Efficiency of applying advanced electromagnetic pulse processing when turning polymer composite materials

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Abstract. The new approach to high-performance turning of polymeric composite materials is presented in this paper. The approach essence is a combination of a conventional work pieces turning with simultaneous irradiation by nanosecond electromagnetic pulses. As a result the changes of studied material structure occur that lead to technological softening the work pieces surface layer. It has been experimentally proved that irradiation of the studied materials with nanosecond electromagnetic pulses for 5 and 10 minutes leads to a noticeable decrease in the strength and hardness of all samples. On the basis of the experimental data the new turning methods for polymer composite materials and the device for its implementation have been developed and patented. Analysis of the experimental studies data allows us to conclude that such approach leads to decreasing in cutting force during work pieces subsequent turning and, therefore to increasing in the process productivity, for example, due to increasing cutting speed or size of the removed allowance.

1. Introduction
Cutting processes are different for polymers and metals [1, 2] because of the specific properties of polymers. High-rate (and, therefore, high-throughput) turning of polymers is still an unsolved scientific and technical task.

The productivity of polymer turning is limited by the lifetime of the cutting tool and the quality of the machined surface. At present, the treatment regime and parameters of the cutting edge are set without considering the polymer condition and structure. This also limits the productivity of processes based on ordinary treatment methods. Thus, increasing the turning throughput of polymer work pieces is a crucial problem for modern mechanical engineering because the technical and economic indicators of the manufactured product could be improved by solving it.

One solution of this problem involves the development and implementation of a new concept for high-throughput polymer turning that includes changing the properties of the treated material using electro physical action on its structure in order to decrease the energetic of the turning.

2. Methods of experimental research
To modify the structure and hence the properties of polymers, thermal, ultrasound, magnetic, and electrical treatment is possible, as well as treatment by electromagnetic pulses [3,4].

In the present work, we consider the influence of treatment by nanosecond electromagnetic pulses (NEMP) on the polymer strength. Representatives of thermoset and thermoplastic plastics, most common in various industries, were selected as the materials of the experimental samples: Caprolon,
To create nanosecond electromagnetic pulses, we use a GNI-01-1-6 generator (South Ural State University) with the following parameters: pulse length 1 ns; power of a single pulse 1 kW; maximum permissible frequency of the generated pulses 1000 Hz; and electric field strength $10^5$ V/m.

A characteristic feature of NEMP is their unipolarity. Therefore, the emitted field does not have oscillating vibrations. As a result, the force during a single pulse is directional in space and time. The structure and physicochemical properties of the substance can be affected under these conditions [5].

The effect of NEMP irradiation on the strength of PCM was studied experimentally as follows. At the first stage standard samples of the studied materials were exposed to NEMP for a certain period of time from 1 to 30 minutes. Then the samples were subjected to uniaxial tension using a loading device of the WDW-50E universal testing machine. The design of the testing machine allows to provides experiments high accuracy, the possibility for implementing several types of samples mechanical loading and processing data using its own mathematical software in real time. The tests are conducted in fixed conditions; the temperature, humidity, speed, and load correspond to the recommendations of State Standard GOST 11262–80 for uniaxial extension.

At the second stage the samples from the materials under study were turned both conventional ones without preliminary electromagnetic pulse processing and those subjected with NEMP irradiation. The turning parameters were established on the basis of previous studies [6] as: cutting speed 145 m/s, longitudinal feed 0.1 mm/return and cutting depth 1.0 mm.

Tables 1 and 2 present experimental data on the studied materials strength and hardness research, respectively, depending on the of exposure time by NEMP. An analysis of the data presented shows that irradiation of the studied materials with NEMP for 5 and 10 minutes leads to a noticeable decrease in the strength and hardness of all samples. At the same time, an increase in the irradiation time over 10 minutes does not lead to a noticeable decrease in both strength and hardness.

The physical and mechanical properties of polymers change characteristically because of electronic excitation of the structure after electric and physical treatment [7]. Electronic excitation of polymer chains decreases their bond energies. This decreases the mechanical stability of the loaded polymer network and facilitates rupture of the chain, generates breaks or propagates microcracks, and increases defects, i.e., loosening and embrittlement, and, therefore, decreases mechanical strength.

