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Laser modification of the surface roughness

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In the paper, the results of examination of laser (rubin laser of Q-switch type) modification of the surface roughness of samples produced of the Cu-Ni alloy being characterized by one-dimensional roughness (R_a: 0.1 – 3.0 μm) are presented. It has been shown in an experimental way that as a result of laser melting of the surface layer a surface of two-dimensional roughness is obtained. The examinations were carried out with both SEM and He-Ne laser light scattering methods applied before and after modification.

1. Introduction

As it is commonly known, one of the properties of a real surface is its roughness being often characterized by a normalized parameter R_a, *i.e.*, arithmetic average of the profile deviation [1]. There are some technological processes (grinding, cool rolling of sheet metal) due to which the resulting roughness is one-dimensional [2]. This is a stochastic ensemble of one-dimensional elevations and cavings. For such surfaces, it is usually assumed that $R_a = 0$ in the direction parallel to that of processing, while the value of this parameter in the direction perpendicular to the latter is considered to be essential (being different from zero). If the roughness is independent of the direction of moving across the rough surface, it is understood that the surface roughness is two-dimensional (as it is the case after sand-blasting or polishing, for example).

In many technological laser modification processes, it is necessary to locally heat up the external layer of a metal object above its melting temperature by using laser radiation. This way of laser processing, connected also with rapid cooling, results in changes of many properties (modification) of the processed layer, including the surface roughness. This is true for both the surfaces treated by the CW and pulse lasers. In the latter case, the processed surface and the laser are moved with respect to each other. The roughness characterizing the surfaces produced in the course of such interaction processes depends on a number of factors, such as, for example, dynamics of heating and velocity, thermo-physical properties of metal, kind of laser operation and the atmosphere surrounding the irradiated object.

Although the first lasers were built over 30 years ago, the problem of laser modification of the surface roughness is still actual and has significant importance in many domains of life. For instance, there exist a possibility of applying a laser in order to worsen locally the roughness of sheet metal used to production of car bodies (which results in improvement of adhesion of the varnish deposited on it [3]). Similarly, the local evaporation of the tooth enamel improves the durability of fitting made on the surface prepared in this way [4]. On the other hand, the laser modification of the magnetic properties of the sheet-irons for transformers (refinement of magnetic domains causing reduction of losses [4], [5]) worsens the roughness and thus increases this part of the magnetic flux which is subject to scattering.

The aim of the examinations presented in this work is to modify the surfaces of definite one-dimensional roughness by employing a suitable laser, under laboratory conditions, and to find the eventual relations between the parameters characterizing the roughness of these surfaces (before and after the laser modification). In the examinations, a laser method of measuring these parameters was applied.

2. Experiment

2.1. Subject of examination and its characteristic features

Six samples were the subject of examination, all of them being standards of one-dimensional surface roughness. Their surfaces consisted of a set of parallel grooves (surface waveness) distributed stochastically. The values of parameter R_a measured by the producer of these samples (a German firm MASSI) in the direction perpendicular to the grooves were equal to: 0.1, 0.22, 0.4, 1.0, 1.4 and 3.0 μm, respectively.

From the examination of the chemical composition of the samples made on an automatic spectrograph of OB2F ES 750-M type, it follows that the standards were produced of Cu-Ni alloy (Cu 90.86%, Ni 3.19%) and covered with a chromium layer of 100 μm thickness (Cr 5.96%).

The microtopography of the sample surface (before and after the laser modification) was recorded with the help of a scanning electron microscope (SEM) of BS 301 type.

The roughness of the surface was modified by local heating of the surface layer of the samples above their melting temperature with the help of a pulse ruby laser LMA 10 working in the Q-switch regime ($E \simeq 0.05$ J, $\tau_l \simeq 30$ ns, $\lambda = 0.69$ μm). All the irradiations were carried out preserving the same geometry. The total area of the modified surface was longer than the cross-section area of the laser beam emitted by the He-Ne laser used to optical examinations.

2.2. Description of the optical measuring apparatus

The optical examinations were carried out with the help of the apparatus, the block scheme of which as well as its detailed description were presented in paper [6]. The only difference is that the indicatrix of the light scattered in the plane of reflection was recorded with the help of a gauge calibrated with respect to a laser power meter of LM 1 type. Besides, there was offered a possibility of inserting a photo camera, instead of a measuring probe, along the path of the reflected light (at a much greater distance from the sample than it was possible for the measuring probe) and registering the angular distribution of the scattered radiation on a photo plate. In the present investigations, a distance between the sample and the photographic plate was chosen such as to visualize the speckling image of the scattered light, which was next subjected to densytometric examinations (using MD 100 microphotometer).

