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Research paper

Strengthening of the Restored Surface Layer of Steel Parts 45 by Laser Boring

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Abstract

By means of the proposed technologies, the relationship and strengthening of the optimal modes of recovery of the restoring layer and the optimal laser treatment modes with bat-retaining straps are chosen. The microstructural, X-ray diffraction studies of the restored surfaces of the cams of the distributing shaft of the car were determined, the wear resistance and microhardness of the working surfaces were determined. By means of the proposed technologies of restoration and strengthening, optimum modes of applying the restoring layer and optimal modes of laser treatment (pumping energy of 20 kJ without melting of the surface) with bat-retaining coatings (thickness 2 mm) were chosen. The unevenness of the pulsed laser treatment with the restriction of the diameter of the laser spot and the treatment of a boron-rich surface layer with overlapping of the corresponding zones leads not only to the quenching but also to the release of individual local microparticles. New phases such as boron carbide, carbides - borides, iron borides, and others are formed. The strengthened surface layer has a complex structure and generally contains a martensite base with thin layers of borides, carbides. The microhardness of the processing zone rises 3-4 times (H_μ 6500-7000 MPa).

Keywords: *borides; laser treatment; microhardness; relationships; technologies.*

1. Introduction

In the mass production of modern cars, there is a significant increase in power, high-speed operating modes and as a result of increased requirements for parts working in difficult operating conditions. The use of doped and high-alloy steels greatly increases the cost of the material, its processing, complicates the manufacturing processes of parts. Thus, the main parts that limit the life of the work, such as the mechanisms of forced internal combustion engines, are from [1]: - electro slag melting steels 18X2H4BA-Sh, 40XH-Sh (crankshafts); - electro slag melting steels 2XH3A, 18X2H4MA with further cementation (camshafts); - and so on. At the same time, in the designs of modern cars perspective is the further use of steel parts 45 [2, 3, 4]. In this case, it is a question of the details of engines of earlier years of release with a large margin ability to repair as the production of the established resource to the appropriate repair. As a rule, it has technological capabilities for machining to a repair size with subsequent operations to strengthen working surfaces. With appropriate methods of surface layer treatment, due to the modification of their surface layer, it is possible to 3-4 times increase the wear resistance and corrosion resistance of parts, significantly increase the life of the parts, reduce the cost of manufacturing parts, the cost of valuable materials while maintaining qualitative and physical and mechanical characteristics.

A comprehensive solution to the problems of forming surface layer car parts is not sufficiently investigated and needs substantial improvement. Strengthening of the average carbon steels is provided at the expense of the following mechanisms of strengthening: solid soluble, dislocation, dispersion, granular and substructural [1]. Necessary values of reinforcing characteristics are provided by selection of steel composition, as well as by thermal, thermomechanical, chemical-thermal and deformation treatments [2].

The criteria for structural strength is strength characteristics and Irwin criteria, describing the ability of the material to inhibit the development of cracks and the following equation is determined this:

$$K_{ic} = a \cdot \sigma_m \cdot \sqrt{(\pi \cdot l_{cr})}\,. \qquad (1)$$

α - coefficient taking into account the shape of the crack;
σ_m - average design voltage;
l_{cr} - critical length of the crack.

In order to evaluate the surface layer of steel parts 45, the following factors need to take into account: geometric dimensional parameters, surface roughness of the part, microstructure and hardness of worn surface layers. Steel 45 refers to medium carbon high quality structural steels of high strength. To study the processes of restoration of worn surface with the subsequent strengthening of the surface layer, the distribution shaft of the engine ZMZ-402 of the GAZ-2410 automobile made of steel 45 was produced. From the same material, the distribution shafts of such engines as AZLK-412E, ZIL-130 (508), ZMZ-53 (66), YMZ-236 (238) and others [4].

2. Presentation of the Main Research Material

To study the microstructure of the restored claws of the camshaft of steel 45, fragments of the body of the claw were cut out. The wear of the tops of the cam at 0.5 - 0.8 mm significantly affects the operation of the gas distributing mechanism. At the same time, the density of pressing the valves to the saddles is disturbed and, as a result, the loss of engine power, the breakthrough of gases, the incompleteness of combustion of fuel occurs - fuel overfilling, the resource of normal operation of the engine is reduced, etc.). Negative consequences of the process of wear and loss of the geometry of the claw profile may be reneved by the restoration of the geometry of the camshaft. To restore the worn surface and apply it to the filler layer of the cam firstly subjected to a blade processing - removal of another 2-3 mm of the surface layer. The main factor in the restoration of the surface is the strength of the deposited layer with the main material. The surfacing material should provide a reliable bonding of the main material with the main material of the component, reduce the risk of formation of chips and concentrates of thermal stresses in the transition zones, have high physical and mechanical characteristics, and be adapted to subsequent reinforcement treatments. OZH-3 electrodes were used to restore the working surface of the cam's steel 45 (Table 1). According to the content of carbon, manganese, silicon, steel surfacing electrodes are close to the components of steel 45 and this ensures reliable adhesion of the filler layer to the main material [2, 3].

