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The Micro Machining of Polypropylene by UV Laser - the Influence of Laser Operating Parameters

TOFIL Szymon

Kielce University of Technology, Faculty of Mechatronics and Mechanical Engineering, Al. 1000-lecia P.P. 7, 25-314 Kielce, Poland

tofil@tu.kielce.pl

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Abstract. This article presents the research on the impact of operating parameters of a TruMicro 5325c laser device with ultra-short pulses and UV radiation on the polypropylene surface. By changing the frequency of laser pulses, the effect of their impact on the surface of the processed material, which was propylene, was studied. To verify the results, a HIROX KH-8700 confocal digital microscope with software for analyzing the obtained image was used. The efficiency of the performed process was calculated and the optimal working parameters of the device, which do not cause damage to the processed material, were determined.

Introduction

Constantly evolving industry requires the development of increasingly new construction materials. Even the latest construction materials can be modified in a way that its designers did not anticipate [1-4]. Requirements for the quality of the surface of materials used are one of the most important selection factors in many different technological processes - e.g. in gluing different constructions. These requirements relate, among others, to the condition of a surface - smoothness or surface roughness, including texture. They may also relate to the increased adhesion of a given surface (important in the gluing process) or its resistance to wear. Increasingly, it also has aesthetic aspects. The importance of various surface issues for polymeric materials is very broad. Certainly, the methods of shaping surfaces of various construction materials - including of course polymeric - include laser techniques. The reasons for using these technologies are associated with the provision of specific requirements for the above-mentioned performance properties of the surface. Laser devices are characterized by different properties of the generated laser beam that affects the surface of a workpiece [5-8]. Particular attention should be paid to laser devices giving the possibility of using the phenomenon of cold ablation, which requires high energy and ultra-short time of impact on the material [4].

Laser ablation is a process in which chemical bonds of macromolecules of modified material break under the influence of concentrated laser light. Then, fragments of these macromolecules break away from their surface layer. This applies not only to polymeric materials, but also to metals - including hard-melt alloys (e.g. titanium, iridium, platinum or tantalum). In the case of processing polymer materials, laser ablation is used in the processes of manufacturing micro-modules of micro modules (microlithography), miniaturized machines and their structural elements, contact lenses, as well as for very precise correction of the shape of miniature objects.

Shaping structure and surface properties of materials can be combined with coating the surface of construction materials with polymeric materials and surface treatment. Obtaining the correct properties of processed materials is conditioned by proper surface preparation in order to ensure physical and chemical conditions of adhesion, very often only adhesion between the base

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material surface and polymer coatings applied to it. In general, the surface treatment of polymeric materials includes cleaning processes that increase adhesion, most often adhesion, and functional modification of the surface. In many cases, these processes combine these functions.

The purpose of laser surface treatment of polymeric materials can improve adhesion, hardness, tribological properties, including scratch resistance, to chemical agents and UV ultraviolet radiation. It should be noted that, above all, surface treatment is aimed at improving the wettability and adhesive properties of many polymeric materials - including polypropylene. Laser techniques allow for pre-treatment on the surface by developing the actual surface of the material, or increasing the free surface energy, so that the difference from the applied surface coverings is not less than 10 mJ / m^2.

Material used for research

Polypropylene (PP) is obtained by polymerizing propylene in the presence of metallographic catalysts. This reaction occurs at a temperature of about 100ºC in an environment of liquid aliphatic hydrocarbons. Polypropylene is one of the lightest plastics. Its density is about 0.92g/cm^3. In its natural form it is a colorless and odorless material and, most importantly, it is non-toxic and harmless to humans.

The physical and chemical properties of polypropylene allow for a wide use of this material in industry and in everyday life. Polypropylene is used, among others, for the production of pharmaceutical packaging, as well as elements of medical apparatus and equipment, e.g. syringes and medicine packaging. Due to high chemical resistance, polypropylene is used to manufacture chemical devices and containers for storing aggressive chemicals. Good mechanical and thermal properties of polypropylene have determined its use with great success as a construction material in the industry for machine components, covers and housings. Good electrical properties in combination with other properties mean that polypropylene is widely used in the electronics industry for the production of various elements of apparatus and equipment for the needs of this industry. The first positive tests of galvanic coating of plastics with metal coatings were carried out on polypropylene products.

Experimental part

Experimental research was carried out on a test bench existing at the Laser Processing Research Center of the Kielce University of Technology.

A test stand is a laser machine for micro machining with automatic axis. The scheme of the test stand is shown in Fig.1.

