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The Strengthening of Surface Layer by the Impulse Laser Irradiation

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Wear resistance and durability of the products depend on the nature of solid solution and microstructure. Materials with optimum alloyed solid solution and fine particles, usually carbide inclusions have minimal wear. Such structure is difficult to obtain using traditional method of manufacturing. Blanks of alloyed steels have coarse grains and carbide inclusions of undesirable shape arranged discretely. It is impossible to change such a microstructure. Therefore the purpose of the present work was to create a desirable microstructure using micro- graphical laser beam treatment and to evaluate influence of the treatment regimes and point drawing to wear resistance of a surface layer.
Keywords: wear resistance, strengthened layer.

1. INTRODUCTION

Modification of surface properties of metals and alloys by concentrated beams of energy, and electron beams, in particular, is stipulated by the following mechanism. As a result of their interaction with a processed material there is a flash heat (up to a melting temperature and higher) of the surface, that as rule, results in essential changes of the structure and properties as compared to the initial state [1].

Use of pulsed high-power laser beams finds application for hardening the surface of metals and alloys.

High density of power in the impulse and continuous regimes, high coherence and monochromatic level are the main properties of the laser irradiation.

During interaction between laser beam and the material due to absorption of the energy of beam surface becomes heated, material melts and sometimes evaporates [2].

After laser beam treatment different structures can be observed: blocks and fine-grained phases, grains and coarse-grained phases, solid inclusions. High velocity quenching results formation of solid inclusions. Metallographical investigations in the heat treated zone showed structural changes, related to changes of grain shape and size, also to formation of solid inclusions during rapid quenching [3].

Structural changes in the carbon and tool steel obtained after laser beam treatment are the same obtained using over methods of rapid heating. However, due to specific characteristic of laser irradiation the same characteristic features appear in the treated steel. Such feature is anomaly high surface hardness.

Defects of crystalline structure (dislocations, vacancies, et.) influence noticeable effect of strengthening. During rapid quenching austenite and carbide particles fuse and obtained structure consists of martensite and particles of non-fused cementite that influence hardness of treated material [4, 5].

Melallographical investigation reveals three zones in the structure of hardened steel of grade 45 [6]: fine grained, sorbite – troostite and coarse-grained martensite. Structure of normalized steel 45 (pearlite + ferrite) after laser beam treatment shows essential changes in the circular zone. On the top zone of fused pearlite of 75 μm thickness, separated from the parent metal by slag inclusions, can be observed. Based on the results of X-ray structural analysis one can state that this layer is highly decarburized. Zones of martensite are observed in the region near to crater (10 μm and more); in the deeper portions of material (300 μm – 450 μm) layer of incomplete hardening reveals. Analogical changes of structure show steel of grades Y8, ШХ15, ХВГ [7, 8].

The opportunity to make the desirable microstructure, do not adding alloying elements in the superficies layers of the product, using micrographic method of laser beam treatment was solved in the present work. Such a point strengthening do not cause strains in the superficies layers and also strains between the layer and parent metal, because conditionally soft matrix of the product reduces strains between thermally strengthened zone and matrix.

2. EXPERIMENTAL

2.1. Test procedures

Micro-spectral analyzer MLA 10 with a ruby laser irradiation (energy of irradiation 0.6 – 1.2 W·s, impulse duration 500 μs) was used for the micro-graphical thermal point strengthening. A laser beam modification is possible altering the laser cassette of water filter, diaphragms, objective lens and changing parameters of power supply unit.

The laser beam analyzator evaporates various amounts of the metal; outcome of this process is a formation of distinct sized craters with white zone in the periphery. It is possible to vary geometrical parameters of strengthened zones: depths from 1 μm up to and including 700 μm and diameters from 10 μm up to and including 2000 μm.

The influence of parameters of laser beam analyzer on the geometry of strengthened zones was analyzed in the present work. Test pieces of structural, carbon and tool steels were selected for the tests. After the micro-graphical strengthening surface of evaporated craters was formed.

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Due to high intensity of irradiation concentration, and high heat absorption in the test piece, white zones in the periphery of the craters were produced.

The test pieces were subjected to the heat treatment in the laboratory furnaces.

The test pieces were prepared from structural steel 45, carbon steel Y8 and tool steel X12Φ1. The composition conforms the requirements of the Russian standard GOST.

