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Laser Treatment on the Coating Surface Having Been Performed by Means of Plasma Surfacing With Powder Made of M2 Steel*

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Abstract. In this study researches were carried out about the impact of pulsed laser irradiation on the surface of M2 steel which had been surfaced beforehand on steel 20 by poweder-pasma surfacing technique. The surface treatment was performed by the single point laser action and by successive imposition of overlapped impulses. During the surfacing the average irradiation power was varied from 15.8 to 21.0 W. The impulse duration in all points was constant and it was 7 msec. In this study it was researched the influence of laser-beam power change on the depth of penetration, changes in the structure and microhardness of treated areas.

Introduction

There are different ways how to solve some issues connected with working surfaces of machinery parts and machines with high mechanical and tribotechnical characteristics, the following are: the coating application with overlaying or sputtering, the thermo treatment, the surface treatment with highly concentrated sources of energy such as: an electronic beam, concentrated arc plasma spray or laser. Special preferences are given to the laser as the means that allows you to change the structure of the metal surface layer at high speed and this means does not require special protection from the ambient air unless the treated material requires it.

With the help of laser treatment researchers are able to solve such tasks as surface texturing and modification [1-3], the increase of wearing capacity, the hardness, the strength and the fatigue resistance of surface parts [1-14]. It is all possible due to the high thermal gradient which arises in the area of laser irradiation. It is possible to achieve austenitic-martensitic transformations in the smallish volume of material due to the rapid heating and cooling processes during the laser treatment thus changing and strengthening separately taken areas [7.8].

The choice of laser irradiation parameters especially influences the structural and characteristic change of the material to be treated. In works [4,9] it is shown that the essential factors affecting the depth of the laser penetration are the following: the wave length of an emitter, the average power, the energy and the radiation energy density and the laser speed under the continuous-wave irradiation. In recent years, the processes of structural changes of steel under the impact of short-term radiation treatment with laser pulses are being actively studied [1-4,7,9]. During the pulse treatment it is necessary to take into account such parameters as: the peak power density, duration and pulse repetition rate. In the work [12] it is shown that the laser treatment in pulsed mode allows you to get greater action depth due to the higher peak power density than the treatment in the continuous-wave mode. Besides the use of pulsed laser treatment allows you to control the surface characteristics with its minimal geometry distortions.

The most efficiency of laser treatment is achieved when it is applied to the steels, which are able to harden themselves and undergo austenitic-martensitic transformations [8]. In this regard, fast-cutting steels as M2, R18, R12 are of interest. In works [13,14] it was shown that coatings on the basis of such kind of steels which were made with electron-beam and plasma surfacing techniques are stable in the conditions of abrasive wear. It might be supposed that the additional treatment of such kind of coatings with laser pulses will considerably enlarge the field of their application by means of the surface texturing, which has proved itself in works [15,16].

Technical publications do not show enough information about the influence of the laser beam power on the structure and hardness formation of tool steels after laser treatment. That is why it is necessary to carry out a research on the influence of pulsed laser irradiation parameters on the penetration depth, structure and characteristics of fast-cutting steels like M2.

Materials and research methods

A pre-polished surface coating made of M2 steel with roughness of Ra 0.08 was treated with laser irradiation. The coating was treated beforehand with plasma powder surfacing technique at current strength of 200 A and surfacing speed of 0.17 cm/s.

The laser welding machine HTF-50T with aluminum-yttrium solid-state laser (YAG: $Nd3 +$) was used as the radiation source.

For the needs of the comparative analysis four single treated areas have been done and also it has been done one linear area which represents a number of impulse treatment points applied against each other with partial overlapping. Modes of surface treatment were remarkable for power pulses of rectangular shape (Table 1). The laser irradiation treatment was performed in the open air without protection for the surface coating against oxidation.

Table 1. Mode parameters for a laser irradiation action on the structure and characteristics of surfaced layer made of M2 steel.

Mode №	Peak power (qp), KW	Average power (qA), W	Pulse energy, J	Pulse duration, ms	Pulse repetition rate, Hz
1	1.50	15.8	10.50	7	Single pulse
2	2.00	21.0	14.00	7	Single pulse
3	2.42	25.4	16.94	7	Single pulse
4	4.05	42.5	28.35	7	Single pulse
5	2.00	21.0	14.00	7	1.5

The studies about treated metal were carried out in the surface layer and in the cross-section along the central axis of the track and points. The study of macro and microstructure was carried out by means of optical and electron metallography. Optical metallography was conducted with the help of a microscope OLYMPUS GX51 and an application module SIAMS 700 in the bright field mode and in the differential interference contrast. Electron microscopy was done with a scanning electron microscope Hitachi S-3400N, equipped with an attachment for elemental analysis EDS, WDS.

