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PENETRATION DEPTH IN LASER MARKING OF COMPOSITE MATERIALS WITH TEXTILE REINFORCEMENT PHASE

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ABSTRACT

This publication investigates the influence of the technological parameters of the laser marking process on the penetration depth of the laser beam in composite materials based on phenolic laminate with a textile reinforcing phase. Studies was conducted at the output power of the laser radiation - P=5÷50 W, marking speed - V=50mm/s and pulse frequency - f=50Hz. A graphical dependence of the obtained experimental results in comparison with the theoretical values is presented.

1. INTRODUCTION

The ever-increasing dynamics of change is one of the few constant characteristics of the reality surrounding us. Technological innovations in industry are continuous and comprehensive. The developing directions of "Industry 4.0" lead to the dynamic development of unconventional electrical technologies, powder metallurgy and other energy-saving technological processes [7].

The laser marking process in recent years, as part of electrophysical technologies, has entered the mass production of metal products and tools, semiconductor devices, glass and ceramic products [5, 6, 8, 16, 17]. It is becoming the norm for most manufacturing areas, as it offers several advantages, such as [1, 8, 12]:

- non-contact operation;
- high repeatability;
- high scanning speed;
- marking width comparable to the size of the laser spot;
- high flexibility;
- high process automation, etc.

Due to the need for identification in the above-described industries, laser marking has found increasing practical application in recent years [14]. It is the preferred method for achieving permanent and highly contrasting surface inscriptions, both on metal [6, 11, 13, 20, 21] and on a wide variety of non-metallic materials, ranging from glass [4], ceramics [9, 15, 16, 17], organic materials [2, 3, 5, 10, 18, 19], etc. The quality of the resulting marking depends on many factors [8]:

- marking geometry;
- heat affected zone expansion;
- presence of microcracks;
- durability under severe operating conditions;
- legibility, etc.

From the literature [13, 20, 21] it is found that the main technological parameters influencing laser marking are:

- average power;
- scanning speed (i.e. marking speed);
- pulse frequency, etc.

In this study, the influence of the output power of the laser installation on the depth of the resulting marking on composite polymer samples reinforced with textile fibers was monitored.

2. RESEARCH MATERIALS AND METHODS

In this study, 10mm thick textolite samples with mechanical characteristics according to DIN 7753/PFCC 202 and IEC 60893 Hgw 2082 - Table 1 were used. They are based on phenolic laminate with a reinforcing phase of cotton fabric, which due to its higher density has good dielectric and mechanical properties,

The marking of the samples was done using a laser installation – Fig. 1, developed on the territory of the company “Adtech”, based on Fiber lazer – RFFL-P-502B. Its main technological characteristics were presented in Table 2. The depth of the marking was studied on a measuring microscope – Fig. 2, using Insize ISD-V150/ V250/V300 software.

The penetration depth was determined by zeroing the Z-axis values at the surface of the marking and taking into account the changes in focus at the bottom of the marked channel. The distance between individual points spaced 10 mm apart was determined by moving the measuring line along the X-axis.

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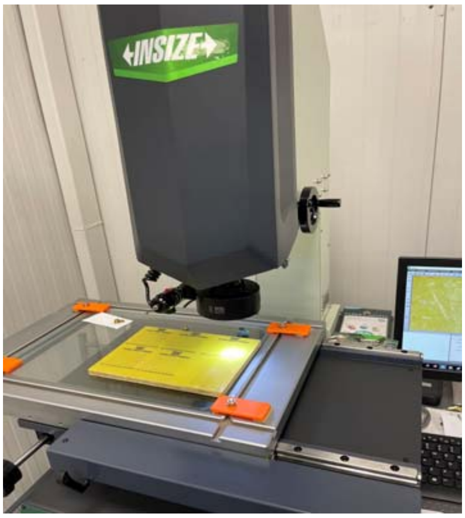
Table 1 *Mechanical charateristics*

