ISSN 2669-2023 (print) / ISSN 2538-8959 (on-line) / https://doi.org/10.47459/cndcgs.2022.37

Laser Shock Wave Surface Processing Possibilities of Structural Materials

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Abstract

Laser shock wave treatment is a newest effective tool for modifying material properties. Irradiation of materials with a laser in the Q-switched mode in different mediums can change the relief and surface structure of the irradiated material. Images of the surfaces of metallic materials under different irradiation conditions were obtained with the help of a scanning electron microscope. It is shown that the energy of the laser pulse and the transparent condensed medium through which the processing is carried out play an important role on the surface structuring. The possible causes of periodic relief are explained.

KEY WORDS: *Laser shock waves,modification,transparent condensed medium.*

1. Introduction

Laser shock wave processing is a modern high-tech method of processing materials with the aim of changing their structure, shape and properties. Features of laser shock wave processing have been intensively researched in the last three decades. Most of the researchesare experimental and focused on understanding the mechanisms of such processing and the effect on mechanical properties.

A shock wave is a compression jump, a thin transitional region in which density, pressure, and velocity of substanceareincreasing at supersonic speed. Shock waves occur during explosions, powerful electric discharges, laser radiation and in other cases [1].

A laser shock wave occurs in a material when powerful laser radiation acts on it. A laser shock wave is jump-like pressureincreasing in the irradiated material, which propagates in it at supersonic speed and is resistant to small disturbances of its profile. During laser irradiation the duration of the compression phase is 3 orders of magnitude shorter than with classical methods of obtaining a shock wave [2]. To obtain laser shock waves we need to irradiated material with pulses which duration $\leq 10^{-8}$ s and flux density $\geq 10^{8}$ W/cm^2 s.The general scheme of the powerful laser influence processes on materials are shown on Fig. 1.Different transparent condensed media are used to increase the time of plasma interaction with material and to increase the plasma pressure on the surface.They are applied to the irradiated surface.

Laser shock waves can be divided into two classes: powerful shock waves (τ_i=5 - 30 ns, q=10^{14} W/cm^2, p=1-100 TPa) and small-amplitude shock waves ($\tau_i \sim 10^{-8}$ s, q=5 $\cdot 10^{7}$ - 5$\cdot 10^{9}$ W/cm^2, p=1 - 10 GPa). The second ones used in the mechanical processing of metals, in semiconductor technology and in the simulation of various physical processes.

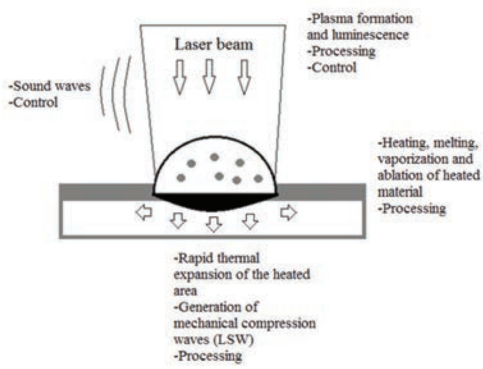

Fig 1.Laser shock waveprocessing of materials

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2. Surface morphology of metallic materials after laser treatment

As research materials in our experiments were used: St3, 15Kh13MF, 25Kh1M1F steels and nanotitanium VT 1-0.Irradiation was carried out by the Nd:glass laser with pulse duration – 50 ns and spot diameter – 4.2 mm.

As shown by experimental studies [3], the selection of a transparent condensed medium must be made based on its physical characteristics (density, absorption coefficient at the wavelength of laser radiation, speed of sound propagation) and some technological features (Table 1).