3. Results

3.1. Results of examination with SEM

In Figures 1–3, the photographs are presented being representative for the examinations carried out in this work and illustrating the influence of R_a on the

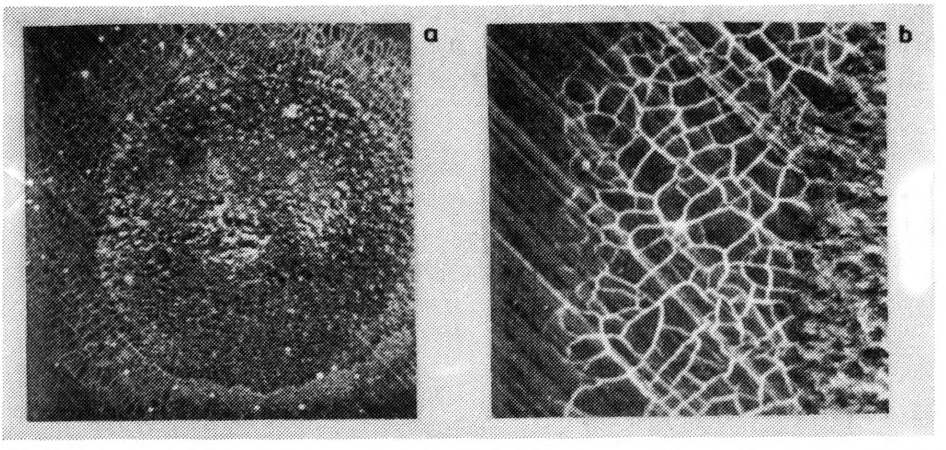
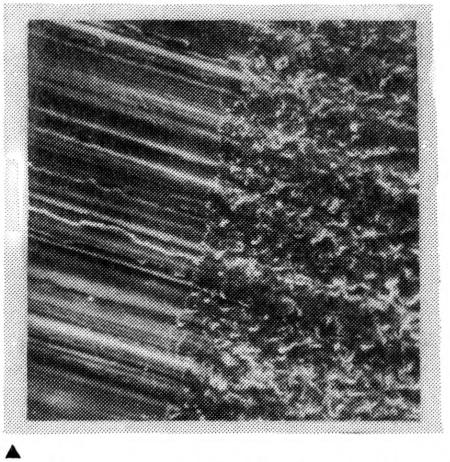


Fig. 1. Microtopography of a fragment of the sample surface (R_a = 0.1 μm). On the photo **b**, the fragment (shown under 4 × bigger magnification than on the photo **a**) of the surface modified due to the laser melting is shown. Also the zone of the thermal interaction surrounding the melted region is visible. In the melted region (of about 0.667 mm in diameter) a surface of two-dimensional roughness appears



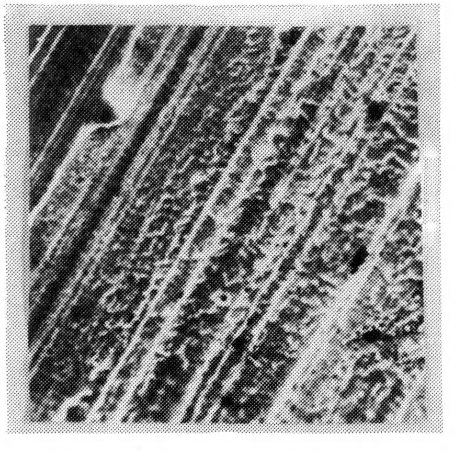


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Fig. 2. Microtopography of a fragment of the sample surface (R_a = 1.0 μm). The roughness of the surface in the melted region is not "purely" one-dimensional

Fig. 3. Microtopography of the fragment of a sample surface (R_a = 3.0 μm). In the melted region, the one-dimensional roughness is preserved to a considerable degree

microtopography of the surface appearing in the process of laser melting of the surface layer of the samples. It may be easily seen that the microtopography of the surface created in this process depends on the roughness of the surface (on its R_a) subjected to the laser melting. On the basis of the microscopic examinations carried out it can be observed that for the surface of small R_a (0.1 – 0.22 μm) only the surface of two-dimensional roughness is obtained (a modification of the examined roughness, Fig. 1).