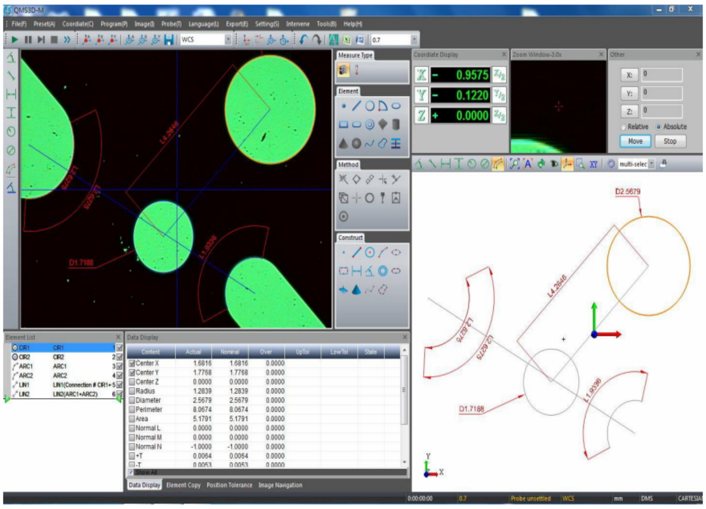
№	Items	Unit	Standard	Test Value (Average value)
1	Bending strength	MPa	130	130
2	Modulus of elasticity	MPa	7000	7000
3	Impact resistance without thread	kJ/m2	30	30
4	Resistance to impact with a rifle	kJ/m2	10/15	14
5	Tensile strength	MPa	80	80
6	Compressive strength	MPa	170	168
7	Brinell hardness	MPa	25÷30	30
8	Peel strength	N	2500	2500
10	Test voltage II / I	kV	8/5	8/5
11	Limit temperature	℃	110	110
12	Thermal conductivity	W/m.k	0,2÷03	0,2
13	Linear expansion	10-6/K	20÷40	32
14	Martens heat resistance	℃	150÷160	160
15	Specific heat	cal/ g.℃	0,35÷0,50	0,446
16	Evaporation temperature	℃	134÷732	700
17	Density	g/cm3	1,3÷1,4	1,4

Fig. 1. General view of Fiber laser – RFL – P – 50Q

Table 2 *Characteristics of the laser installation*

№	Items	Unit	Standard Value	Variation Step
1	Output Power	W	5÷50	25
2	Frequency	kHz	50÷100	25
3	Marking Speed	mm/s	1÷2000	1000
4	Defocusing	+/- from the focal length		
5	Focal spot	µm	37÷42	1





a. *b.*

Fig. 2. Overview of measuring microscope PHILIPS URD – a and software for 2D and 3D INSIZE ISD – V150 – b

3. EXPERIMENTAL PART

Samples were marked using the equipment shown in Fig. 1. The power values varied in the range 5÷50 kW, the marking speed was 50 mm/s with a focal spot diameter of 40μm and a pulse purity of 50 kHz.

The penetration depth of the laser beam was measured at 5 control points located along the marked line at a distance of 10mm. Some of the measurements are presented in Fig. 3, and all experimental results are shown in Table 3.

From Fig. 3 it is seen that the channel profile is not uniform along the length of the marking. This is also proven by the experimental results in Table 3 and Fig. 4, where the values for δ vary in relatively wide intervals. At an output power of the laser radiation up to 20W, the measured values are in the range from 5 to 50 μm. When increasing the output power from 20 to 50W, the fluctuations of the experimental results are 50÷200 μm. These fluctuations in the values of the depth during marking are the result of the different evaporation temperature of the reinforcing and matrix phases that make up the polymer composite.