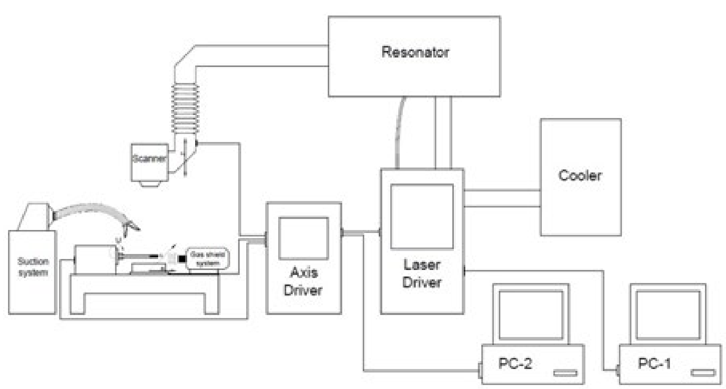

Fig.1 The scheme of the test stand with TruMicro 5325c laser.

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The characteristics of the basic units of the laser machine for micro machining are as follows: Laser TruMicro 5325c - type of laser: pulsed diode impulse laser disk with 3 harmonic generation,- wavelength: 343 nm, - average power: 5 W, - minimum pulse duration: 6.2 ps, - 400 kHz pulse frequency with the possibility of dividing by natural numbers from 1 to 10000, - maximum pulse energy: 12.6 µJ, - mod: TM_{00}, - M^2=1.3 - maximum fluency: 4.8 J/cm^2.

The purpose of the research was to determine how changing the operating parameters of the laser device used affects the quality of the polypropylene surface. In the presented research, only one parameter of the micro machining process changes, which was the pulse frequency. Tests were carried out for the following laser device operating parameters: pulse energy - 12.6 µJ, laser beam scanning speed - 1000 mm/s and pulse frequency from 12.5 kHz to 400 kHz. The results of the work are presented below. A HIROX KH-8700 digital microscope with built-in software for analyzing the obtained image was used to analyze the results of the micro machining.

Research results and analysis

The results of the carried out tests are presented below (Table 1). Each test was carried out with an interval of 1 minute in order to obtain repetitive initial conditions of the tested sample - temperature stabilization. In addition, this time was needed to position the sample and change the operating parameters of the laser device. The performed laser micromachining process was repeated five times for each frequency used.

Table 1. Measurement results of the effects of the laser beam on the material being tested.

Pulse repetition [kHz]	Measured values	Results
12,5	Depth [µm]	minimal impact on the material - unmeasurable values
	Volume [mm^3]	
	Machining efficiency [g/s]	
25	Depth [µm]	minimal impact on the material - unmeasurable values
	Volume [mm^3]	
	Machining efficiency [g/s]	
50	Depth [µm]	24.802
	Volume[mm^3]	0.00661656
	Machining efficiency [g/s]	38.75
100	Depth [µm]	39.140
	Volume [mm^3]	0.0095722
	Machining efficiency [g/s]	56.06
200	Depth [µm]	75.628
	Volume [mm^3]	0.0296643
	Machining efficiency [g/s]	173.74
400	Depth [µm]	significant material damage
	Volume [mm^3]	
	Machining efficiency [g/s]	

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For samples made with 12.5 kHz (Fig.2) and 25 kHz frequencies, the result on the material was insignificant. Therefore, these results were rejected. However, due to the interesting effect of individual interactions at this frequency, these results may constitute separate material for research.

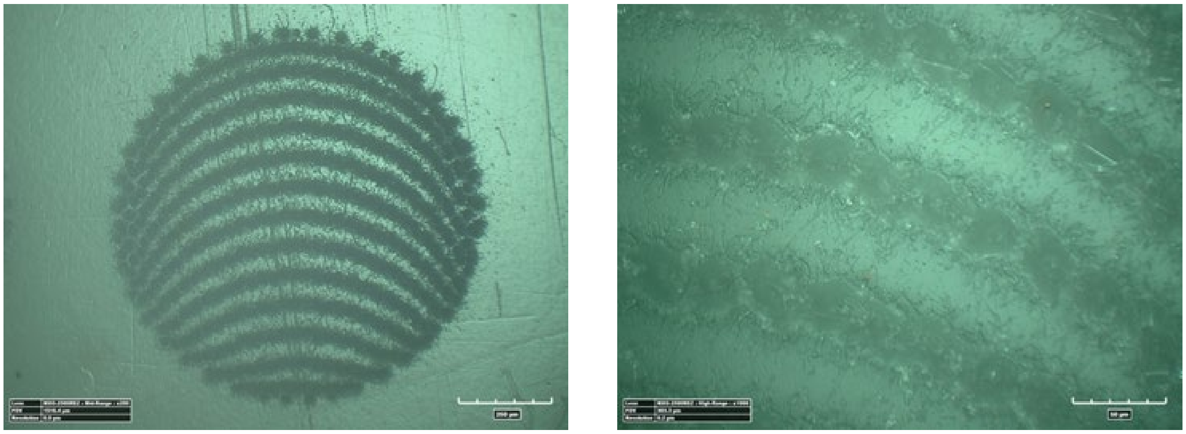


Fig. 2. View of a single micro texture element made with a pulse repetition rate of 12.5 kHz. Magnification: left – x200 (the marker is 250 μm); right – x1000 (the marker is 50 μm).

