48,** no. 3,2011, p.259
21. STEIU G., OPREAN C., LĂZĂRESCU I.D., STETIU M., 1994, Teoria si practica sculelor aschietoare, Editura Universitatii din Sibiu
22.DAVIM J.P., MATA F., 2007, New machinability study of glass fibre reinforced plastics using polycrystalline diamond and cemented carbide (K15) tools, Materials and Design, 28, p.1050–1054
23. MATHUKRISHNAN N., DAVIM J.P., 2009, Optimization of machining parameters of Al/SiC-MMC with ANOVA and ANN analysis, JMPT, 209, p.225-232
24. STAN F., 2010, Simulation of Delamination using Discontinuous Galerkin Finite Element Methods and Cohesive Models, Advances in Fracture and Damage Mechanics VIII Book Series: Key Engineering Materials Volume: 417-418, p. 501-504.
25.WYETH D.J., ATKINS A.G., 2009, Mixed mode fracture toughness as a separation parameter when cutting polymers, Engineering Fracture Mechanics, vol. 76, p. 2690-2697.
26. *** www.ceproinv.ro

Manuscript received: 6.08.2013