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Influence of the Parameters of the Laser Marking Process on the Depth of Penetration in Layer-reinforced Composites

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***Abstract.* In the present study, we track the influence of the change in the energy parameters of a laser installation based on Fiber laser - RFFL-P-502B, on the depth of penetration in marking layer-reinforced polymer-based composites. To determine their influence on the depth of the marked strokes, experiments were carried out at speed V= 50÷250 mm/s, output power P = 5÷50 W, pulse frequency f = 50 kHz and diameter of the focal spot 40µm. Tabular results and graphical dependences of the obtained experimental results are presented.**

Keywords: plasma marking, textolite, glass textolite, marking stroke depth

I. INTRODUCTION

The successful development of quantum electronics in the second half of the last century created good conditions for the development of laser technologies [1]-[5]. Lasers, by their very nature, are generators of electromagnetic waves in the ultraviolet, visible and infrared spectrum of radiation, where the light waves are characterized by a high degree of monochromaticity and high coherence. Thanks to these qualities, lasers can focus on extremely small surfaces, theoretically commensurate with the square of the wavelength of light. In this situation, modern laser systems can reach record levels of energy concentration, giving new possibilities in the heat treatment of metals - fig. 1[1].

The process of laser marking has entered massively in the production of metal products and tools, semiconductor devices, glass and ceramic products, but in recent years it has become more and more widespread in the marking of non-metallic materials as an alternative to traditional marking methods [6] -[13].

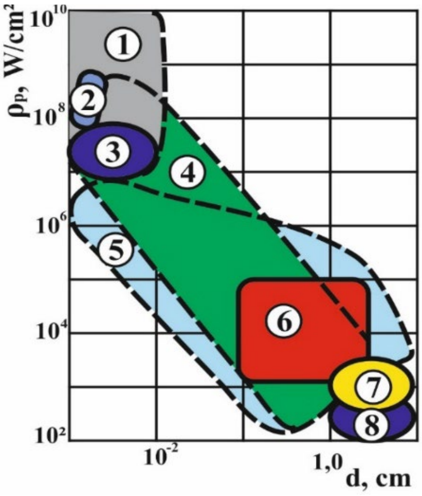

Fig. 1. Energy concentration in the focal spot with different heat sources:
1 – pulsed periodic lasers; 2 – spark discharge;
3 – laser radiation; 4 – laser with continuous radiation;
5 – electron beam; 6 – welding arc;
7 – arc plasma; 8 – gas flame

This is an innovative method that is very different from marking in any other way, without the use of consumables. Through the laser beam, the surfaces of the products are processed extremely precisely, qualitatively, quickly and have clear contours. Laser marking is a non-contact impact on the structure of the processed material, resulting in a permanent contrast image. Information in the form of: inscriptions, identification symbols (letters and numbers), bar codes, matrix codes (2D), special characters, serial numbers, images, decoration, etc. can be applied to the surface of the product with this method. [14]-[16]. In practice, with the help of the laser, it is very easy to create an arbitrary image of your own design.

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The development of the innovative industry - "Industry 4.0" in recent years has led to the implementation of innovative non-conventional technological processes in modern production, while at the same time stimulating the use of non-conventional materials, most often various types of organic and polymer-based composites [17] - [19].

In this regard, the aim of the present study is to follow the influence of the laser marking process on the penetration depth of the laser beam when marking layer-reinforced polymer-based composites.

II. MATERIALS AND METODS

In the present study, textolite samples with a thickness of 10 mm and mechanical characteristics according to DIN 7753/PFCC 202 and IEC 60893 HGW 2082, as well as glass textolite samples of type PTGC 201 with a thickness of 10 mm and mechanical characteristics according to IEC/EN 60893-3-1 were used.

The qualitative analysis of laser marking was performed on a PHILIPS URD measuring microscope - fig. 2 using INSIZE ISD software – V150 – fig.3.