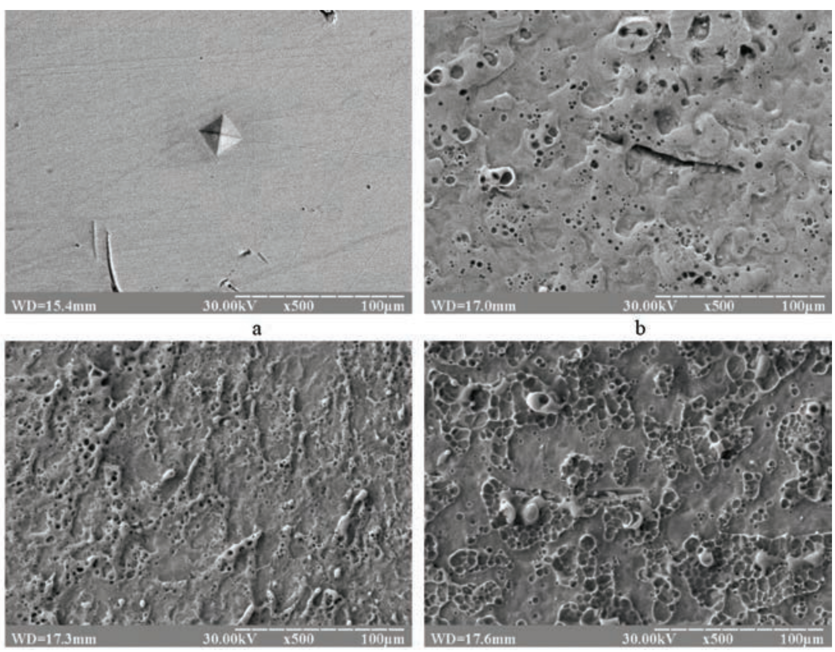
Table 1

Physical parameters of some transparent condensed medium

Medium	**ρ, 10^3 kg/m^3**	**c_l, 10^3 m/s**	**z=ρ . c_l, 10^6 kg/(m^2· s)**	**n**
Water (20°C)	0,998	1,497	1,494	1,333
Ethanol (20°C)	0,79	1,165	0,92	1,36
Epoxy resin	1,27	2,87	3,64	–

The surface of the materials before and after irradiation was studied using scanning electron microscopy.

In fig. 2 and fig. 3 shows the surface morphology of St3 steel before and after irradiation with different energies and in different transparent condensed media.



c d

Fig 2. Surface morphology of St3 steel before and after irradiation in various transparent condensed medium with energy E = 15-16 J:a – surface before irradiation; b – epoxy resin; c – water; g - ethanol

Periodic structures with pits can be seen on the surface after laser irradiation in transparent condensed medium.

The shape of the formed structures can be differ: calm frozen material (fig.2, b), frozen sea waves (fig. 2 c, fig. 3 b, c)frozen spume (fig. 2 d) and frozen squama (fig. 3. a). An increase in the energy in the laser pulse leads to an increase in the number of pits on the surface of the material by approximately 3-4 times.The diameter of the formed pits is from 200 nm to 10 µm.

A change in the surface substructure is observed after laser treatment of 15Kh13MF steel in epoxy resin(fig. 4 b). It is clearly visible that the surface has a martensitic structure, which is accompanied by the appearance of large microtwin crystals of needle martensite, and its amount increases significantly compared to the original ferrite-martensitic steel

In fig. 5 shows the surface of VT 1-0 nanotitanium after laser irradiation in various transparent condensed medium.A wave-like periodic relief is observed, pits are practically absent on the surface [4].