The durability of tools and products is based on the wear resistance of the components. Consequently investigation of wear resistance of the test pieces has followed laser beam strengthening and heat treatment operations. In order to estimate the influence of micro-graphical strengthening on the durability of the superficies layer, the technique allowing examination wear processes in the small areas was used.

Wearing surface was maximally reduced until the narrow strip, into which the diamond-indenting tool of Rockwell hardness test machine leaves indentation for measurements of reduced area (Fig. 1).

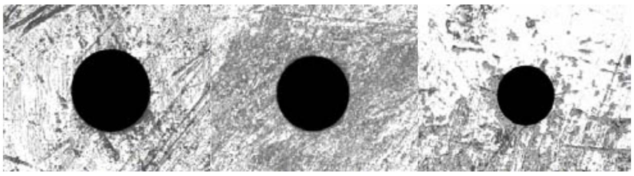

Fig. 1. Dynamics of the test machine indentation during wearing

Due to the small area of worn surface it was possible to evaluate influence of the micro-graphical strengthening on the wear resistance of aforesaid steels.

Suggested method of the pressing permitted free movement of the test piece in the clamper, so that the edges of the worn wear-out specimens stayed sharp. Thus during wearing surface of the test piece was flat. It enables to evaluate not only the conic print of measurement, but also the changes of structural elements of the steel during wear.

Two schemes of the strengthening were suggested: first scheme with density of the strengthening points of 2.6 points/mm^2, and second – 5.2 points/mm^2.

After some cycles of wear the digital camera YCCH – 15 fixes a view of a conical imprint, and the area of the print was defined using computer soft wear. Knowing the angle of cone height surface (120°) it was possible to calculate the height of the worn surface layer. This measurement was performed with accuracy of 1 μm.

2.2. Hardness test

The hardness test is the most common method of the estimation of the mechanical properties of the product. For the hardness test a test load of 100 g was used; testing rate: every 0.01 mm through the strengthened zone. So whole surface around the craters was tested.

The illustration of hardness test results of micro graphically strengthened zones by laser irradiation is presented in Fig. 2.

According to the results of the test one can state that maximum hardness of zone showed slopes of the craters. Hardness reduces coming to the virgin portion of the material, in some cases self-tempered zone can be observed; hardness of self-tempered zone 4005 MPa (Fig. 2).

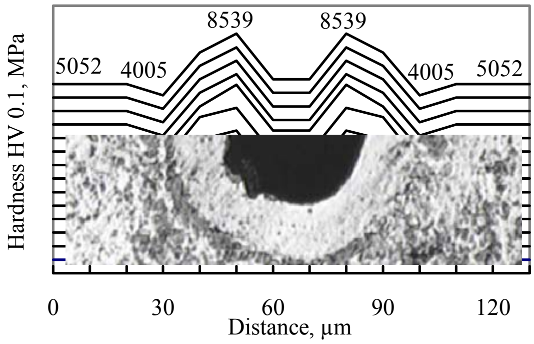

Fig. 2. Hardness of the strengthened point of tool steel У8 (hardness of the virgin metal 54 HRC)

Such a behavior remarkable in the strengthened zones of the test pieces prepared from the carbon steel when the hardness of the parent metal greater than 40 HRC. Test pieces prepared from the eutectoid steel showed this behavior when hardness greater than 30 HRC. Cohesion between matrix and strengthened point in the test pieces of the eutectoid steel is relatively low. It is possible that during working self-tempered zones can be deformed by zones of highest hardness. This can cause uneven wearing of strengthened portion of the material; abrasive particles formed during wearing reduce wear resistance of the test piece.

Strengthened zones of steel У8 (hardness of the parent metal 40 HRC) and steel 45 (30 HRC) did not reveal self-tempered zones. There is no distinct transition between hardness results of the strengthened zone and the parent metal.

Test results showed, that hardness of the strengthened zones on the surface of carbon steel does not depend on the hardness of the parent metal. Hardness of strengthened zones in the steel Y8 is the same, although hardness of the parent metal is different. Low hardness difference can be observed in the test pieces of steel 45. When hardness of the parent metal exceeds 50 HRC the hardness of strengthened zone is higher. But this difference is 11 %.

Different character of strengthened zone hardness was observed when testing ledeburitic type die steels (X12Φ1). Studying results of hardness test we recognize that the slopes of white zone around the recesses have different hardness.

