The Method of Materials Surface Defects Analysis Created by Laser Processing

Vitalii Mocharskyi [1], Bogdan Kovalyuk [1], Oksana Sitkar [1], Volodymyr Hutsaylyuk [2], Marcin Wachowski [2]

[1] *Ternopil Ivan Puluj National Technical University, Ruska street, 56, Ternopil, 46001, Ukraine*
[2] *Military University of Technology, General Sylwester Kaliski street, 2, Warsaw, 00-908, Poland*

Abstract

Laser processing allows changing the defective substructure of materials in order to control their properties. Critical values of temperature and pressure in the laser-processing zone create unique opportunities for obtaining various structures on the surface and in the depth of materials. Simplicity, safety and ease of automation contribute to the fact that laser processing finds more and more applications in various fields of science and technology. There are many different ways to determine defects on the surface of materials after laser treatment. Some of them are connected with the use of special devices, and some with the use of special algorithms, models and software products for automatic identification and calculation of created defects. Each of the means has its advantages and disadvantages. In this work, we propose the model for the analysis of SEM images with the aim of not only qualitative but also quantitative analysis of defects in materials. This model makes possible to obtain the values of defect areas in relation to the base material. This is important for a more accurate and high-quality selection of laser processing parameters in order to create materials with predetermined structure and properties. In addition, such model can facilitate the calculation of surface defects for scientists, engineers and technologists.

Keywords

Defects, laser, model

1. Introduction

Laser processing is a modern physical and technical method of changing the structure and properties of materials. Thanks to high temperatures and pressures, all materials can be laser processed. In addition, laser technologies have a number of advantages over other traditional processing methods: manufacturability, accuracy, safety, ease of automation. The change in the properties of materials after laser treatment is associated with a change in the defective substructure of the materials. A defect should be understood as any change in the structure of the material after processing, which differs from the structure of the original (base) material. At the same time, defects can both improve and worsen the properties of materials.

Very often, during research, there is a need to quickly, qualitatively, and quantitatively evaluate defective changes in the material after laser treatment. It should be noted that there are many methods for surface analysis [1-3]. Some of them are standard, and some are based on specially created algorithms, models and software products [4-6]. One of the most important methods of studying the structure of materials after laser processing is the method of microscopy [7, 8] (optical, electronic, etc.). Microscopy is usually a component of a complex and expensive measuring system for surface or structure research [9, 10]. Therefore, it is of interest to develop simple, inexpensive algorithms, models and systems for analyzing microscopic images of the defective surface of materials.

Proceedings ITTAP'2023: 3rd International Workshop on Information Technologies: Theoretical and Applied Problems, November 22–24, 2023, Ternopil, Ukraine, Opole, Poland
EMAIL: vitaliimocharskyi@gmail.com; kovalyukdan@ukr.net; manjovska@gmail.com; volodymyr.hutsaylyuk@wat.edu.pl; marcin.wachowski@wat.edu.pl
ORCID: 0000-0003-4153-6832; 0000-0002-8085-0165; 0000-0001-9352-4660; 0000-0003-4812-5737; 0000-0002-6732-5972

2. Types of defects during laser processing of materials

For laser processing of materials, we used a system based on Nd:glass laser (Figure 1). The pulse duration is 50 ns, the radiation flux density is 2×10^8 - 5×10^9 W/cm^2.

Experiments conducted on laser shock wave treatment of ZnO nanopowder using a thermal protective copper screen showed that a large number of dimples are formed on the reverse side of the copper foil (Figure 2).

There are two possible mechanisms for the formation of these dimples: the first is caused by the pressing of ZnO conglomerates into the surface of copper (stamping effect), since the nanopowder has a higher hardness than copper, the second is related to the chipping pulse due to the passage of a shock wave through the material.