The structure identification of the treated metal was accomplished by dipping the pre-polished surface into reagents with the following compositions: HNO3(ml):C2H5OH(ml)=4:100; HCl(ml):CuCl2·H2O(g):H2O(ml):C2H5OH(ml)=20:1:15:65. Metal holding time in the solutions ranged from 20 to 60 seconds.

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Microhardness was measured with HVS-1000 device with 100 microns depth in each step at 5H load.

Results and discussions

Figure. 1 represents the microstructure of the single points surface, the microstructure was figured out with optical metallography only after the surface polishing and etching. All points have three distinctive areas: reflow zone (RZ) - the central part of the spot; hardened zone (HZ) - unevenly etched circle which is remarkable for the structural heterogeneity; heat-affected zone (HAZ) - bright circle which is ringed with the dark, well-etched circle.

Thermocapillary and capillary phenomenon that occur in melting points as well as the martensitic transformations both result in the surface deformation due to the surface tension and due to the cracks formation in the center of the spot. At the same time, the greater the coefficient of penetration shape is (k=h/d), which increases along with power growth of laser irradiation, the larger deformations and cracks become (Figure. 1,d).

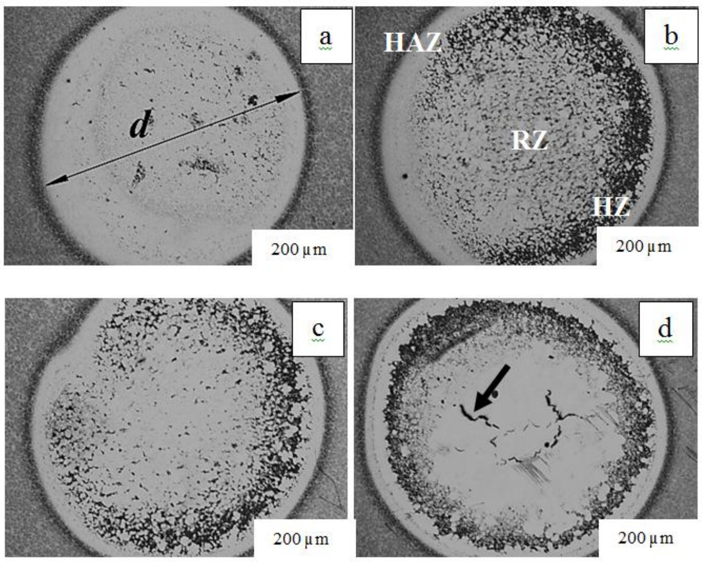

Figure 1. The microstructure of the point surface which was achieved with average laser irradiation power: a – 15,8 W, b – 21.0 W, c – 25,4 W, d – 42,5 W

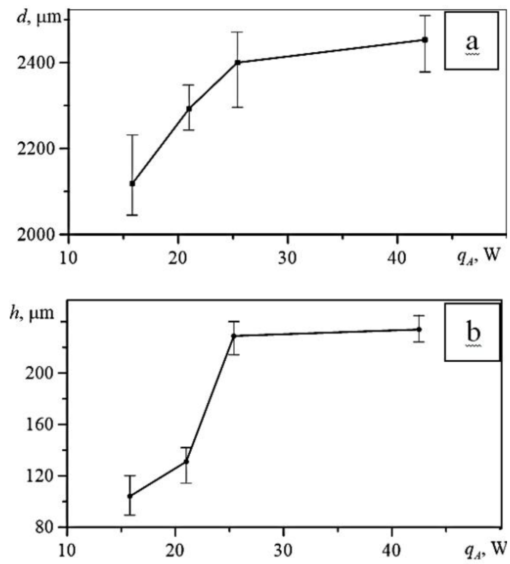

Figure 2. The graph of the spot irradiation diameter (a) and the penetration depth (b) by laser power growth

The total length of the laser heating zones was accepted as the total depth of laser action zone, while structural and phase changes occurred in laser heating zone with respect to the original steel structure. The penetration depth increases along with the growth of power or pulse energy (Figure. 2b), however, these changes are of irregular character. The heating depth is 100 ... 130 μm when an average power laser pulse is 15.8 ... 21.0 W. The further power increase up to 25.4 W leads to the step like increase of the penetration depth up to 230 μm with a simultaneous increase of the molten metal layer on the walls of a steam-gas channel, as a result it occurs the slowdown of penetration even when the power is increased up to 42.5 W. The Form of laser action points in the cross section is close to hemispherical.