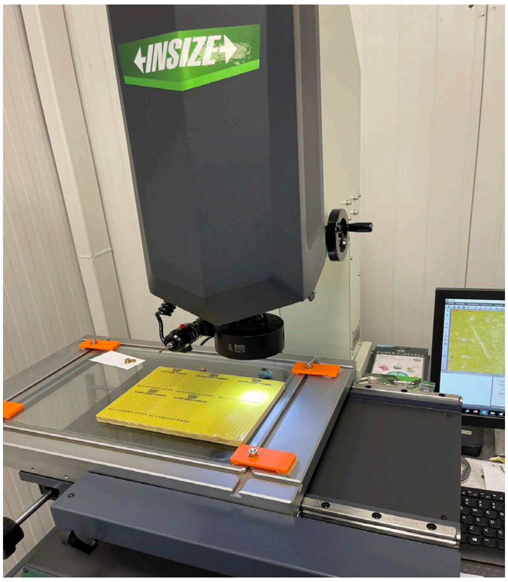
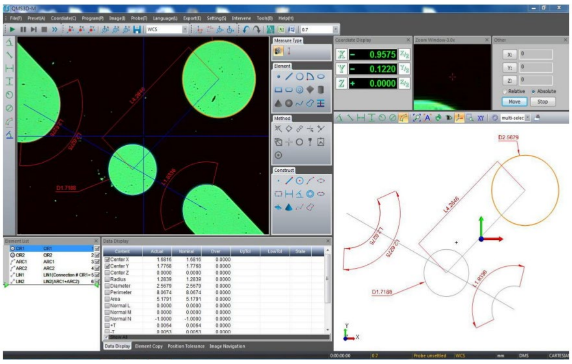


Fig.2. General view of PHILIPS URD measuring microscope



CIR1	CIR1	1
CIR2	CIR2	2
ARC1	ARC1	3
ARC2	ARC2	4
LIN1	LIN1(Connection # CIR1+	5
LIN2	LIN2(ARC1+ARC2)	6

Content	Actual	Nominal	Over	UpTol	LowTol	State
☑ Center X	1.6816	1.6816	0.0000			
☑ Center Y	1.7768	1.7768	0.0000			
☐ Center Z	0.0000	0.0000	0.0000			
☐ Radius	1.2839	1.2839	0.0000			
☐ Diameter	2.5679	2.5679	0.0000			
☐ Perimeter	8.0674	8.0674	0.0000			
☐ Area	5.1791	5.1791	0.0000			
☐ Normal L	0.0000	0.0000	0.0000			
☐ Normal M	0.0000	0.0000	0.0000			
☐ Normal N	-1.0000	-1.0000	0.0000			
☐ +T	0.0064	0.0064	0.0000			
☐ -T	0.0053	0.0053	0.0000			

Fig.3. Software for 2D and 3D INSIZE ISD – V150

Fig. 4. ZEISS type profilometer

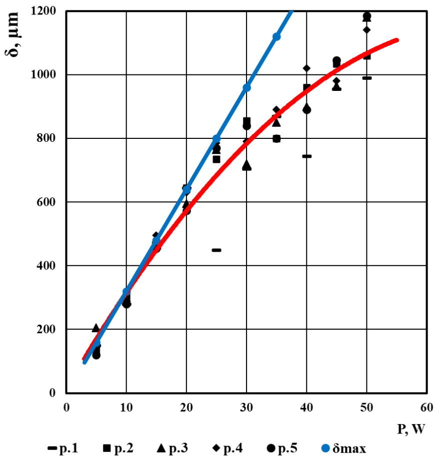
The roughness of the examined surfaces was measured with a portable ZEISS type roughness meter - fig.3, according to the requirements of ISO 4287 ISO 12085. The technical characteristics of the device are:

- Measuring range for Ra are 0.050 ÷10.00 µm and for Rz are 0.020 ÷100.0 µm;
- Resolution – 0.001µm;
- Measuring sensor - SB10 (R=2µm, 90°);
- Measuring length - 0.25 - 0.8 - 2.5 mm;
- Number of measurements at one positioning – 1÷5;

III. RESULTS AND DISCUSSION

The main technological parameters in the laser marking of polymer-based layered composite materials are the marking speed and the output power of the laser unit. To determine their influence on the depth of the marked strokes, experiments were made at marking speed V= 50÷250 mm/s, output power P = 5÷50 W, pulse frequency f = 50 kHz and diameter of the focal spot 40 µm. The depth of penetration – δ µm, was determined on a measuring microscope (Fig. 2). The measurements were made at 5 control points located along the marked line at a distance of 10 mm. The obtained results are presented in graphic form - fig. 4 and 5.