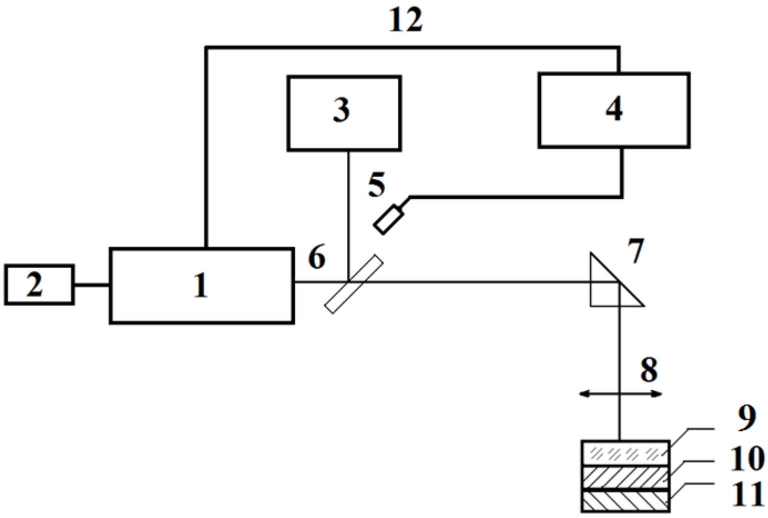
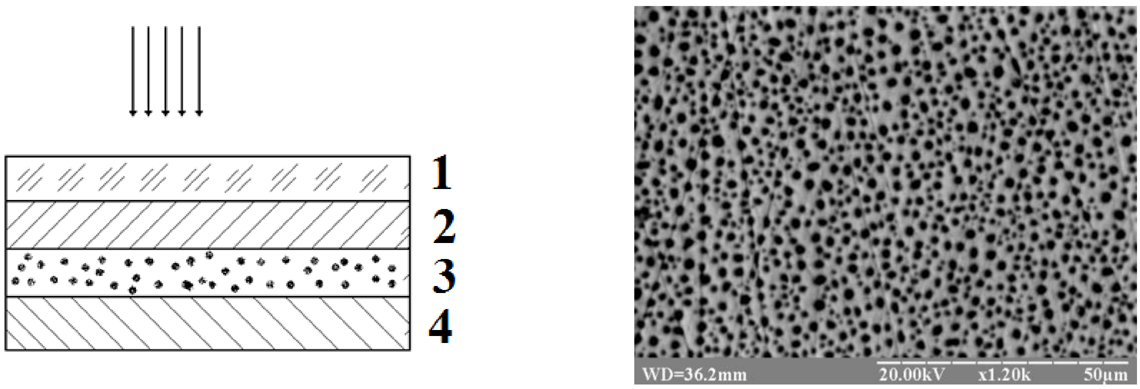


Figure 1. Experimental equipment for laser material processing: 1 - Nd:glass laser; 2 - helium-neon laser; 3 - energy meter; 4 – oscilloscope; 5 – photodiode; 6 - optical plate; 7 - optical prism; 8 - focusing system; 9 - transparent condensed medium; 10 - thermal protective copper screen; 11 – sample; 12 - synchronization system

With help of a laser possible to accelerate small particles of materials to high speeds (≤10 km/s). In this way, it is possible to simulate the impact of micrometeoroids on the surface of various spacecraft. This can reduces the risks of damage to spacecraft after collision with space debris, and it can also help to protect life and health of astronauts.