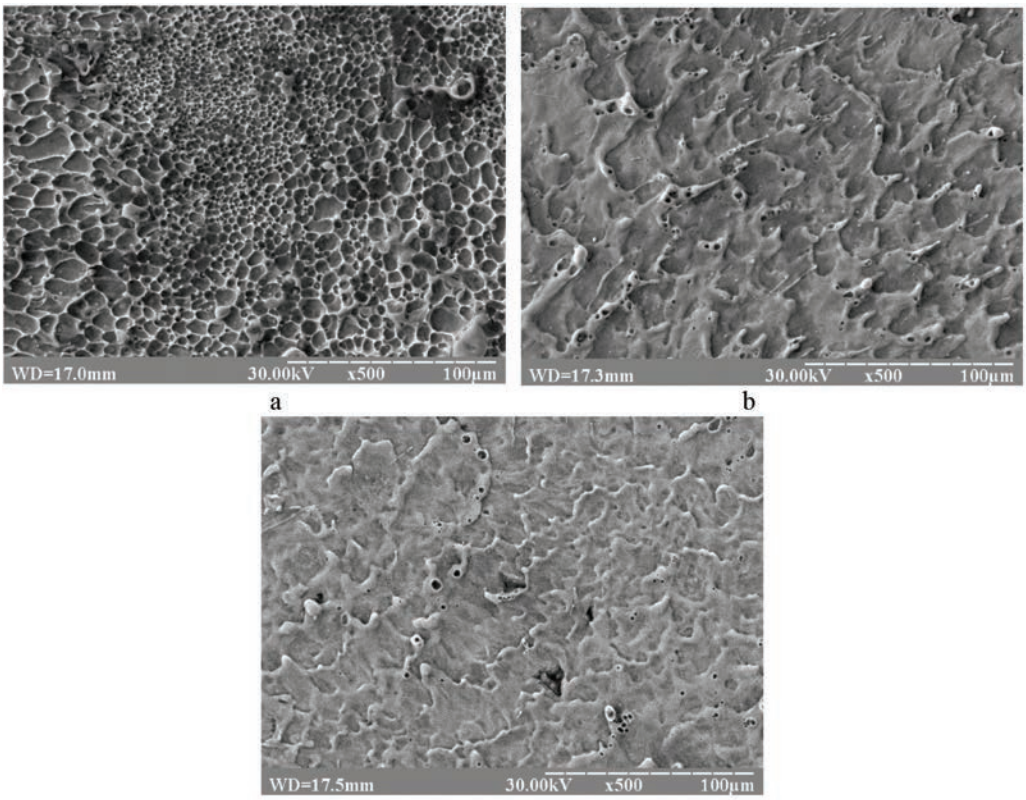
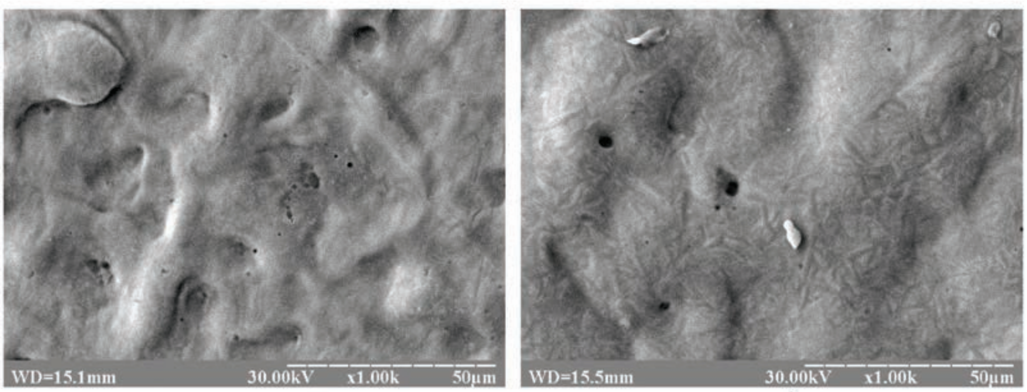


Fig. 3. Surface morphology of St3 steel after irradiation in various transparent condensed medium with energy E = 5–6.5 J:a – epoxy resin; b – water; c – ethanol



a b

Fig. 4. Surface structure of 15Kh13MF steel after irradiation with a laser pulse:a – in the air; b – in epoxy resin

In order to confirm the periodicity of the structures formed on the surface, as well as to determine the height of micro-uniformities, the method of profilography was used (Fig. 6). It is shown that the height of micro-uniformities is from 1 to 4 µm [5].

The analysis of the St3, 15Kh13MF steel surfaces and nanotitanium VT 1-0 after laser irradiation showed:

1. Periodic structures are formed on the surface of materials after irradiation.

2. A change in the radiation energy leads to a change in the surface structure both when processed in the air and when processed in the transparent condensed medium.

3. The geometric dimensions and shape of the structures formed on the surface depend on the transparent condensed medium in which the irradiation is carried out.

4. Irradiation in a transparent condensed medium leads to an increase in the number of pits on the surface of the treated material compared to irradiation in air.

5. Irradiation in transparent condensed media leads to a change in the substructure of the material.

A wave-like periodic surface arises as a result of the instabilities formation due to the occurrence of thermocapillary processes associated with the dependence of the surface tension coefficient of the heated material on the temperature and subsequent inhomogeneous melting.The process is also affected by the recoil pulse of plasma and vapors, as well as the unloading wave with a steep front reflected from the back side of the sample, which meets on the surface with a heat wave that has a propagation speed much lower than the unloading wave [6].The unloading wave has a steep front due to the transition of an elastic wave into a shock wave at a depth of about 20-100 μm according to flux densities which used in our experiments.