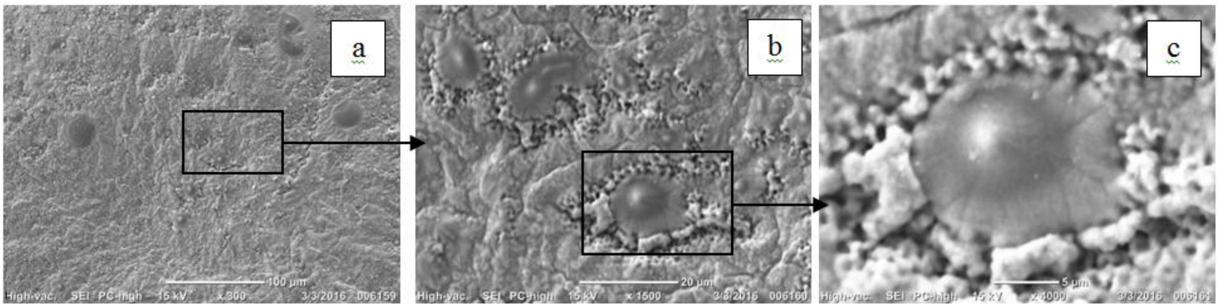

Figure 3. Microstructures of reflow zone.

The protection absence of the treated melt surface during the laser air reflow results in the gases absorption from the ambient under the influence of the convection flows in a thin surface layer. This facilitates the metal oxidation on the whole surface of the points, and this is proved by a large amount of oxygen discovered with microroentgen spectral analysis (Figure. 4).

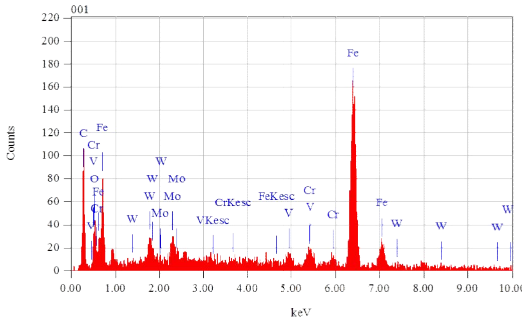

Figure 4. Microroentgen spectral analysis carried out on the reflow zone.

Element	Wt%	At%
C	04.18	15.16
O	07.69	20.93
Mo	03.32	01.51
V	01.95	01.66
Cr	03.69	03.09
Fe	71.76	55.87
W	07.5	01.78

The hardened zone offers the austenitic-martensitic matrix with a grid of eutectic carbides which are situated along the grains boundaries (Figure. 5a). Unlike the lamellar structure of eutectic carbides, which are in the initial state in the steel M2, carbides in the hardened zone are offered as dispersed formations which are situated closer to the reflow zone, and the rods which are situated closer to the heat-affected zone. At the same time the amplification of eutectic phases branching occurs close to the HAZ. It is observed a large number of dispersed precipitates with size of ~0.5 μm inside grains. Resting on the results of X-ray structural analysis carried out in works [17,18], it can be assumed that the precipitates present carbides which compositions include W, Mo, Cr, V and Fe.

Heat-affected zone is well etched in the reagent HNO3(ml):C2H5OH(ml)=4:100 (Figure. 5,b.). The photomicrograph clearly shows coarse-acicular martensitic structure with a grid of eutectic carbides at the grain boarders. Fine-dispersed precipitates are not observed in the heat affected zone while they are typical for the hardened zone. The HAZ width does not depend on the laser beam power and it can range from 80 to 110 μm.

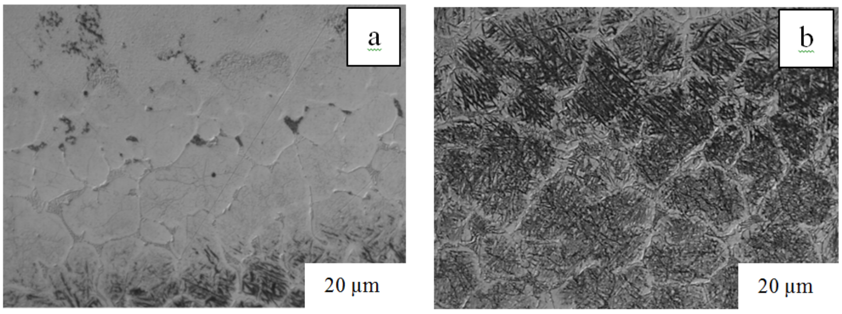

Figure 5. Microstructure of a hardened zone (a) and heat-affected zones (b).