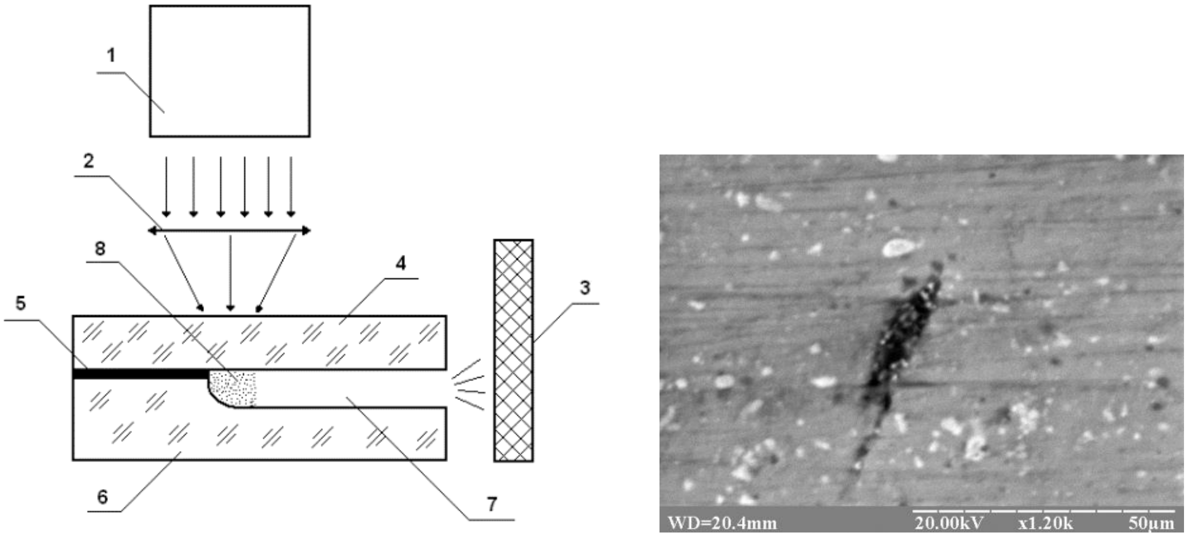


a b

Figure 2. Scheme of laser shock wave processing of ZnO nanopowder (a) and SEM image of the reverse side of copper screen after processing (b): 1 - transparent condensed medium; 2 - thermal protective copper screen; 3 – ZnO nanopowder, 4 - steel substrate

Based on the device for laser shock-plasma acceleration of fine-dispersed materials (Patent 86399 Ukraine, IPC C23C 24/00) was developed a new method for modeling the impact of micrometeoroids on the surface of spacecraft materials (Figure 3).

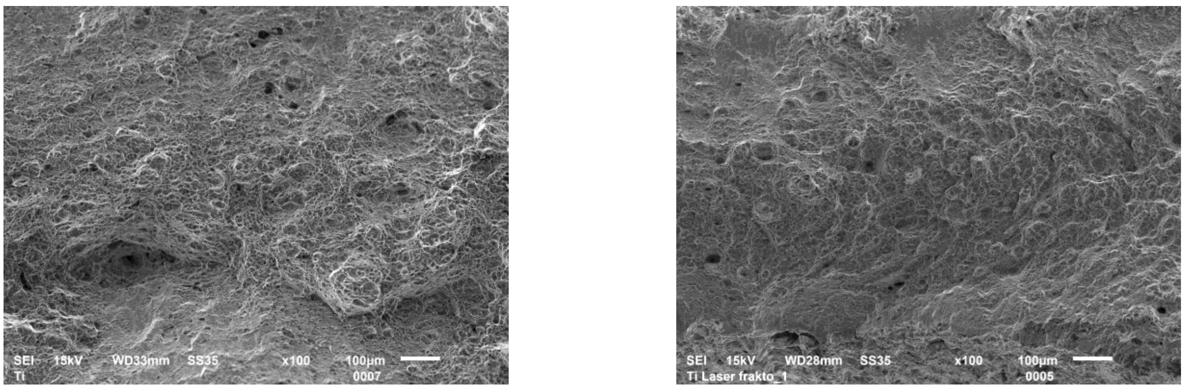
As can be seen from the figure, when aluminum microparticles collide with a target made of the same aluminum, defects (dimples or craters) form on the surface. The shape and size of the craters depend on the shape and size of the microparticles, as well as on the parameters of the laser pulse.



a b

Figure 3. Scheme of device for laser shock-plasma acceleration of fine-dispersed materials (a) and SEM image of the crater formed after the collision (b): 1 – laser, 2 – focusing system, 3 – target, 4 – transparent plate, 5 – glue, 6 – additional transparent plate, 7 – groove, 8 – fine-dispersed material.