Table 1: Composition of chemical elements of worn steel 45 and material for surfacing OZH-3

№ / №	Composition of chemical elements,%	Filler material OZH-3	Steel 45
1	C	0,4	0,42-0,5
2	Mn	0,5	0,5-0,8
3	Si	1,9	0,17- 0.37
4	Cr	9,9	0,25
5	S	0,013	0,04
6	P	0,021	0,035
7	Cu	-	0.3
8	Ni	-	0.3

After application to the prepared surface of the surfacing layer, blade processing followed by grinding to obtain the corresponding geometry and roughness was performed. The removed metal layer removes welding defects (pores, micro cracks and other defects).

The aim of the work is conducting microstructural, X-ray diffraction studies of the restored surfaces of the claws of the camshaft of the engine, determining their micro hardness. With the help of the proposed technologies of restoration and strengthening, optimum modes of applying the restoring layer and optimal modes of laser treatment (pumping energy of 20 kJ without melting of the surface) with bat-retaining coatings (thickness 2 mm) were selected. On fig.1 shows photographs of the microstructures of the corresponding areas of the cam. To determine the changes in the physical and mechanical condition of subjected surfaces to reinforcement operations, the following research methods were used: metallographic analysis of transverse section of prototype samples, X-ray diffraction analysis of structures; measure the microhardness of the corresponding zones. The metallographic analysis of the data obtained showed the following. There is a formation of new structures from the components of the medium of influence on the original structures of steel 45 with an uneven character of their distribution by defining zones. Thus, in the transition zone, the residual austenite into a ferrite with the formation of two phases: is transformed particles of ferrite (dark cascades of rice .1g. (819),) and the phase "borides + carbides" – boride-carbide (white spray) on Fig. 1.b (818). The main transformation of the structure occurs in the surface (50-100 microns) and subsurface zones of the deposited material (up to 50 μm) [5]. Steel 45 in the structure of carbide inclusion with cementite grating Fe_3C has the following phase composition a + Fe_3C and a + $Fe_3(C, B)$ + Fe_2B after lazer treatment [6]. According to diffractometric analysis, solid solutions based on *a*- or γ-modifications of iron, isostructural cementite, ferrite carbide-boride $Fe_3(C, B)$ and Fe_2B [6] are present on the work surface. The presence of a Fe_3C type in the matrix structure of carbides creates the preconditions for the crystallization of a boron-rich melt of isostructural phase, which, in addition to carbon, contains boron. Phase components of the surface layer in laser borehole significantly affect the crystallization of the doped layer and stimulate the formation of phase analogues. The highest values of hardness according to the durometric analysis are characteristic of zones with a concentration of Fe_2B, FeB borides [6].

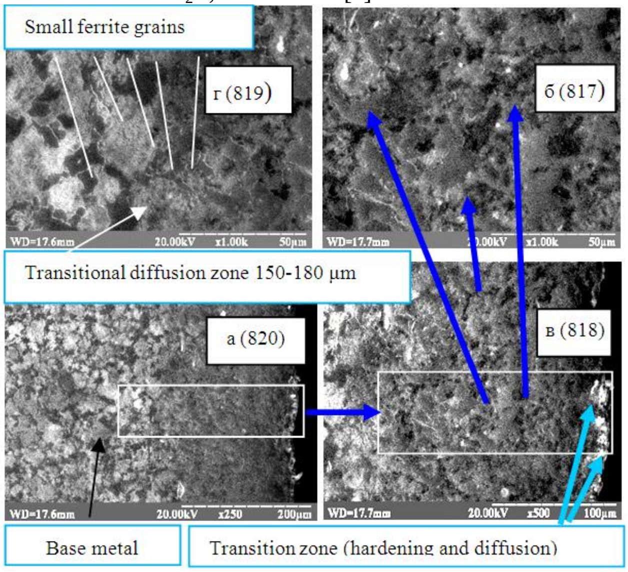

Fig. 1: Photographs of microstructures of the claw sector (a. (820), g. (819), c. (818) middle), b (817) of the transitional, sublayer and extreme zone.

X-ray diffraction analysis was performed on an X-ray diffractometer DRON-2 in monochromatic *Co-Ka* radiation (λ = 1.7902 A). The identification of the connections (phases) was carried out by comparing the interplanar distances (d, A) and relative intensities (I_{ri}-I/I_o) to the experimental curve with the data of the PCPDFWIN electronic card index [5]. The main lines of fig. 2, which on an X-ray diffraction pattern of sample number 3, are a-Fe, which, by intensity, make up more than 90% are observed are observed.