The first measurable effects of the laser radiation allowing for measurements made outside the scale of measurement error could be observed for a pulse repetition rate of 50 kHz. The pulse repetition frequency of 100 and 200 kHz also allowed for the measurement of traces of the laser beam's impact on the tested material. However, for a pulse repetition frequency of 400 kHz, visible material damage was seen - it was melted down, which resulted in the rejection of these results from the result analysis process. Therefore, samples made with 50 kHz, 100 kHz (Fig.2, Fig.4, Fig. 5) sand 200 kHz pulse repetition rates were accepted for testing.

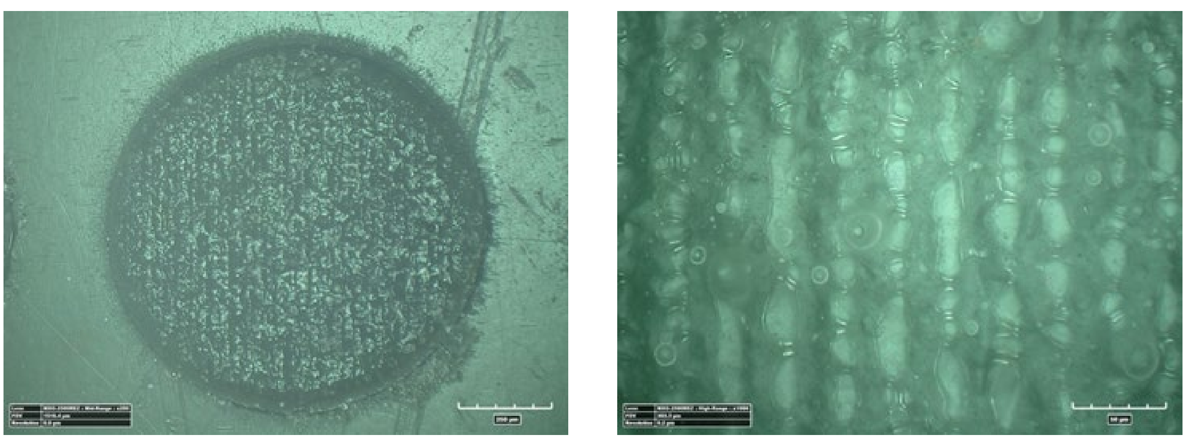
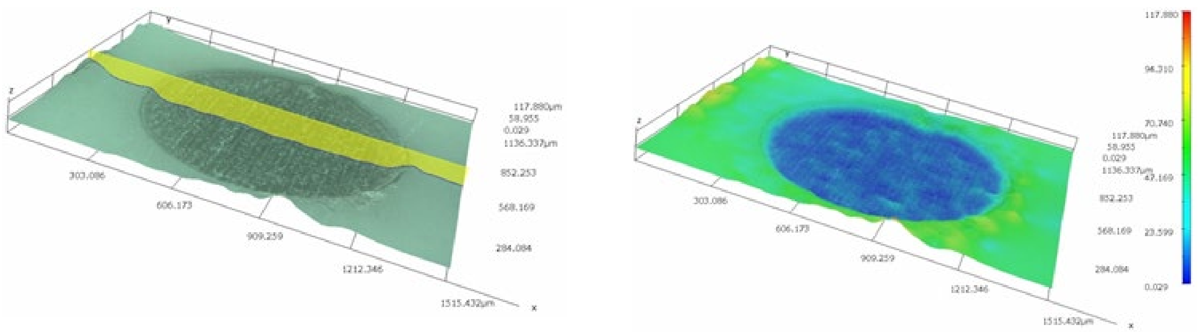


Fig. 3. View of a single micro texture element made with a pulse repetition rate of 100 kHz. Magnification: left – x200 (the marker is 250 μm); right – x1000 (the marker is 50 μm).