Also, with the help of lasers, it is possible to change the structure of the material at depths significantly exceeding the depth of the thermal action of the laser pulse. Thus, after irradiation of titanium through a transparent condensed medium without a thermal protective coating, its strength increased, and plasticity decreased. The study of fractography of titanium samples after static stretching showed a decrease in the number of pores in the material after laser treatment due to the passage of the shock wave, which can be the reason for the change in mechanical properties. (Figure 4).



a b

Figure 4. Fractography of titanium samples before (a) and after (b) laser treatment

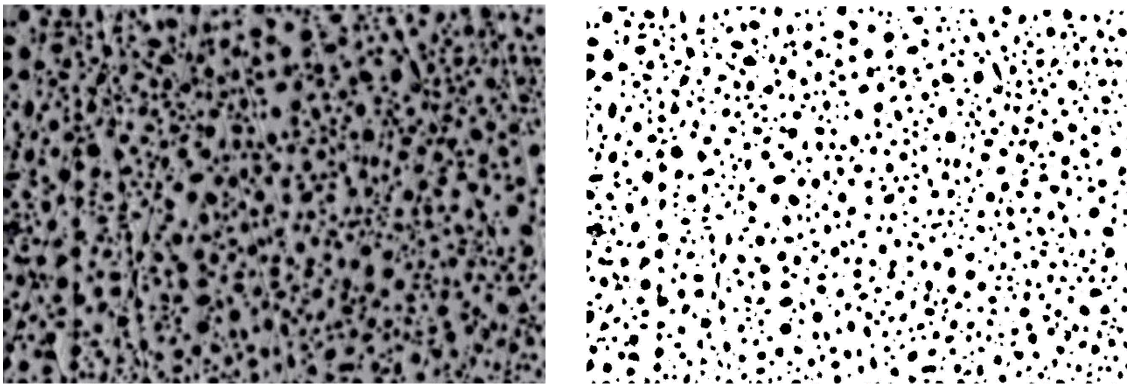
3. Defects analysis on the surface of materials

The algorithm for SEM images analyzing is based on a matrix model [11, 12], that is, we consider a gray image from an electron microscope as a matrix of size m by n, where m and n are the width and height of the image in pixels, and the number is the shade of gray (from 0 to 255 shades, 0 - maximum black, 255 - maximum white).

Then we conducted an empirical elemental analysis and found that the defects in the SEM images have a shade from 0 to 50, and the base material has a shade from 51 to 255. In this way, we can convert a gray image to binary (black and white), where all shades up to 50 will be equal to 0, and shades from 51 to 255 will be equal to 1.

Then we can calculate the number of black pixels in the received image, this number will be equal to the number of defects on the surface. After that, we can compare the number of black pixels to the total number of pixels in the image, that is, look for the ratio of the area of defects to the area of the entire surface of the material. Or we can compare the areas of defects before and after laser treatment on two different images.

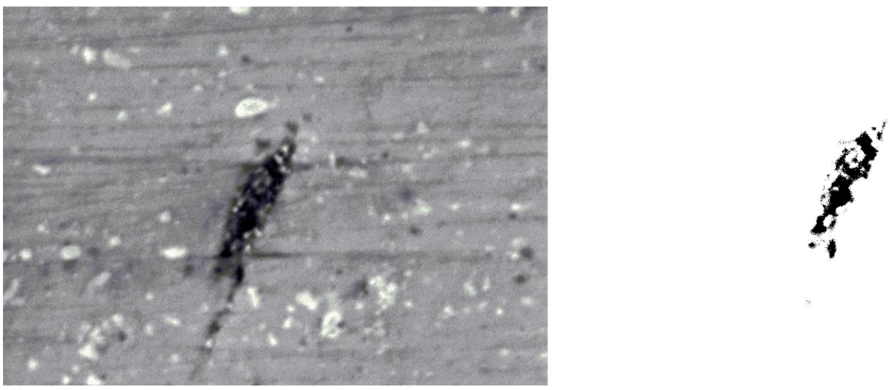
Image analysis of the copper screen reverse side with the help of the proposed model using the MATLAB (Figure 5) showed that the ratio of the area of dimples to the area of the entire material is 18.28%.