During forming of the layer temperature in the slopes is uneven. The top layers of the slopes warm up better when deeper layers. High chromium steel after hardening has high quantity of retained austenite. The quantity of the austenite depends on the heating temperature during hardening. The superficies layers of the slope were heated up to very high temperature, so after strengthening high quantity of austenite was formed, and hardness of white zone decreases. Such effect of hardness reduction was observed also in the test pieces with parent metal hardness of 44 HRC.

Formation of the retained austenite in the slopes is positive phenomenon, because during working, when relative pressure is high it transforms into the martensite which increases wear resistance of the product.

Test showed, that hardness of the strengthened zones of X12Ф1 steel depends on the hardness of the parent metal. When hardness of parent metal is 56 HRC hardness of the layer exceeds 7599 MPa, when hardness of parent metal 44 HRC – hardness of the strengthened zone was just 5212 MPa.

2.3. Wear resistance of the test pieces

The most details and tools work in the hard intensive wearing conditions. Their durability depends on the wear resistance of the superficies layers. Micro graphical laser strengthening method of the superficies layers of the tool is described in the present work. Localized zones of the product can be strengthened, creating a graphical scheme of the strengthened zones.

The technology of the laser beam treatment, and two schemes of strengthening was designed.

Wear resistance of the test pieces prepared from the carbon, eutectoid, and tool steels, strengthened by suggested procedure was tested. Test results are given in the Table 1.

Table 1. Wear resistance of the test pieces

Steel / HRC	Scheme	Wear height, μm						
		Wear way, m						
		150	300	450	600	750	900	1050
Y8 / 54	–	3.20	6.10	9.00	12.10	15.40	18.80	22.31
	I	2.00	3.70	5.80	8.10	10.80	14.20	18.60
	II	1.10	2.30	3.80	5.60	7.70	10.80	14.60
Y8 / 40	–	4.40	8.70	12.60	16.70	20.70	24.80	29.25
	I	1.30	2.50	3.30	4.50	6.30	8.60	11.70
	II	0.70	1.20	1.70	2.50	3.40	4.80	7.10
45 / 50	–	3.60	7.40	11.00	15.20	18.90	22.90	27.36
	I	1.90	3.00	4.80	7.20	10.30	14.50	19.46
	II	0.80	1.70	2.80	4.40	6.40	9.20	12.73
45 / 30	–	4.20	8.30	12.80	18.20	23.50	29.30	35.40
	I	2.40	4.80	7.90	12.00	18.00	24.20	31.80
	II	1.40	3.10	5.50	9.50	14.90	21.00	28.12
X12Ф1 / 56	–	2.00	3.38	5.26	7.05	8.93	10.80	12.97
	I	1.28	2.16	3.20	4.32	5.60	7.60	10.27
	II	0.89	1.50	2.10	3.00	4.30	6.10	8.86
X12Ф1 / 44	–	1.95	3.83	5.77	7.72	9.81	12.10	14.33
	I	0.89	1.39	1.89	2.40	3.38	4.57	6.87
	II	0.40	0.70	0.95	1.30	1.90	3.00	4.69

According to the test results we can state that wear resistance of not strengthened Y8 steel depends on the hardness. Test pieces with hardness of 54 HRC have higher wear resistance. Curve of wear resistance of not treated test pieces is close to the straight line.

Wear resistance of the test pieces increases after laser strengthening. Wear curves character varied, because of the reducing of the strengthened zone area during working. Influence of the strengthening scheme is specified in the Table 1. Higher wear resistance was obtained using a second scheme of treatment. A density of strengthening zones using first scheme was 2.6 points/mm^2, second – 5.2 points/mm^2. Such a tendency is seen independent of the hardness of the parent metal.

When hardness of the parent metal of Y8 steel is reduced, wear resistance increases. Such a phenomenon is important for the products when requirements for plasticity are very high. Formation of the self-tempered zones reduces wear resistance of the test pieces with higher parent metal hardness. The self-tempered zones separate strengthened zones and matrix.

Wear resistance of Y8 steel can be increased four times using second scheme of the strengthening (Fig. 3).