For the surfaces of great R_a (1.0 – 3.0 μm), after application of laser melting, the obtained surface exhibits the "components" of roughness (Figs. 2 and 3), *i.e.*, that of one-dimensional type, which appears in the process of sample production, and of two-dimensional type – caused by laser melting of the surface layer. Thus, a different kind of modification occurs in this case than for the small R_a.

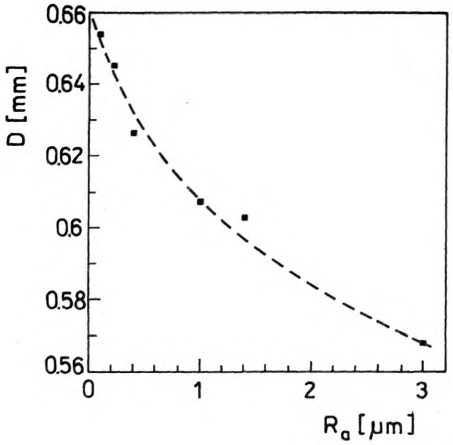


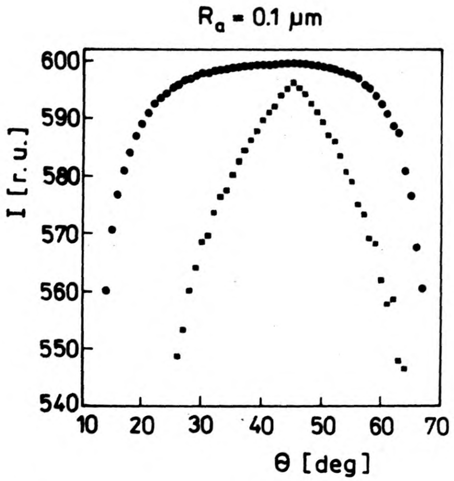
Fig. 4. Diameter D of the melted region as a function of R_a for the surface before its modification

Besides, it has been observed that the diameter D of the melted region diminishes with increase of R_a (Fig. 4). Also a laser-induced damage threshold for the optical surface was observed [8]. Thus D depends on the effective surface of interaction in spite of the fact that originally it was a surface of one-dimensional roughness.

3.2. Results of optical examinations

One of the most fundamental features of light scattering effect is asymmetry of its angular distribution (visible immediately on the screen with naked eye). The angular width of the indicatrix of the scattered light in the reflection plane is much greater than in the plane perpendicular to the latter. This is true for the surface both before and after its laser-melting.

In Figures 5 and 6, some examples of indicatrices of the light scattered from the surface (for chosen R_a) of the samples made by the producer before and after their laser modifications are shown. A distinct difference in the shape and parameters of these distributions for each surface before and after laser modification is visible.



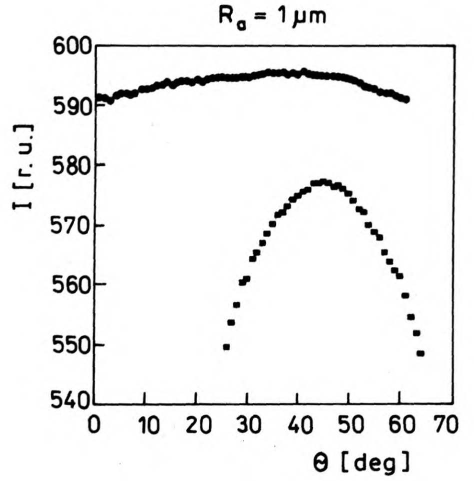


Fig. 5. Angular intensity distributions of the light scattered from the surface of one-dimensional roughness, $R_a = 0.1$ µm (black circles) and after its laser modification (black rectangles)

Fig. 6. Angular intensity distribution of the light scattered from the surface of one-dimensional roughness, $R_a = 1$ µm (black circles) and after its laser modification (black rectangles)

It has also been observed that the direction in which the scattered light intensity is maximal (I_{max}) is not identical with that of the mirror reflection. From the analysis of the obtained indicatrices it follows that the angular distance θ_s (Fig. 7) between the