a b

Figure 5. The surface of the copper screen reverse side before (a) and after (b) analysis

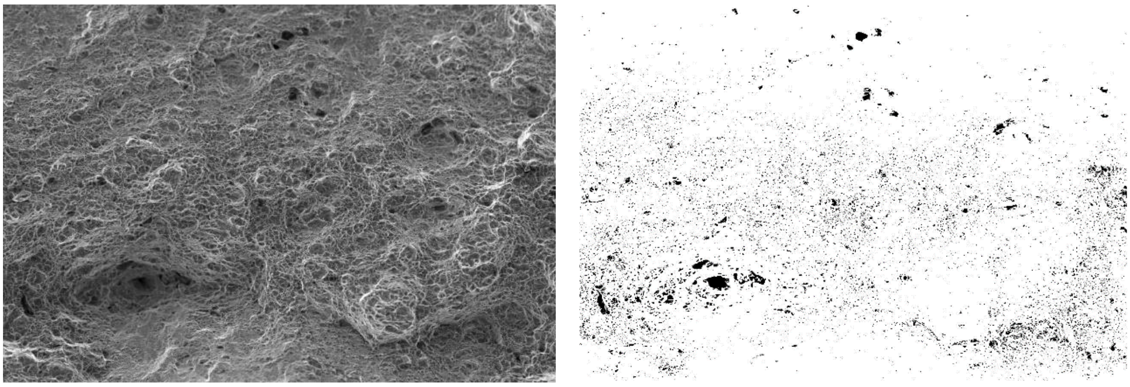
Surface analysis of the aluminum target after aluminum microparticles impact with help of the proposed model (Figure 6) showed that the ratio of the area of the formed craters to the area of the entire material is 0.95%.



a b

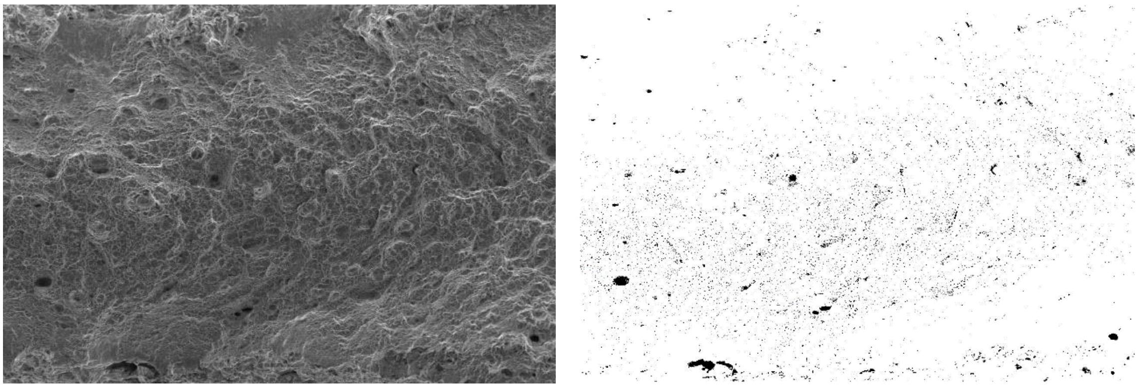
Figure 6. The surface of an aluminum target after microparticles impact before (a) and after (b) analysis

Fractography analysis of titanium before (Figure 7) and after (Figure 8) laser shock wave treatment using the proposed algorithm showed that the ratio of the pore areas before and after irradiation to the area of the entire material decreased from 4.19% to 1.95%, or approximately 2.15 times.



a b

Figure 7. Titanium fractography before laser treatment using the proposed model before (a) and after (b) analysis



a b

Figure 8. Titanium fractography after laser treatment using the proposed model before (a) and after (b) analysis

4. Conclusions

There are many different ways to determine defects on the surface of materials after laser treatment. Some of them are connected with the use of special devices, and some with the use of special algorithms, models and software products for automatic identification and calculation of created defects. Each of the means has its advantages and disadvantages.

