Polymer materials turning on the base of blanks preliminary twisting

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Abstract. The theoretical and experimental research results of the new method for polymeric materials turning are presented in the article. The workpiece material preliminary deformation by twisting is the distinctive feature of the developed method. It is theoretically shown that the maximum stresses value during twisting is formed on the workpiece surface layer. It has been experimentally proved that the workpiece deformation by twisting leads to changes in the stress-strain state of the polymer chain. The workpieces pre-deformation by twisting allows obtaining the more qualitative surface layer than in case of the traditional turning.

1. Introduction
Currently there are a number of technical solutions to ensure the conditions for the implementation of polymer composite materials high-quality turning. The parts and products from polymer composite materials are successfully used in chemical and oil and gas enterprises. Part of the decision is based on the advanced cutting tools using [1, 2, 3] and the rational cutting conditions choice [4, 5, 6]. The other part solutions [7, 8, 9, 10, 11] technical essence is the workpiece material treating by means of various types preliminary impacts in order to obtain high quality indicators of the parts processed surface. At the same time in most cases the workpiece material entire volume is pretreated which causes the numerous internal defects formation for example breaks in polymer chains, sub- and microcracks. Such defects also are remained in material volume after turning.

This work purpose is to develop and investigate the effectiveness of new method for polymeric materials billets turning based on the preliminary billet twisting.

2. Theoretical backgrounds
It is known [12] that when the workpiece is twisted under the action of the moment $M$ pure shear conditions arise in it and only shear stresses act in cross sections and normal stresses are zero.

The task to establish the stresses connection with internal efforts is solved in several stages. Consider the workpiece cross-section $o$ located at some distance $dx$ from the clamped, where $M = T$ (Figure 1, c). The elementary force $(\tau dA)$ and the elementary torque which relative to the axis of the shaft is $\rho(\tau dA)$ will act on the elementary area $dA$. The resultant moment of tangential stresses $T$ in the section is equal

$$T = \int_{A} \rho(\tau dA).$$

(1)
To find the shear stresses $\tau$ we consider the physical side of the problem which is described by Hooke’s law during the shear

$$\tau = G\gamma.$$  \hspace{1cm} (2)

This law establishes the relationship between the tangential stresses $\tau$ and the shear deformation $\gamma$. The shear deformation $\gamma$ will be found by considering the geometric side of the problem.

The blank left end with length $x$ (Figure 1, a) will rotate by the angle $\varphi$ under the external twisting moment $M$ action. In the element with length $dx$ the elementary angle $d\varphi$ is similar (Figure 1, b). The cylinder generator deviates from the initial position by the angle $\gamma$. The angle $\gamma$ takes the maximum value $dS / (dx) = rd\varphi / dx$ on the element surface at radius $r$.

Inside a cylinder of arbitrary radius $\rho$ the element angle $\gamma$ is:

$$\gamma = \rho \frac{d\varphi}{d}.$$ \hspace{1cm} (3)

Next we substitute equation (3) into the expression (2) of the Hooke's law and obtain the expression for tangent stresses $\tau$

$$\tau = G\rho \frac{d\varphi}{dx}.$$ \hspace{1cm} (4)

Equation (4) is inserted into equation (1) and we obtain the expression:

$$T = \int \rho^2 G \frac{d\varphi}{dx} dA = G \frac{d\varphi}{dx} \int \rho^2 dA.$$ 

Denoting $\int \rho^2 dA = I_\rho$ as the polar moment of inertia we get:

Figure 1. Settlement schemes: a - billet under the action of an external twisting moment $M$; b- deformation of the elementary workpiece part with the length $dx$; c - internal force $T$ and stresses $\tau$ in cross section; d - distribution of tangential stresses $\tau$ in cross section.
\[ T = I_p G \frac{d\varphi}{dx} \] from where \[ \frac{d\varphi}{dx} = \frac{T}{I_p G}. \] (5)

The relative twisting angle of the elementary area \( \frac{d\varphi}{dx} \) from expression (5) is substituted in (4) and we obtain the final expression for estimating the stress at an arbitrary point of the section:

\[ \tau = \frac{G \rho T}{GI_p} = \frac{T \rho}{I_p \rho} \] (6)

Analysis of expression (6) allows us to conclude about the linear distribution of tangential stresses while in the center \( \tau = 0 \), since \( \rho = 0 \) and at the periphery \( \tau = \tau_{\text{max}} \), as \( \rho_{\text{max}} = r \) (Figure 1, d).

3. Description of the new turning method

This paper presents a new method [13] of polymeric materials turning. The method technical essence is that the workpiece is subjected to processing by twisting before turning. In this case the workpiece twisting is produced to the tangential stresses magnitude not more than 0.6 ÷ 0.8 of the of the workpiece material strength limit. The method scheme is presented in Figure 2.

The method is implemented as follows. The workpiece 1 from a polymeric material is fixed in the lathe chuck 2 by a known manner. The clamps 3 are installed on the workpiece 1 and tightened with tie rods 4. Then the workpiece 1 is pretreated by twisting when the clamps 3 rotation relative of the workpiece 1 longitudinal axis is performed. The friction interaction occurs between the clamps 3 inner surface and the workpiece 1 outer surface. Wherein the workpiece 1 material undergoes shear deformations which causes shear stresses in the workpiece 1 cross section. As proved above the shear stresses maximum value is at the edge section i.e. in the surface layer of the workpiece 1.