### Table 1. The results of PCM strength measurement after NEMP irradiation.

| Material of samples | Strength, MPa |
|---------------------|---------------|
|                     | Base value    | NEMP irradiation time, min |
|                     |               | 1   | 5    | 10   | 15   |
| Caprolon            | 70.5          | 53.6 | 42.9 | 35.4 | 35.6 |
| Teflon              | 17.7          | 14.1 | 11.5 | 10.2 | 10.4 |
| Getinaks            | 122.8         | 99.5 | 81.4 | 78.7 | 78.2 |
| Textolite           | 100.3         | 86.9 | 60.9 | 58.4 | 58.9 |
| Polymethacrylate    | 56.7          | 50.2 | 42.9 | 41.2 | 41.8 |
Table 2. The results of PCM hardness measurement after NEMP irradiation.

| Material of samples | Base value | NEMP irradiation time, min |
|---------------------|------------|-----------------------------|
|                     |            | 1 | 5 | 10 | 15   |
| Caprolon            | 142.8      | 140.9 | 131.6 | 115.5 | 115.9 |
| Teflon              | 31.8       | 29.8  | 23.5  | 21.9  | 20.1  |
| Getinaks            | 215.1      | 210.7 | 190.8 | 180.3 | 181.1 |
| Textolite           | 198.8      | 194.3 | 180.6 | 163.7 | 164.1 |
| Polymethacrylate    | 208.4      | 203.2 | 186.8 | 163.7 | 164.1 |

3. New methods of polymer composite materials turning

On the basis of the experimental data, we have developed a high-productivity method for polymer composite materials turning [8] and a device for its implementation [9]. The technical aims of the inventions are to increase the productivity of a workpiece processing by reducing the power parameters of cutting. The feature of the new method is that a workpiece is simultaneously irradiated with NEMPs and cut. The diagram of device for processing PCM work pieces presented on figure 1.

The workpiece 1 is fixed in a lathe in a known manner. The workpiece 1 is rotated by the drive 2. The cutter 3 moves along the workpiece 1 due to the feed mechanism 4 and is insulated by gaskets 5 from the lathe metal parts. The sliding element 6 and the cutter 2 are connected to the generator 8 of nanosecond electromagnetic pulses by means of cables 7, which allows them to be as the electrodes for processing the workpiece 1.

After turning on the machine, the workpiece 1 begins to rotate. Then apply voltage to the generator 8 and process the workpiece 1 with nanosecond electromagnetic pulses, which are transmitted via cables 7 to the cutter 2 and element 6.

Figure 1. Diagram of device for processing PCM workpiece.

At the same time the workpiece 1 is machined with the cutting tool 2 to form chips. Such a combined treatment, due to the manifestation of the above effects, leads to the formation of the material softened surface layer which will increase the cutting speed and therefore increase the productivity of turning.
The cutting force component $P_z$ was measured during turning of the work pieces using a CB1A-K3 bending beam load cell attached to the cutter and measured data were displayed on the liquid crystal screen of the DN-10 indicator (figure 2).

![Figure 2. The CB1A-K3 bending beam load cell: 1 – cutter; 2 - force sensor; 3 – indicator; 4 - lathe tailstock.](image)

The experimental data on the change in cutting force $P_z$ are summarized in table 3. Analysis of these data allows us to conclude that the advanced processing by NEMP of work pieces from the studied in this work materials leads to a noticeable decrease in the cutting force $P_z$. Moreover an increase in the irradiation time more than 10 minutes does not lead to a noticeable decrease in the cutting force. The reduced $P_z$ value was explained by the disordering of the processed workpiece surface layer that occurred because of the development of existing and the formation of new external and internal defects (microcracks) resulting from NEMP irradiation [7,10].

| Material of samples | Cutting force, $P_z$, N |
|---------------------|------------------------|
|                     | Base value | NEMP irradiation time, min |
|                     |            | 1  | 5  | 10 | 15 |
| Caprolon            | 255        | 242| 17 | 129| 131|
| Teflon              | 128        | 121| 95 | 73 | 78 |
| Getinaks            | 438        | 393| 345| 281| 288|
| Textolite           | 4036       | 389| 326| 318| 321|
| Polymethacrylate    | 217        | 191| 136| 131| 127|

4. Conclusions

1. Thus, we have developed a high-productivity machining method for polymers, in which nanosecond electromagnetic pulses are applied in the course of turning. It has been experimentally proved that the electro physical effect through irradiation with nanosecond electromagnetic pulses of samples from studied materials leads to decreasing in such mechanical properties as strength and hardness.
2. So, a new concept for high-throughput turning of polymers was formulated based on the additive effect of combining ordinary turning with electro physical treatment, i.e., NEMP irradiation. The inclusion in the technological process of turning polymer composite materials of the operation of electromagnetic advanced processing by means of nanosecond electromagnetic pulses is advisable. Such approach leads to decreasing in cutting force during work pieces subsequent turning and, therefore to increasing in the process productivity, for example, due to increasing cutting speed or size of the removed allowance.

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