The work presents various types of defects after laser processing, which was used in our previous experiments. The proposed model allows to quantitatively estimate the number of defects after laser processing. The model for analyzing SEM images makes it possible to obtain the values of defect areas in relation to the base material. The analysis algorithm is based on a matrix model implemented in MATLAB. This is important for a more accurate and high-quality selection of laser processing parameters in order to create materials with predetermined structure and properties. In addition, such model can facilitate the calculation of surface defects for scientists, engineers and technologists.

5. References

[1] Kafayat Eniola Hazzan, Manuela Pacella. Surface defect detection and prediction in carbide cutting tools treated by lasers. Procedia CIRP, Volume 108, 2022, Pages 851-856.

[2] Wei, X.; Liao, Z.; Wei, S.; Chen, G.; Lu, H.; Liang, Y.; Cai, M.; Shen, J. Surface Post-Treatment Induced by Nanosecond Pulsed Laser Processing of HVAF-Sprayed Fe-Based Metallic Glass Coating. Metals 2022, 12, 1788.

[3] Laura Convert, Eric Bourillot, Manuel François, Nicolas Pocholle, Florence Baras, Olivier Politano, Sophie Costil. Laser textured titanium surface characterization. Applied Surface Science, Volume 586, 2022, 152807.

[4] Moldovan, E.R., Concheso Doria, C., Ocaña, J.L., Istrate, B., Cimpoesu, N., Baltes, L.S., Stanciu, E.M., Croitoru, C., Pascu, A., Munteanu, C., Tierean M.C. Morphological Analysis of Laser Surface Texturing Effect on AISI 430 Stainless Steel. Materials 2022, 15, 4580.

[5] Erju Liu, Xi Chen, Yang Jin, Yanbin Chen, Jie Xu, Debin Shan, Bin Guo. Surface morphology evolution and tribological behavior in nanosecond pulsed laser polishing of S136 mold steel. Journal of Materials Research and Technology, Volume 22, 2023, Pages 3230-3244.

[6] Yuling Wu, Xia Xiang, Jingxia Yu, Xiaodong Yuan, Huahai Shen, Wanguo Zheng, Xiaotao Zu. Review: Research progress on nanosecond laser irradiation damage of optical films, Nuclear Analysis, Volume 1, Issue 4, 2022, 100045.

[7] Boustie M, Berthe L, De Resseguier T, Arrigoni M. Laser Shock Waves: Fundamentals and Applica-tions. Proceedings of the 1st International Symposium on Laser Ultrasonics: Science, Technology andApplications. 2008. pp. 1–6.

[8] Tendero I, Rossi MC, Viera M, Amado JM, Tobar MJ, Vicente Á, Yañez A, Amigó V. Laser Surface Modification in Ti-xNb-yMo Alloys Prepared by Powder Metallurgy. Metals. 2021; 11(2):367.

[9] P. O. Maruschak, V. S. Mocharskyi, I. M. Zakiev and Y. M. Nikiforov, "Morphology of periodical structures on surface of steel 15Kh13MF after the nanosecond laser irradiation accompanied by generation of shock waves,"2012 IEEE International Conference on Oxide Materials for Electronic Engineering (OMEE), Lviv, Ukraine, 2012, pp. 192-193.

[10] Kormpos P, Unaldi S, Berthe L, Tserpes K. A Laser Shock-Based Disassembly Process for Adhesively Bonded Ti/CFRP Parts. Processes. 2023; 11(2):506.

[11] Narica P., Teilans A., Lazov L., Cacivkins P., Teirumnieks E. Mathematical Model of the Distribution of Laser Pulse Energy. Published in:Proceedings of The 9th EUROSIM Congress on Modelling and Simulation, EUROSIM 2016, The 57th SIMS Conference on Simulation and Modelling SIMS 2016. Linköping Electronic Conference Proceedings 142:116, p. 794-799.

[12] Mocharskyi V., Kovalyuk B., Sitkar O. Modelling the Distribution of Laser Energy in the Pulse by the Photoemulsion Method. CEUR Workshop Proceedings, 2022, 3309, pp. 447–452.