Table 3 *Experimental data*

№	**P, W**	***δ, μm***						
		p.1	***p.2***	***p.3***	***p.4***	***p.5***	***Σp1÷p5 / 5***	***δ_{max}, μm***
V= 50mm/s								
1	*5*	*85*	*94*	*85*	*90*	*90*	*89*	*91*
2	*10*	*162*	*164*	*161*	*150*	*158*	*159*	*182*
3	*15*	*220*	*232*	*225*	*224*	*219*	*224*	*273*
4	*20*	*315*	*298*	*290*	*288*	*269*	*292*	*364*
5	*25*	*405*	*398*	*397*	*402*	*413*	*403*	*455*
6	*30*	*476*	*492*	*490*	*480*	*497*	*487*	*546*
7	*35*	*610*	*605*	*608*	*618*	*599*	*608*	*636*
8	*40*	*725*	*720*	*710*	*709*	*721*	*717*	*727*
9	*45*	*701*	*700*	*708*	*705*	*706*	*704*	*818*
10	*50*	*667*	*655*	*658*	*660*	*685*	*665*	*909*

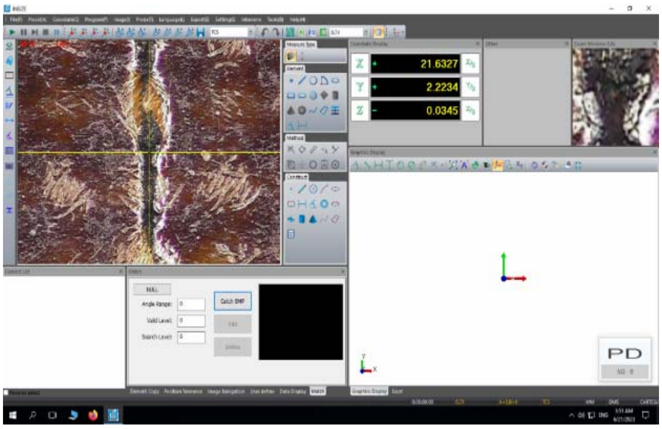
Theoretically, for non-metallic materials, the maximum penetration depth of the laser beam – δ_{max}, can be calculated using expression 1 [7]:

$$\delta_{max} = \frac{2P}{\pi . r . \rho . c . T}, \qquad (1)$$

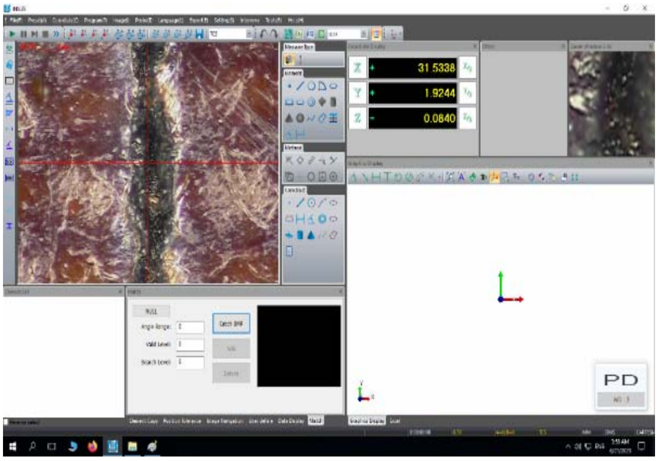
where: P - laser radiation power, W;
r - focal spot radius, μm;
ρ - density of the material, g/cm^3;
v – marking speed, mm/s;
c – heat capacity of the material, J/kg.ºC;
T – evaporation temperature, ºC.

Using the data from Tables 1 and 2, as well as reference data, the maximum theoretical values of the penetration depth during laser marking of the studied materials were calculated. (column 9 of Table 3).

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 experimental results obtained show that this is valid only for low marking powers - up to 20W. In these cases, the experimental results differ from the theoretical ones by less than 10%.



a.