The diameter of the circle-shaped micro texture was about 1006 μm. The assumed diameter was 1 mm. The small diameter deviation was within the measurement tolerance.



f100 P100 V 1000 PP okrag 200x.tdr

	Name	Height [μm]	Width1 [μm]	Area [μm^2]	Diagonal [μm]	Surface Length [μm]	RoughnessRa [μm]	RoughnessRz [μm]	RoughnessRzjis [μm]
1	Profile	39.140	1006.497	7954.512	1007.258	1033.902	0.628	1.724	1.396

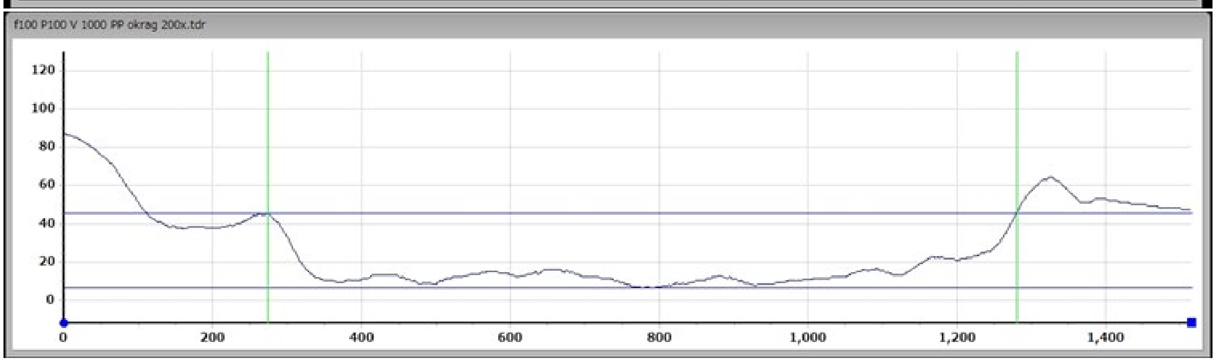
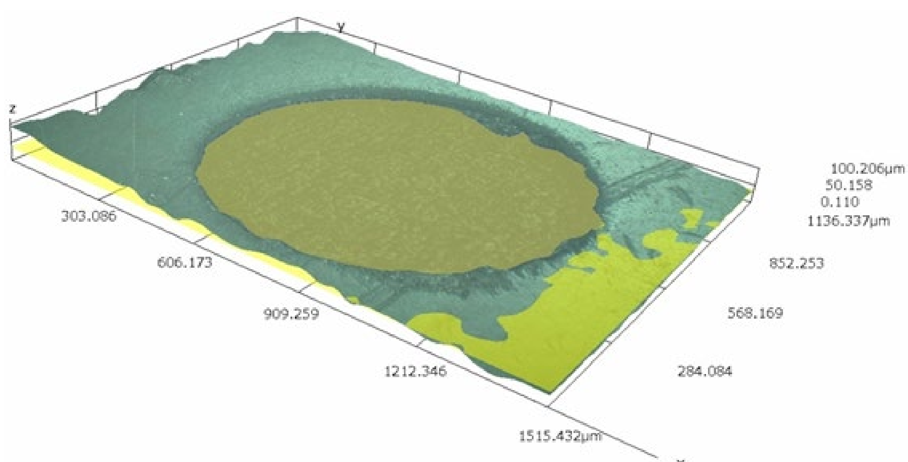


Fig. 4. The 3D view of a single element of micro texture (with a pulse repetition frequency of 100 kHz at magnification x200) in a pseudo-color and with a surface profile with a table of values for its width, height, roughness.



f100 P100 V 1000 PP okrag 200x A.tdr

	Name	Center X [μm]	Center Y [μm]	Cross-S Area [μm^2]	Volume [μm^3]	Surface Area [μm^2]
1	Area/Volum	798.943	589.493	724702.539	9572199.381	763617.283

Fig. 5. The 3D view of a single element of the micro structure (with a pulse repetition frequency of 100 kHz at magnification x200) and the estimated volume.

Conclusions

Tests and observations have shown that a laser emitting UV radiation at 343 nm in picoseconds pulses can be recommended as a tool for the micro machining of elastomeric materials including polypropylene. The micro machining of recesses is efficient and precise and the workpiece does

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not lose its elasticity. For pulses repetition up to 200 kHz at the site of the treatment and its surroundings, no charring and other signs of overheating were observed. At 200 kHz, a slight remelting of the material could be observed, but not yet significantly damaging the surface. At 12.5 kHz and 25 kHz, there was no significant processing effect but only low traces of individual pulses. At 400 kHz, significant material remelting could be observed. This indicates that the heat supplied to the surface of the material was too high. Dimensions of single micro pockets retained their characteristic dimensions with a +/- 5% deviation along the entire diameter, which demonstrates high repeatability and accuracy of the machining.

Detailed microscopic examinations are required to evaluate structural changes at the work site. The conducted research confirms the possibility of applying a developed technology to shape the surface of elastomeric materials. This opens new prospects for improving the properties of elastomeric materials, for example to glue it with other materials.

Acknowledgment
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