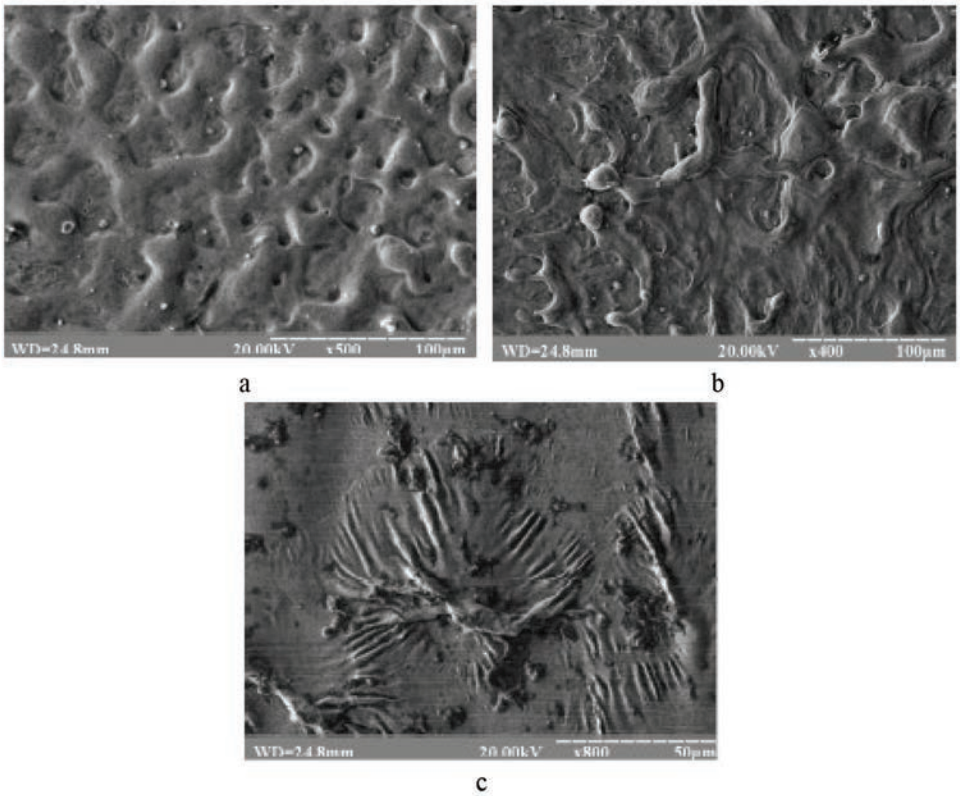


Fig. 5. Surface structure of VT 1-0 nanotitanium after laser irradiation:a – in air, b – in water, c – in epoxy resin

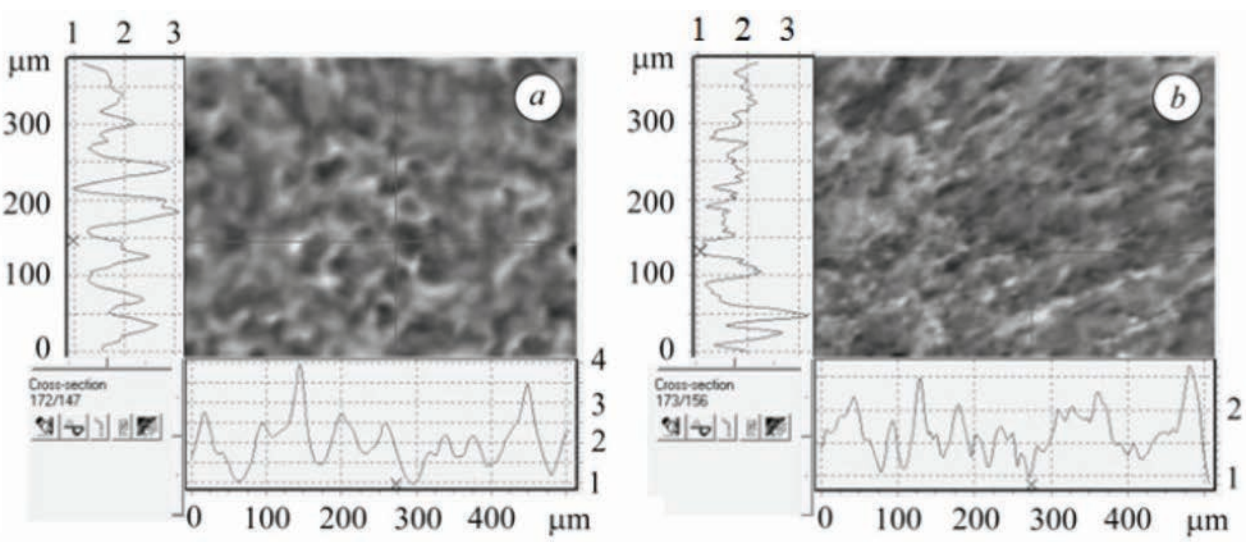
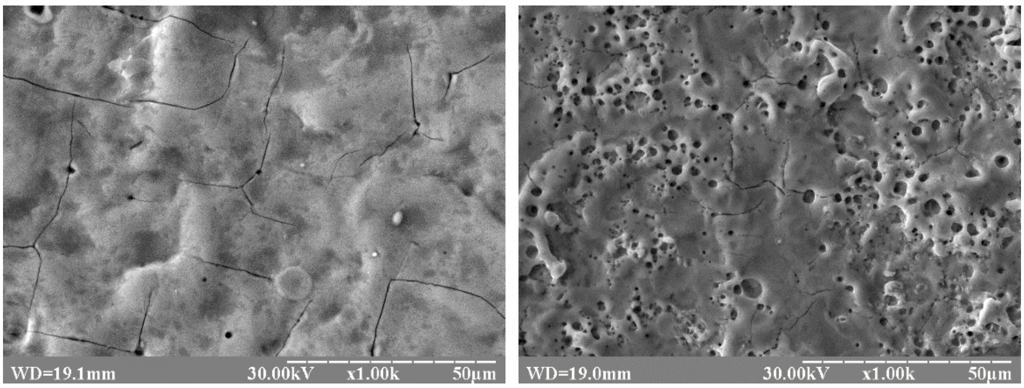