In this case the material structure is formed so that one part of the chemical bonds is destroyed and another bonds part is stressed and has low bond activation energy. This condition is responsible for breaking of the part excited bonds in the polymer chains by thermal fluctuations. Since the maximum values tangential stresses are in the surface layer of the workpiece 1 the most technologically advanced material is also located in the surface layer. Then workpiece 1 is turning with a cutting tool. Due to the pre-fracture zone formation the process of deforming the shear layer is facilitated when the workpiece 1 surface layer interacts with the cutting tool wedge. The trunk crack acquires a more sustainable direction of development along the cutting line. The main crack stable direction is a premise for improving of the machined surface quality indicators since it reduces the probability of digging, chipping and similar defects formation in the workpiece 1 material at cutting.

The condition that the preliminary shear stresses \( \tau \) do not exceed the value 0.6 ÷ 0.8 of the workpiece material tensile strength ensures the workpiece 1 dimensions and shape stability when it is deformed. And such loading mode corresponds to the elastic deformation region i.e. before the development of the forced elasticity phenomenon or before the moment when the workpiece 1 modified cross section is formed [14].

At the same time the use of clamps 3 with the tie rods 4 for the workpiece 1 preliminary twisting is a very simple and economical constructive solution. The solution implementation requires a minimum of material, labor and time costs.
4. Experimental studies

The purpose of the experimental studies is to obtain new data on the preliminary twisting effect on the turned surface quality of details from polymeric materials.

Some polymer composite materials were used as the test materials from which a wide range of parts and products for chemical and oil and gas equipment are manufactured.

The workpiece turning was carried out on the chuck-center lathe machine model RT755F311. The tool material and the cutting part geometry as well as the cutting process parameters rational values are established on the basis of the technological system stability analysis results [15].

In these studies the treated surface quality is estimated by the roughness parameters values. The nomenclature and characteristics of roughness parameters are detail described in [2].

Table 1 summarizes the numerical values of the roughness parameters under study. We will analyze the basic roughness parameters for each material studied. The values of the parameter $R_{sk}$ for each material and processing option confirm the validity of the treated surface roughness assessment by the basic parameters $R_a$, $R_z$ and $R_{max}$ [15].

The results of workpiece turning made from caprolon. The analysis of the of the $R_a$, $R_z$ and $R_{max}$ parameters values shows the effectiveness of the use of pre-twisting blanks while the parameter $R_a$ decreases by 1.76 times, the parameter $R_z$ by 4 times, the parameter $R_{max}$ by 2.5 times compared to conventional turning.

The results of workpiece turning made from Teflon. The analysis of the of the $R_a$, $R_z$ and $R_{max}$ parameters values shows the effectiveness of the use of pre-twisting blanks while the parameter $R_a$ decreases 21 times, the parameter $R_z$ 1.44 times, the parameter $R_{max}$ 2.15 times compared with conventional turning.

The results of workpiece turning made from Textolite. The analysis of the of the $R_a$, $R_z$ and $R_{max}$ parameters values shows the effectiveness of the use of pre-twisting blanks while the parameter $R_a$ decreases by 2.6 times, the parameter $R_z$ by 2.5 times, the parameter $R_{max}$ by 2.47 times compared to conventional turning.

The results of workpiece turning made from getinaks. The analysis of the of the $R_a$, $R_z$ and $R_{max}$ parameters values shows the effectiveness of the use of pre-twisting blanks while the parameter $R_a$ decreases 2.1 times, the parameter $R_z$ 2.3 times, the parameter $R_{max}$ 2.1 times compared with conventional turning.
The numerical values of the remaining geometrical roughness parameters of the studied materials treated surface listed in Table 1 also confirm the fact that the use of the workpieces preliminary twisting provides a significant reduction in the roughness level.

| Workpiece Material | Turning types | Roughness parameters, µm |
|--------------------|---------------|--------------------------|
|                    |               | $R_a$ | $R_z$ | $R_{max}$ | $R_p$ | $R_y$ | $S_m$ | $R_{sk}$ |
| Caprolon           | Turning after twisting | 4.39 | 5.68 | 9.01 | 5.32 | 3.69 | 1.38 | -0.17 |
|                    | Turning usual  | 7.6  | 22.72 | 35.97 | 14.02 | 21.95 | 0.33 | 0.27 |
| Teflon             | Turning after twisting | 3.13 | 14.34 | 18.03 | 9.11 | 8.920 | 0.50 | -0.12 |
|                    | Turning usual  | 8.7  | 20.20 | 37.90 | 14.80 | 23.10 | 0.20 | 0.13 |
| Textolite          | Turning after twisting | 3.75 | 16.14 | 22.80 | 10.99 | 11.81 | 0.23 | -0.23 |
|                    | Turning usual  | 10.0 | 40.53 | 48.43 | 26.27 | 22.16 | 0.21 | 0.56 |
| Getinaks           | Turning after twisting | 4.37 | 16.52 | 23.73 | 11.04 | 12.69 | 0.29 | 0.05 |
|                    | Turning usual  | 10.0 | 37.93 | 56.48 | 26.02 | 30.46 | 0.25 | 0.6  |

5. Conclusions

It is theoretically proved that tangential stresses form in the bulk of the material when a cylindrical billet is twisted and the stress maximum value is in the billet surface layer and the stress is zero in the billet center. Thus the technological weakening effect of the workpiece surface layer is achieved. The stress distribution nature minimizes the possibility of the workpiece material internal defects when twisting and increases the parts and products reliability during their operation.

The new method has been developed for turning polymeric composite materials on the basis of workpiece preliminary deformation by twisting. It has been experimentally proved the workpiece deformation by twisting leads to the polymer chain stress-strain state changes.

The results of the processed surface roughness experimental studies for parts made from polymer composite materials allows us to conclude that it is advisable to use the workpieces pre-deformation by twisting since such processing allows to obtain the more qualitative surface layer than in case of the traditional turning.

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