When conducting the experiments, it was found that with an output power of the laser radiation up to 20W and a marking speed of 50mm/s, the measured values for the depth of the marking varied within the limits of 20÷80 µm, and with an increase in the output power from 20 to 50W, the fluctuations of the experimental results reach limits of 100÷300 µm.



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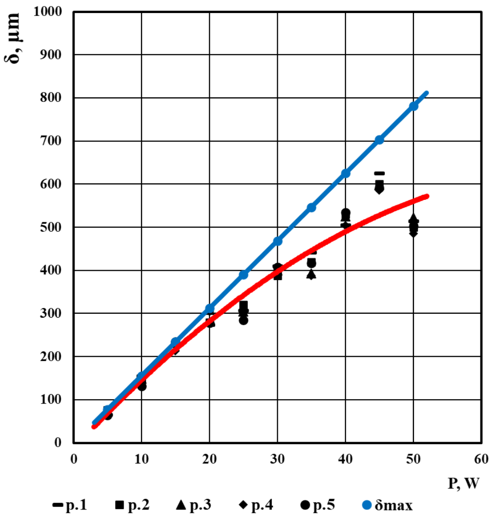

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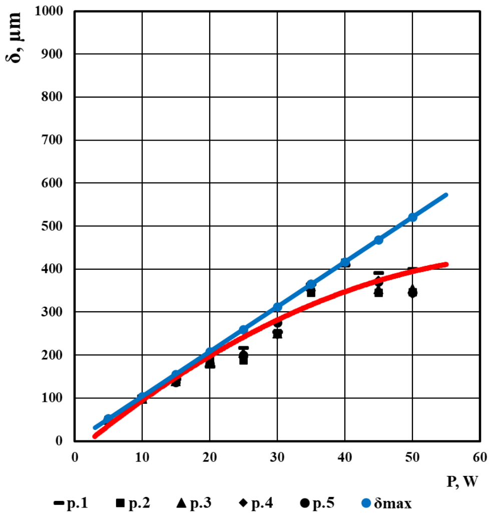

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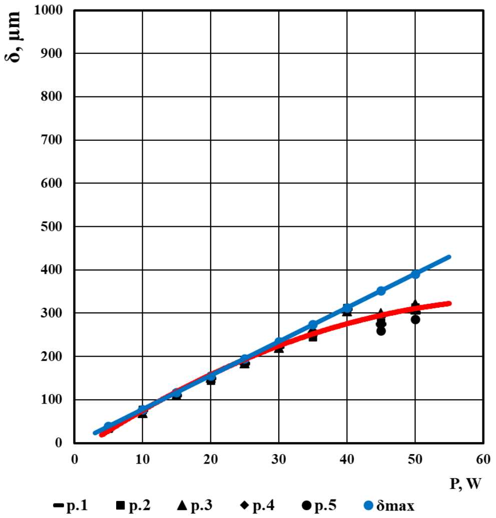

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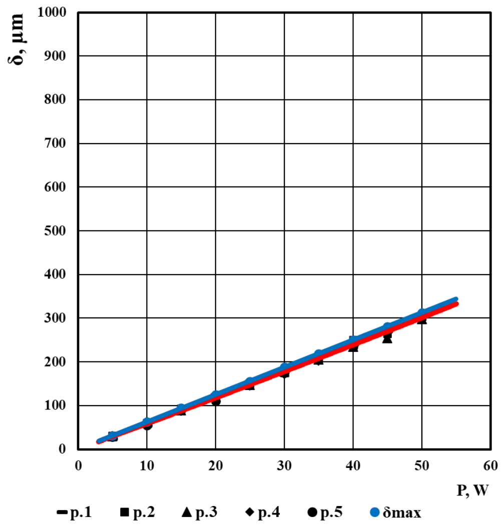