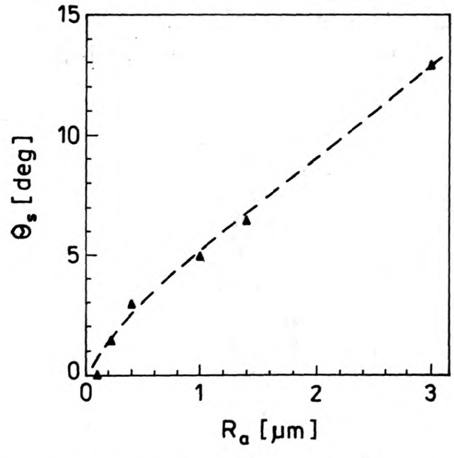
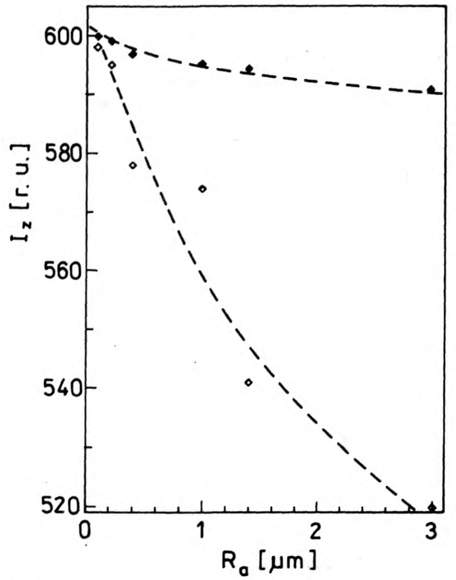


Fig. 7. Angular distance θ_s as a function of R_a

direction of the mirror reflection and that of I_{max} increases with the increase of R_a. This may indicate that the local angle of incidence of the laser light beam does not cover the incidence angle on the same nominal surface [2].

In turn, in Figures 8 and 9 the light intensity in the mirror reflection direction I_z as well as the halfwidth of the scattering indicatrix are presented as they depend on R_a. Similarly, as was the case in works [6], [9], [10], I_z diminishes monotonically



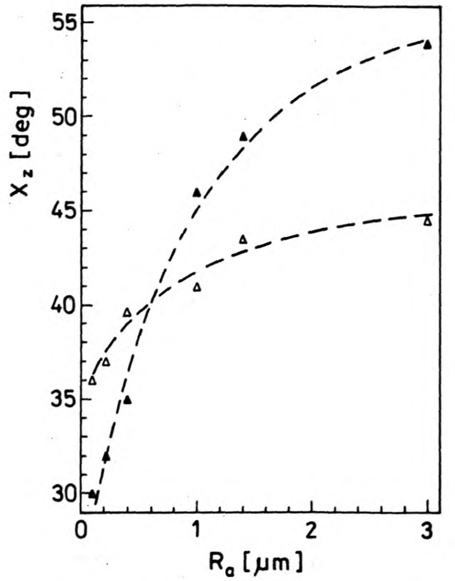


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Fig. 8. Light intensity I_z in the direction of mirror reflection (surface before modification — black rectangles, after modification — white rectangles) as a function of R_a

Fig. 9. Halfwidth of the indicatrix X_z (before modification — black triangles, after modification — white triangles) as a function of R_a

as a function of R_a (for both the kinds of surface), except for the fact that this dependence is stronger for the two-dimensional roughness.

In Figures 10 and 11, the photos of the angular distribution of the light intensity in the vicinity of the mirror reflection being enclosed inside the solid angle