Fig. 6. Two-dimensional assessment of the surface morphology of 15Kh13MF steel after laser shock wave treatment in air (a), in water (b)

3. The appearance of cracks on the surface during laser processing

In fig. 7 shows the surface of 25Kh1M1F steel with cracks that appeared after irradiation. Experimental showed that cracks on the surface appeared both when processed in the air and when processed in all transparent condensed medium. At the same time, there is no predominant direction of crack propagation. The number of cracks and their length decrease in the direction from the center to the edges of the irradiation zone by approximately 1.5-2 times.

One of the reasons for the cracksappearance can be thermoelastic stresses caused by significant temperature gradients (10^5-10^6 °C/cm) during laser irradiation of materials [7]. Also the action of the recoil pulse can lead to additional destruction of the material. The pressure that is achieved at a radiation flux density of 10^8-10^9 W/cm2 is 10^8-10^9 Pa. Stresses that arise in this case can exceed the strength characteristics of materials, which leads to the appearance of cracks on the surface.



a b

Fig. 7. The surface of 25Kh1M1F steel with cracks that appeared after irradiation: a – in air; b - in water

4. Conclusions

In this paper, it is shown that the surface morphology of different structural materials after irradiation with nanosecond laser pulses has the appearance of periodic structures and depends on the type of material, transparent condensed medium and laser flux density. Laser shock waves make it possible to obtain predetermined structures on the surface of materials. It has been studied that cracks may form on the surface with such processing of some materials and possible mechanisms of their occurrence are explained.

References

1. **Зельдович Я.Б., Райзер Ю.П..** Физика ударних волн и высокотемпературных гидродинамических явлений.М. Государственное издательство физико-математической литературы, 1963. 632 с.
2. **Янушкевич В.А., Полянинов А.В., Пруцко Е.Г., Полыгалов Г.А.**Механизм образования и ионизации точечных дефектов в полупроводниках при импульсном лазерном облучениию. Изв. АН СССР. Сер. физич. 1985. Т. 49, № 6. С. 1146-1152.
3. **NikiforovY., YakovynaV., Berchenko N.**Laser shock waves as a tool of changing the strains in materials. Materials science and engineering A. 2000. Vol. 288, № 2. P. 173-176.
4. **Maruschak P., Menou A., Czausow M., Mocharskyi V.** Fractographic analysis of surface and failure mechanisms of nanotitanium after laser shock-wave treatment. Key Engineering Materials 592, 2013, p. 346-349.
5. **Maruschak P., Zakiev I., Mocharsky V., Nikiforov Y.**Experimental study of the surface of steel 15Kh13MF after the nanosecond laser shock processingSolid State Phenomena 200, 2013.p. 60-65
6. **Марущак П.О., Гладьо В.Б., Никифоров Ю.Н., Ковалюк Б.П., Мочарский В.С.** Морфология поверхности стали после ударноволновой лазерной обработки. Нанорозмірні системи. Будова-властивості-технології: тези конференції. Київ. 2007. С. 267.
7. **Рыкалин Н.Н., Углов А.А., Зуев И.В., Кокора А.Н.** Воздействие лазерного излучения на материалы. М. Наука, 1989. 496 с.