e,

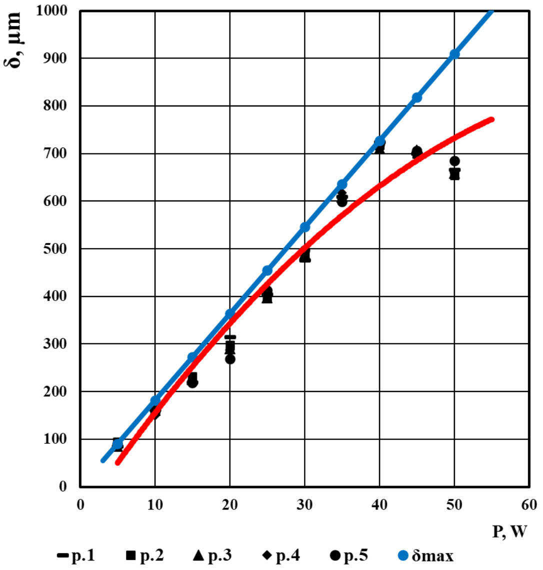
Fig.5. Change in the depth of the laser marking on samples of glass textolite depending on the power of the laser radiation at a frequency of 50 Hz and speed:
a – 50 mm/s; b – 100 mm/s;
c - 150mm/s; d – 200 mm/s;
e – 250 mm/s.

This is a result of the different vaporization temperature of the reinforcing and matrix phases making up the polymer composite.

Theoretically, for non-metallic materials, the maximum penetration depth of the laser beam – δ max, can be calculated with the expression 1 [20]:

$$\delta_{max} = 2P/ (\pi . r . \rho . \upsilon \ . \ c . T) \quad (1)$$

where: P – laser radiation power, W;
r - focal spot radius, μm;



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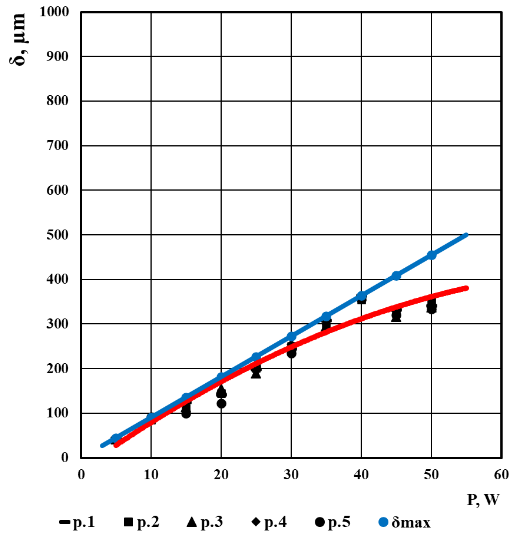

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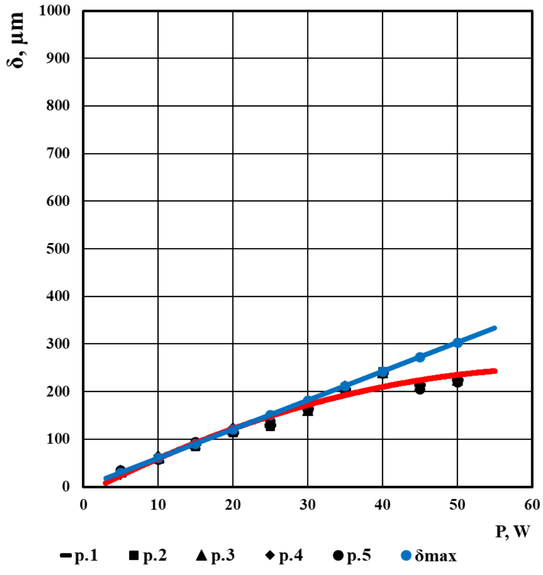

