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On the applicability of reflexometric optical method for measurements of the roughness of samples used in examinations of laser microprocessing

KAZIMIERZ ROŻNIAKOWSKI, MIROSŁAW BIAŁKOWSKI

Institute of Physics, Technical University of Łódź, ul. Wólczańska 219, Łódź, Poland.

In examinations of interaction of strong laser radiation beams with metals the roughness of the metal surface within its regions, which is subject to irradiation, seems to be one of the factors influencing the parameters of these interactions [1, 2]. This quantity (roughness) is most frequently defined, from the shape of the profile in the plane perpendicular to the surface, by such parameters as: the uneveness height R_z, arithmetic average profile deviation from the average line R_a, or the greatest height of uneveness R_m. The first two of these quantities allow the surfaces of different roughness to be classified among roughness classes [3].

The measurements of roughness are usually carried out by using optical or mechanical methods. Optical methods are both more accurate and nondestructive, and allow us to determine the average roughness within the region of optical beam incidence. Hence, they are more suitable to our investigations concerning the interactions of strong beams of pulsed laser light with metals [4].

The optical method is based on the effect of light reflection from rough surfaces. This effect is very complex in this case and it requires that such phenomena as single- and multi-reflection, scattering diffraction and interference be considered simultaneously [5–8].

In a simplified version of the method the rough surface is considered as a set of micromirrors of similar sizes located on the plane under different angles (close to 90°) and on different heights. The mirrors are assumed to be large compared to the wavelength.

According to papers [9, 10] for such a model of the surface its roughness may be characterized by the parameter $\bar{h}$ expressed by the formula

$$\bar{h} = \frac{\lambda}{\cos i_0} \tag{1}$$

where: λ – wavelength of the measuring light beam,

i_0 – limiting angle mirror reflection of interference-diffraction nature.

The same author gives also an empirical dependence for a relative intensity I of the light reflected from the surface characterized by the parameter $\bar{h}$

$$I = \bar{r} I_0 \exp\left(-\frac{k\bar{h}^2}{\lambda^2}\cos^2 i\right) \tag{2}$$

where: I_0 – relative intensity of the light incident on the surface,
k – numerical coefficient determined experimentally,
$\bar{r}$ – effective index of reflection,
i – angle of beam incidence onto the surface ($90 > i > i_0$).

The dependence $\ln\frac{I_0}{I} = f\left(\frac{\cos^2 i}{\lambda^2}\right)$ is linear (the coefficient of correlation > 0.99), directional coefficient being equal to $p = k\bar{h}^2$. The constant k is calculated for each measurement from $k = \ln(I_0 r)$, where $r = e^{-y'}$ (y' is the point of intersection of the graph with the axis $y = \frac{\ln I_0}{I}$, i.e., it is the value of the function for the argument $\cos^2 i/\lambda^2 = 0$). This constant was in average equal to 4.49 with the standard deviation equal to 0.41.

In the examinations two sets of samples produced of the 45 steel and MO60 brass in the form of discs of 20 mm diameter and 10 mm thickness were used. Their surfaces were polished by using abrasive papers of different gradations.

The measurement setup consisted of He-Ne laser – 1, rotating stage –2, sample – 3, photoelement – 4 (Fig. 2). The He-Ne laser was chosen as a source of radiation due to high coll mation of the beam and exact knowledge of its wavelength ($\lambda = 6328$ Å). The plane of polarization made the angle of 15° with the surface of the sample.

In the examinations on interactions of strong radiation beams with the metals suitable for roughness measurement, a He-Ne laser adjusting the resonator of the pulsed laser (for instance, Nd^{+3} laser) may be used to determine the parameter $\bar{h}$ immediately before the strong pulsed beam interaction and exactly in the region of incidence. To this end a microscope-telescope setup, for instance, may be employed [11].

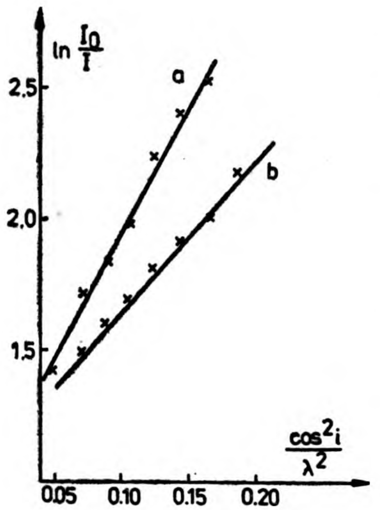

Fig. 1. Graphs of the function (2) for two chosen samples made of steel and a comparison of the results of roughness calculated according to this dependence with the results of calculations based on the formula (1). a – $\bar{h}(2) = 1.45$ μm, $\bar{h}(1) = \bar{h}(i_0 = 65°) = 1.50$ μm, b – $\bar{h}(2) = 1.12$ μm, $\bar{h}(1) = \bar{h}(i_0 = 54°) = 1.07$ μm

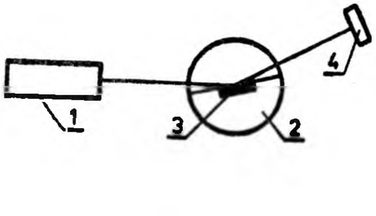

Fig. 2. Experimental setup. 1 – He-Ne laser, 2 – rotating stage, 2 – sample, 4 – photometer

In order to determine the parameter h both formulae (1) and (2) were applied. The comparison of the results have shown that the differences are contained within the measurements error $\Delta h < 10\% \, h$ (Fig. 1). This error was inevitable also due to nonuniformity of the granularity of the abrasive material even within the same sheet of abrasive paper.

The final results of the roughness measurements are presented in Table.

45 steel								
Gradation of abrasive paper	800	500	400	180	150	100	80	*N*
Roughness h [μm]	0.47	1.43	1.12	3.4	3.3	5.9	7.6	16

MO60 brass									
Gradiation of abrasive paper	800	600	500	400	180	150	120	100	*N*
Roughness h [μm]	0,66	1.4	0.90	0.87	3.3	2.1	9.1	6.6	18

N – sample of surface smoothed with a knife without polishing with an abrasive paper

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