The metal structural changes after laser reflowing allows for a change in hardness in some areas of laser action. Distribution of microhardness across the reflow points was measured after the surface polishing when roughness reached Ra 0.08 µm.

Heat-affected zone represents the most weakened area of the laser action points. The level of hardness in the HAZ decreases by 25 ... 30% in comparison with the hardness of the initial material which has not been treated (Figure. 6). This is due to the tempering of the martensitic boundary which is close the hardened zone, this process happens in a very short period of time in the case of the metastable structure heating [4].

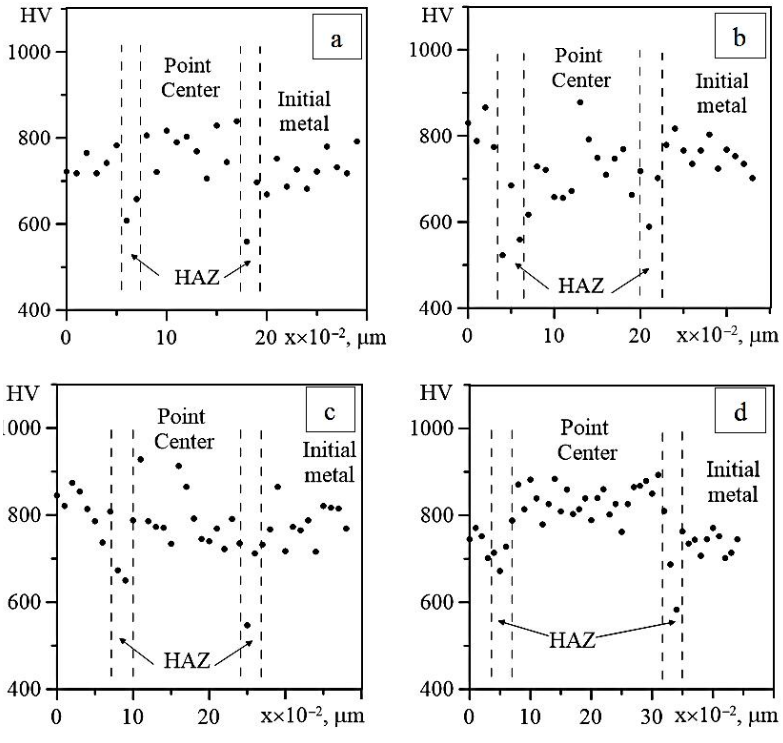

Figure 6. The length wise distribution of microhardness over laser action points.

It is observed an uneven distribution of microhardness due to the formation of structural heterogeneity in the central part of points and in the hardened zone, this is particularly evident during the laser beam treatment with the power from 15.8 to 25.4 W (Figure. 6, a-c). The average hardness of these zones is comparable with the hardness of M2 steel which is in its condition after surfacing (~790... 800HV).

When the laser power is increased up to 42.5 W, so the average level of the treated metal hardness is increased by 10 ... 15% mainly due to the widening of the hardened zone which contains a large amount of eutectic and secondary carbides (Figure. 6,d). Alignment around a heating spot is facilitated by the increase of the laser action power, along with the increase of the average level of the treated metal hardness.

While the surface is being treated by overlapped laser points, it is necessary to consider the presence of narrow weakened areas under pulsed laser action on M2 steel.

When the surface of M2 steel is treated by successive imposition of intersecting laser pulses, so it happens a uniform penetration of the initial metal to the depth of ~130 ... 140 µm, what corresponds to the penetration depth for a single pulse with power of 21.0 W (Figure. 7,a).