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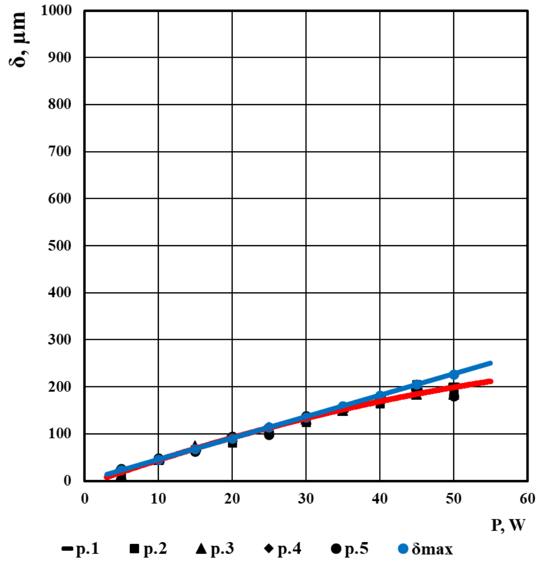

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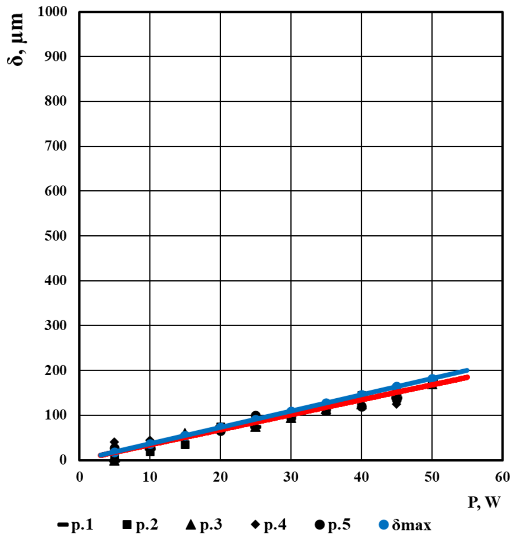

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Fig. 6. Change in the depth of the laser marking on textolite samples depending on the power of the laser radiation at a frequency of 50 Hz and speed:
a – 50 mm/s; b – 100 mm/s;
c – 150 mm/s; d – 200 mm/s; e – 250 mm/s.

ρ – material density, g/cm^3;
υ – marking speed, mm/s;
c – specific heat, cal/g.°C;
T – evaporation temperature, °C.

Using reference data for the studied materials, the maximum theoretical values of the penetration depth during laser marking were calculated - δ max (Figs. 4 and 5).

Comparing the theoretical and experimental results, it can be seen that, according to formula 1, the penetration depth is linearly dependent on the power of the laser radiation. The obtained experimental results when marking the glass textolite samples show that this is valid only at low marking powers – up to 20 W. In them, the experimental results differ from the theoretical ones by less than 10%. As the output power values increase above 20 W, the margin in the measured marking depth values increases from 4 to 30%. The biggest differences are fixed in the samples marked with minimum speed – 50÷100 mm/s. At high marking speeds, the differences decrease, and at a speed of 250 mm/s, the experimental results overlap with the theoretically calculated ones.

The results for the marking of the textolite samples are also similar. At output power up to 15 W, the obtained results differ by 10÷15 %, with an increase in output power above 15 W, the differences in measured values range from 4 to 27 %. At high marking speeds – 200÷250 mm/s, the differences between the measured and theoretical curves are minimal – below 10 % and in practice they overlap.

In all investigated marking modes, the results obtained on the glass-textolite samples were better compared to those obtained on the textolite samples. This is related to the reflectivity of the material – R.

It is known that the laser effect on matter under incident radiation is different for different non-metallic materials and is related to the reflection and absorption of the radiation. When a parallel beam of rays falls on a smooth non-metallic surface, it is reflected, and the rays are also parallel to each other. On rough surfaces, the incident parallel beam of rays is reflected in different directions and diffuse reflection occurs. The reflectivity - R, is a dimensionless quantity and can have values from 0 to 1. It is a function of the wavelength of the laser radiation - R = f (λ) and is defined by the relation 2 [21].

$$R=J_T / J_o \qquad (2)$$

where: JT – intensity of the reflected beam;
Jo - intensity of incident radiation.

The reflectivity - R, mainly depends on the condition of the treated surface [2]. Its main characteristic is the roughness class. As the roughness class of the processed surface increases, the reflective ability decreases. Wavelength roughness significantly increases the penetration depth of laser radiation.