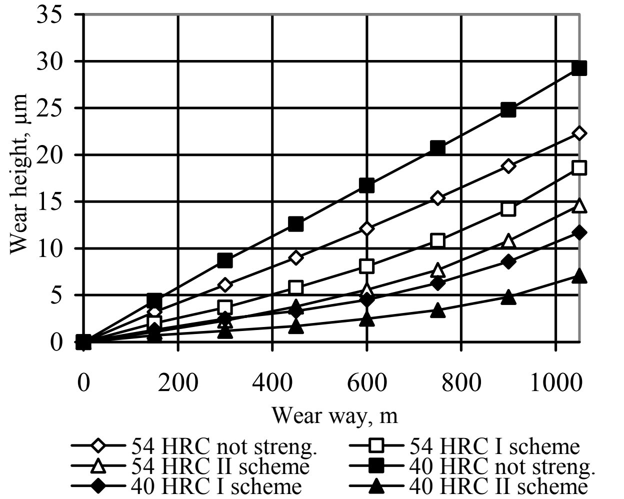

Fig. 3. Wear resistance of the test pieces prepared from Y8 steel

Wear resistance of strengthened test pieces of 45 steel (hardness of the parent metal 50 HRC) increases against of the formation of the self-tempered zones. First scheme of the strengthening increases wear resistance of the test piece in 26 %, second – 52 %. This effect decreases, and wear resistance increases negligible, when hardness of the parent metal was reduced until 30 HRC.

It can be explained by the equalization of parent metal hardness and hardness of the self-tempered zone.

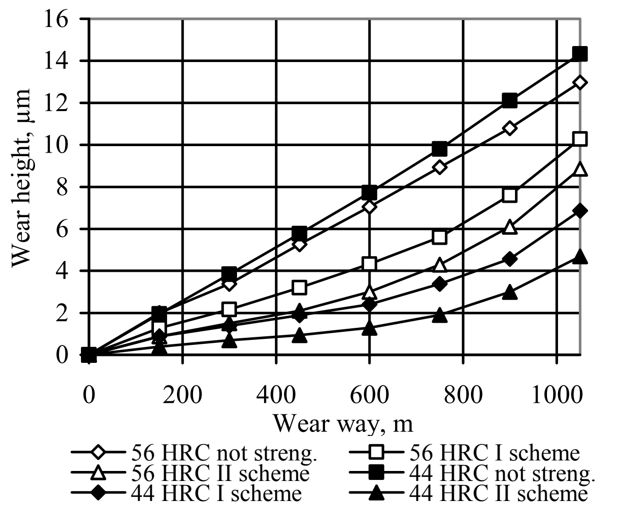

Fig. 4. Wear resistance of the test pieces prepared from X12Ф1 steel

Ledeburitic die steel is used for the manufacture of complex shape tolls. Wear conditions of such toll is unequal in the different part, and for increasing tool durability it is important to strengthen the cutting edges. Suggested method of the strengthening can be successfully used for the preparation of the cutting tool.

Wear resistance of the test pieces prepared from X12Φ1 steel without strengthening effect depends on the hardness. The main influence of the wear resistance in such type of steel has a carbide phase.

The slopes of recesses formed during micro graphical strengthening warm up uneven. An internal layer warm up better. After such a heating and cooling retained austenite is formed and high hardness of the white zone remains just in the narrow rim. Retained austenite transforms into the martensite during working. Due to these changes wear resistance of the test pieces increases.

Wear resistance of the strengthened test pieces increases negligible although hardness of the parent metal, of the zone peak, and slopes was 6807 MPa, 7599 MPa and 4616 MPa respectively. In this case quantity of the retained austenite was low.

Maximum effect of strengthening using test pieces of the X12Φ1 steel was obtained when hardness of the parent metal was 44 HRC (Fig. 4).

Using second scheme of the strengthening wear resistance increases three times, although hardness of the parent metal, of the zone peak, and slopes was lower 3600 MPa, 6212 MPa, and 4118 MPa respectively. Formation of retained austenite increases further hardness.

3. CONCLUSIONS

1. Self tempered zones around the strengthened craters of test pieces prepared from carbon steel were formed, when hardness of parent metal was higher than 50 HRC.
2. Retained austenite in the structure of the high chromium steel reduces hardness of strengthened points.
2. Micro-graphical strengthening of the surface 4 times increases wear resistance of eutectoid steel, 2 times – structural steel and 3 times increases wear resistance of die steel. Wear resistance of the test pieces depends on the density of the strengthened points.
3. Such a technology of strengthening can be used for increasing of durability of fine products and tools, composing a desirable microstructure.

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