

DETERMINATION OF CONDITIONS FOR NANOPOROUS STRUCTURE FORMATION IN A METALLIC MATERIAL BY PULSE-PERIODIC LASER ACTION

S.P. Murzin, A.I. Safin, A.A. Shimanov, M.V. Blokhin, S.A. Afanasiev

Samara National Research University, Samara, Russia

Abstract. Determination of spectrums of samples responses on external vibro-excitation via pulse-periodic laser action by CO₂ laser ROFIN DC 010 and registration of their wave forms have been performed. While analysing the samples' responses using pulse-periodical laser action, it has been found that vibration rate increases in the case of frequencies, which are divisible by the frequency of initial oscillation, during the amplitude decrease and the frequency increase. The dependence of heat rate on the nanoporous structure formation in the absence of the metallic material melting has been researched. While heating the sample, its temperature was highest at its centre. An increase of the laser action time led to a rise in the temperature of the sample's centre, causing the rate of pore formation has increased. Since the diffusion coefficient is related to the temperature through an exponential law, the temperature rise is an effective way to increase rate of the process. However, non-permanent elastic deformation, which is caused by high-powered external action, is a necessary condition for developing a generic thermodynamic moving force, which increases the rate of nanoporous structure formation in metallic material.

Keywords: formation, nanoporous structure, laser action, metallic material, frequency, vibration rate, temperature.

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Introduction

The use of pulse-periodic laser action is a progressive way of forming nanoporous layers on the surface of metallic materials. Conditions for formation of such layers in two-component Cu-Zn alloy brass L62 with a 60.5–63.5% copper content have been defined in printed works [1-3]. It is stated that as a result of the laser action, single nanopores, as well as ones that form branched channels, appear in the near-surface

layer and on the surface. Both are uniformly distributed on the area [4, 5]. Such structures develop via appearance of vacant sites and their coagulation is a result of Zn sublimation from the material surface, inducing a concentration gradient and diffusion of this component with higher vapour tension at the surface [6-8]. Non-permanent local deformation, caused by high-powered external action, is a condition for intensification of mass transfer in the solid phase of metallic materials [9-11]. At that, laser action with pulse-periodic radiation allows a persistent stress condition to develop on the surface of the samples [12, 13]. In order to redistribute the power density in the cross-sectional area of the laser beam, the use of a diffractive optical element – focuser of laser radiation, is expedient [14–17]. The aim of this work is to define the conditions for formation of nanoporous structure in metallic materials via pulse-periodic laser action.

Pulse-periodic laser action on the metallic material

Samples of Cu-Zn alloy brass L62 with dimensions of 30x20x0.05 mm have been researched. Spectra of the samples' responses to external vibroexcitation via pulse-periodic laser action have been measured and their wave forms have been defined. Power action has been performed by a ROFIN DC 010 CO₂ laser with adjustable output power range of 100-1000 W. A three-component scanning laser vibration-measuring instrument Polytec® PSV-400-3D was used to measure the vibration rate. The instrument has three scanning heads, each of them fitted with an interferometer and video camera, as well as a PC and three data management controllers. Data management has been synchronized by PSV 3D software, the user interface is used for visualization of dynamic processes in the form of animated 3D oscillation distributions in the investigated frequency range. Pulse-periodic laser action has been performed with frequencies of 100, 500, and 5000 Hz. After the analysis of the samples' responses on the described external vibroexcitation, it has been found that vibration rate increases in case of frequencies, which are divisible by the frequency of initial oscillation, during the amplitude decrease and the frequency increase. Fig. 1 shows images of the sample, which have been re-established with the use of PSV Presentation software. The oscillation shape corresponds to a frequency of 500 Hz. It has been defined that maximum vibration rate occurs on the periphery of the sample; however, the intensity of the pore formation is much lower here than in centre.

A Mikron M7604F thermovision camera was used to research the heating of the samples via laser action. Fig. 2 shows the temperature field of the sample under pulse-periodic laser action. The highest temperature of the sample was in its centre. An increase of the laser action time led to a rise in temperature of the sample's centre area, due to this, an intensity of pore formation increased. The dependence of the heating on the nanopores structure formation in the absence of the metallic material melting has been researched. Inasmuch as the diffusion coefficient is related to the tem-

perature of an exponential law, the temperature rise is an effective way to increase the atoms mobility. However, non-permanent elastic deformation, which is caused by high-powered external action, is a necessary condition for development of generic thermodynamical moving force, which provides an intensification of the nanoporous structure formation in a metallic material.

Research of the material's fine structure

Fine structure of the material has been researched with the use of a scanning electron microscope, VEGA \ SB, Tescan. It was found that the laser action creates nanoporous structures in near-surface layer. Channel type nanopores ~100 nm wide, which organize nanoporous network, mainly appear. Dimensions and shapes of the nanopores, equally distributed on the surface of subgrains, are relatively stable.