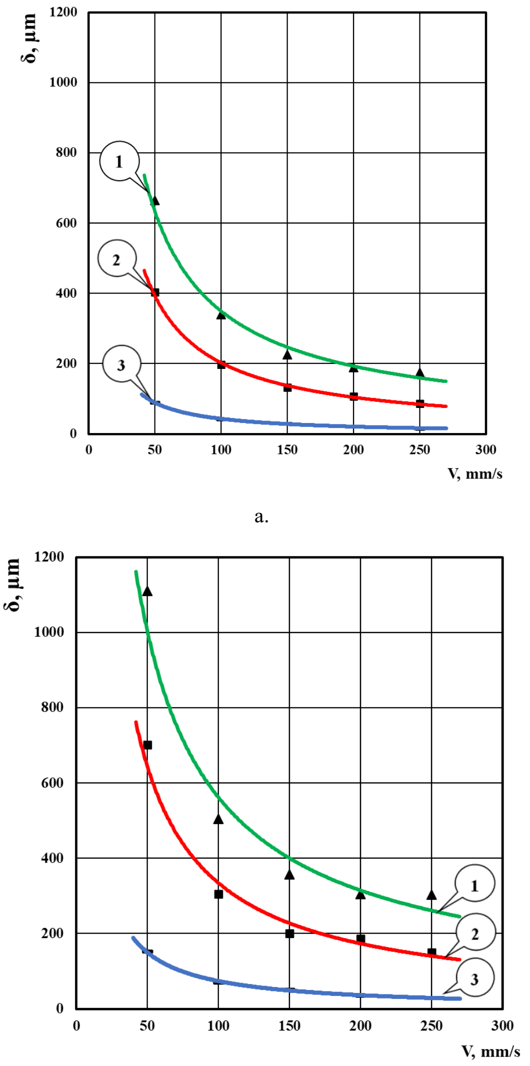
In the particular case, the radiation length is λ=1.06 µm.

The roughness of the marked surfaces at five random points was measured with a ZEISS profilometer and the results are presented in Table 1.

It can be seen that for textolite samples the average roughness – Ra, is close to the wavelength of the laser radiation, but the values for Rz are more than 4 times larger than the wavelength. This leads to significant scattering of the laser radiation power and reduced values for δ.

Table 1 Surface roughness.

№	Ra	$\Sigma Ra_{1\div5}/5$	Rz	$\Sigma Rz_{1\div5}/5$
textolite				
1	1,026	1,021	4,337	4,375
2	1,018		4,409	
3	1,024		4,381	
4	1,018		4,376	
5	1,019		4,372	
glass textolite				
1	0,231	0,225	1,705	1,703
2	0,219		1,709	
3	0,219		1,701	
4	0,217		1,701	
5	0,229		1,699	



a.

b.

Fig.7. Influence of the marking speed on the depth of the marking strokes on the examined samples at radiation power:
1 – 50 W; 2 – 25 W and 3 – 5 W
a – textolite; b - glass textolite

For the glass-textolite samples – Table 1, the values for Ra 0.225 µm and are more than 4 times smaller than the length of the laser radiation, and for Rz = 1.703 µm they are commensurate with the length of the incident radiation.

This also explains the differences in the values for δ, for the two materials studied by us.

On the basis of the obtained experimental results, graphical dependencies were developed for the influence of the marking speed on the depth of the formed marking strokes - fig. 7.

IV. CONCLUSIONS

The following more important conclusions can be formulated from the conducted research and the results obtained:

The influence of the technological parameters (P = 5÷50 W; V+50÷250 mm/s) on the depth of the formed slit during laser marking with pulse frequency f = 50 kHz and diameter of the focal spot 40μm was monitored of layered polymer-based composites.

Graphical dependencies have been developed for the influence of technological parameters of laser marking of layered polymer composites on the depth of the formed marking strokes.

It has been proven that with an output power of laser radiation up to 20 W and a marking speed of 50mm/s, the measured values for the marking depth vary in the range of 20÷80 μm, and when the output power is increased from 20 to 50 W, the fluctuations of the experimental results reach limits of 100÷300 μm, which is the result of the different evaporation temperature of the reinforcing and matrix phase making up the polymer composite.

It has been shown that the better results of the glass-textolite samples compared to the textolite ones are due to the better reflectivity of the glass-textolite

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