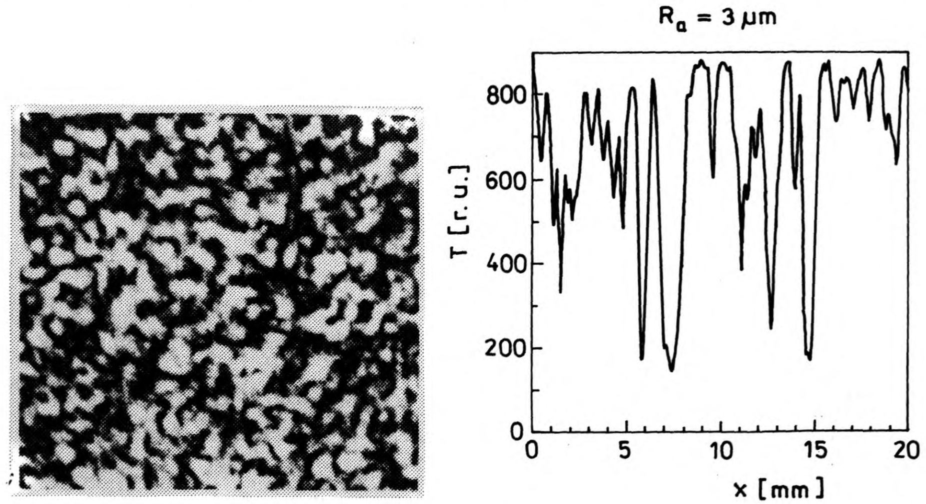

Fig. 10. Photograph and densitogram presenting the angular intensity distribution of the light scattered by the surface of one-dimensional roughness ($R_a = 3.0$ μm)

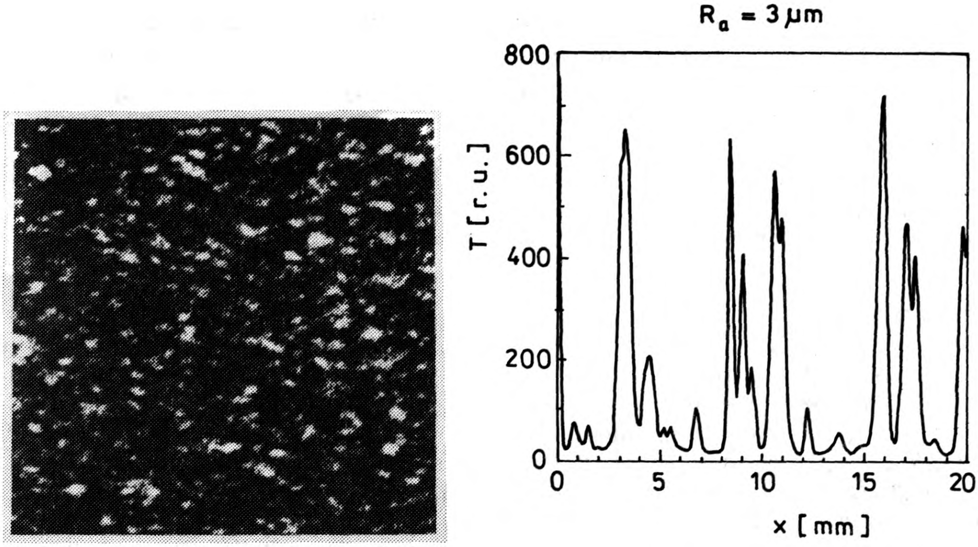

Fig. 11. Photograph and densitogram presenting the angular intensity distribution of the light scattered by the surface created due to laser modification of one-dimensional surface roughness $R_a = 3.0$ µm

equal to 2.82×10^{-4} steradian are shown together with exemplified densitograms (taken along one line passing through their centre, which corresponds to the reflector plane). Here, also a big difference is observed between the parameters of the speckles (sizes, light intensity in the speckle and their spatial distribution) produced by the surfaces before and after their laser modifications.

4. Conclusions

On the basis of the results obtained the following conclusions can be formulated:

1. Laser radiation (in the case of modification and examination of the surface metal roughness of metals and their alloys) may be exploited in two ways. On the one hand, it may be used to estimation of some parameters characterizing the surface roughness. On the other one, the laser light beam (ruby laser of Q-switch type) may be used to modify the surface roughness. As a result of laser melting of the surface layer of one-dimensional roughness, either another surface of two-dimensional roughness may be obtained or a surface of roughness being a kind of the sum of one-dimensional and two-dimensional versions. This means that the surface roughness is subjected to modification.

2. Parameters (such as: I_z, X_z, asymmetry, speckle) of the angular distribution of the scattered light intensity (indicatrix) concerning the non-modified surface and the one melted with a ruby laser are distinctly different. Thus, if the changeability of the parameters mentioned above is accepted as a criterion of the roughness modification, then the process of laser melting of the surface layer of a metal modifies the surface roughness.

3. The results presented in this work may be considered as a basis for more complex technological and measuremental works, which when carried out automatically and in an on-line system could, significantly improve the quality of not only conventional technological processes.

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