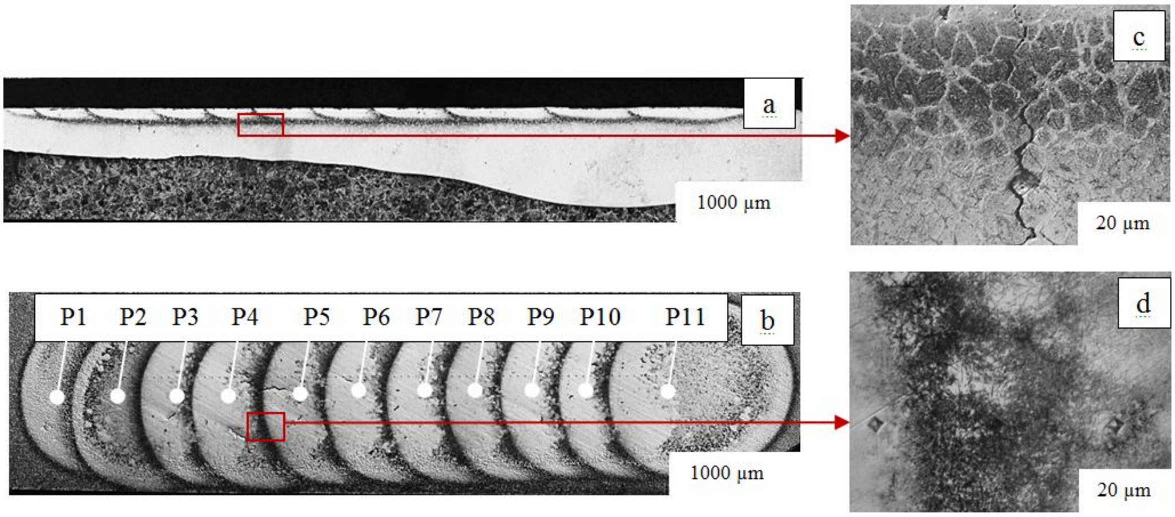

Figure 6. The microstructure of the cross section (a) and the path surface (b) done by a series of laser irradiation pulses and the HAZ microstructure in cross section under the point P.5 (c).

It is observed the cracks formation on the surface of central points (P.3 P.6 ... in Figure. 6,b), and also below them in the HAZ (Figure. 6c).

It is formed a narrow heat-affected zone in areas where points are overlapped (Figure. 6. a,b). This area having been formed on the pre-reflowed metal area has a fine-acicular martensite structure (Figure. 6d). The hardness of this area is 20 ... 30% lower than the hardness of the reflow zone and the hardened zone (Figure. 7). In general, the average level of metal hardness that has been treated with a series of pulses is ~800HV and it is at the level of coating hardness that has been made of M2 steel immediately after surfacing.

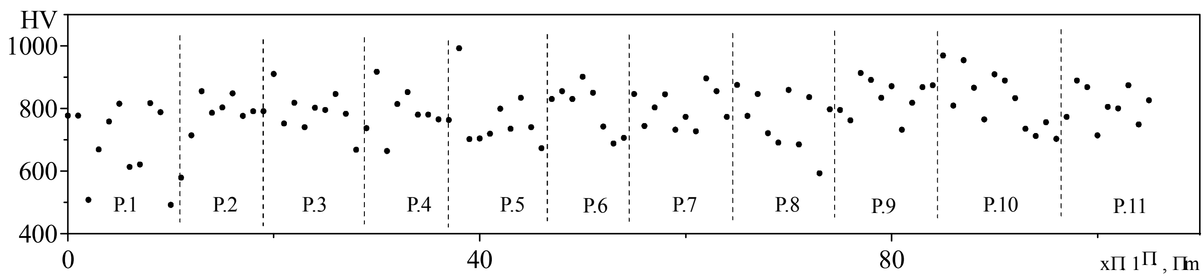

Figure 7. The microhardness distribution in the surface layer of the laser path action which is directed from the first point to the last one.

Thus, thermal cycling which occurs when M2 steel is consecutively treated by pulse laser irradiation does not allow considerably change the hardness of the treated layer in comparison with the hardness of M2 steel after surfacing.

Conclusion

The increase of the average laser pulse power from 15.8 W up to 25.4 W results in the twofold depth increase of laser action on the M2 steel coating. Further increase in the average power up to 42.5 W facilitates the growth of the molten metal layer on the walls of the steam-gas channel, which leads to the decrease of penetration depth.

The three zones formation under laser treatment facilitates the irregular distribution of microhardness on the surface of the treated material. It does not occur the considerable strengthening of the surface when M2 steel is treated by single laser pulses with power ranging from 15.8 to 25.4 W. The average hardness of the treated area with laser irradiation is within the limits of the M2 steel hardness after plasma surfacing. The hardness increase of the treated area is facilitated by laser irradiation power increase up to 42.5 W and this is 10 ... 15% higher in comparison with the hardness of M2 steel after surfacing. Mode with an average power of 42.5 W and pulse energy of 28.35 J is considered to be the best in respect to the structure formation, the hardness change and the laser action depth.

The treatment of the steel surface with the help of successive imposition of laser irradiation in overlapped manner facilitates the initiation and development of cracks in the areas under the laser action, at the same time the structures that are being formed do not allow to increase the hardness of the M2 steel with the help of periodical weakening of the treated material in the HAZ while the points are overlapped.

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