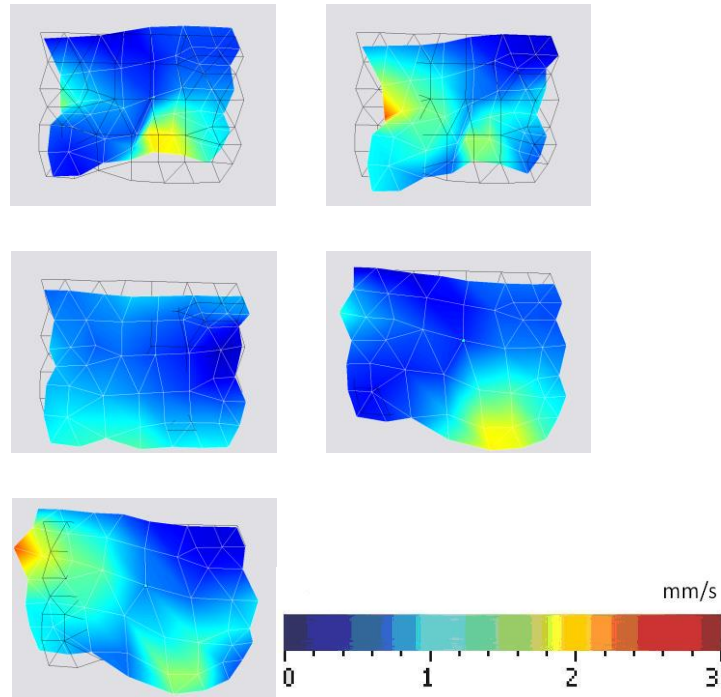


Fig. 1. Images of the sample, which have been re-established with the use of PSV Presentation software and which correspond to the frequency of 500 Hz; time step is 0.2 ms

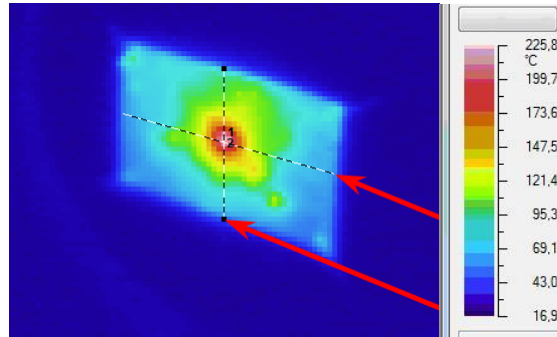


Fig. 2. Temperature field of the sample during its pulse-periodic laser action

Fig. 3 shows image of characteristic nanopore up to 100 nm wide, which organize into a nanoporous network in the metallic material during its pulse-periodic laser action. The main mechanism of nanoporous structure formation is the sublimation of the component with higher vapour tension; in this case it is Zn. A concentration gradient is set up in the material and this component sublimates with the surface to the extent to which diffusion of it to the surface from the inner layers is provided. In time, the thickness of the Zn depleted layer increases and the diffusion becomes a limiting factor of the sublimation process. Non-permanent local deformation, caused by high-powered external action, is a condition for intensification of mass transfer in the solid phase of metallic materials. Inasmuch as the diffusion coefficient is related to the temperature of an exponential law, the temperature rise is an effective way to increase the intensity of the process.

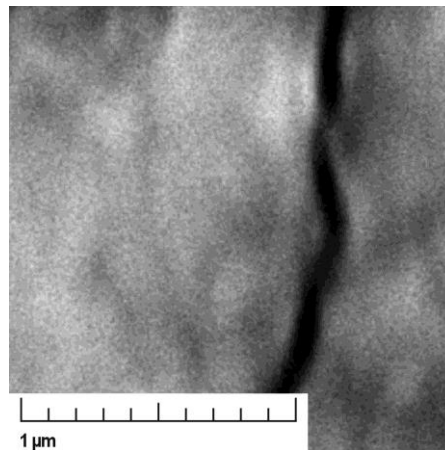


Fig. 3. Image of a ~100 nm wide nanopore formed as a result of laser action on the sample's metallic surface

Conclusion

In analysing of the samples' responses to pulse-periodical laser action, it has been found that the vibration rate increases in case of frequencies, which are divisible by the frequency of initial oscillation, during the amplitude decrease and the frequency increase. While heating the sample, its temperature was highest at its centre. An increase of the laser action time led to a rise in temperature of the sample's centre area, due to this, an intensity of pore formation increased. Non-permanent local deformation, caused by high-powered external action, is a condition for intensification of mass transfer in the solid phase of metallic materials. Inasmuch as the diffusion coefficient is related to the temperature of an exponential law, the temperature rise is an effective way to increase the intensity of the process. The further research will be connected to the definition of self-resonant frequencies and shapes of the oscillations.

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