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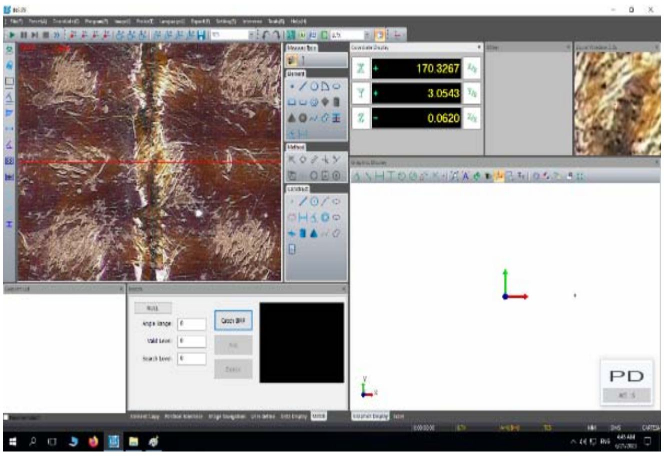

c

Fig. 3. Experimental results for marking textolite with V=50mm/s and f= 50kHz a - 25W ; b - 35W ; c - 50W

With an increase in power above 20W, the depth of the marking decreases by 20÷30% compared to the theoretical one and the temperature curve is not linear, but acquires a parabolic character. This can be explained both by the difference in the evaporation temperature of the matrix and reinforcing phases, and by the increase in power losses due to absorption of the emitted particles by the aerosol released in the treated area.

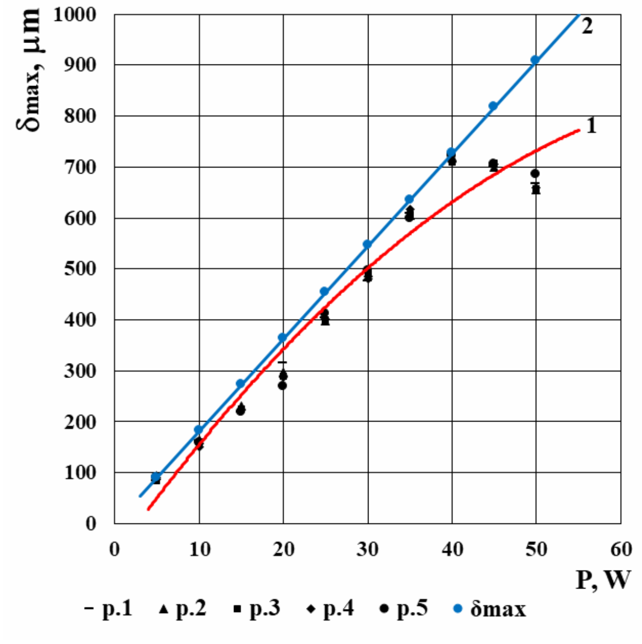

Fig. 4. Change in the bubble of the marking at P = 5÷50W , V = 50 mm/s, f= 50Hz – 1 and theoretical values 2

4. CONCLUSIONS

From the conducted research and the obtained results, the following important conclusions can be drawn:

- The depth of laser-marked composite materials based on phenolic laminate with a textile reinforcing phase has been studied at laser radiation output powers ranging from 5 to 50 W.
- It has been proven that the average marking depth was increased from 90 to 650 μm as the output power of the laser beam was increased from 5 to 50 W, while keeping the marking speed constant at 50 mm/s and the frequency at 50 Hz.
- It has been proven that, due to the different thermophysical characteristics of the matrix and the reinforcing phase in the composite, the measured values were found to vary within relatively wide limits. At an output power of up to 20 W, values of up to 100 μm were recorded, whereas at 50 W the values were observed to vary within the range of 100 to 300 μm.
- It has been proven that, unlike in single-component non-metallic materials, the depth of the marked layer in layered reinforced composites is not changed in a directly proportional manner with respect to the power. At powers up to 20 W, a directly proportional dependence was observed, but as the output power was increased to 50 W, the dependence was found to follow a parabolic curve. This behavior is attributed to power loss caused by the absorption of part of the radiation in the aerosols released during marking.

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