Lines of Fe_2B, FeB are less intense (up to 4%), and Fe_3C iron is present in a small amount (up to 3%), and FeCr compounds are observed. The presence of the latter is due to the composition of the surface layer, where the components of the metal layer containing Cr (0.2%) to the worn surface after the welding with the electrodes of OZH-3 were transferred.

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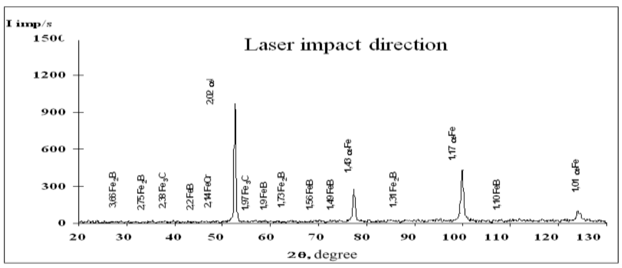


Fig. 2: X-ray diffractogram of specimen number 3 after laser boring in Co-Ka radiation.

Using an X-ray fluorescence spectrometer ElvaX3 (Fig. 3), an analysis of the components of the restored cams after laser boring was performed. The results of the measurements are in Table 2.

Table 2: Chemical composition of the surface layer of the recovered cam obtained using the X-ray fluorescence spectrometer ElvaX 3.

At. nom.	Element	Series	Intensity	Concentration
26	Fe	K	1427011	98.2831 ± 0.032%
25	Mn	K	7716	0.6753 ± 0.027%
14	Si	K	26655	0.2875 ± 0.051%
13	Al	K	8963	0.2190 ± 0.078%
24	Cr	K	3738	0.2035 ± 0.025%
29	Cu	K	923	0.1173 ± 0.012%
27	Co	K	1209	0.064 ± 0.083%
16	S	K	276.36	0.055 ± 0.0011%
28	Ni	K	257	0.046 ± 0.0204%
15	P	K	6355	0.029 ± 0.0019%
42	Mo	K	235	0.0074 ± 0.0049%
33	As	K	133	0.0066 ± 0.0036%
22	Ti	K	32	0.0044 ± 0.082%
23	V	K	0	<0.027%

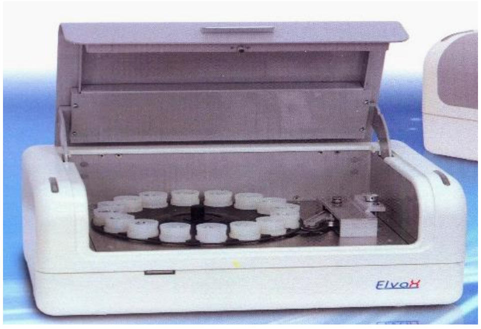
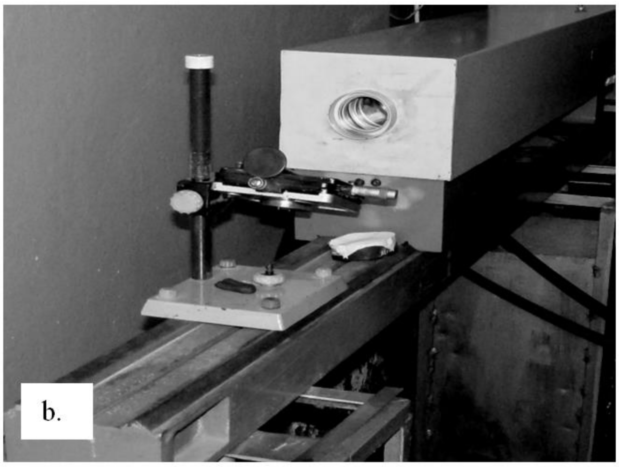


Fig. 3: X-ray fluorescence spectrometer ElvaX 3.

Laser hardening was carried out on a pulsed solid-state laser GOS-1001. A clear boundary between the primary and secondary boundary layers and the modified layer of the surface of the part is imposible be carried out because they are in a state of dynamic equilibrium. There is a constant exchange of ions, mass transfer, accompanied by permanent oxidation and thermo-oxidation processes. For heat treatment of the working surface of the cams of internal combustion engines, a pulsed solid-state laser GOS 1001 was used (Fig. 4a, b).



a - a laser control panel; b – laser
Fig. 4: - Solid State Laser GOS 1001.

Laser treatment was carried out in a divergent laser beam, because it allows to ensure optimum performance indicators for the strengthening of working surfaces of parts. The characteristics of the strengthened area include geometric sizes of the laser action zone, microhardness and surface roughness of the part. When applied to a single spot, the geometric dimensions of the laser action zone are shown by its depth and width. With the strengthening of the working surface of the parts with a melting, that is, when E> E_{kr}, there is a change in the roughness of the surface of the part. The greatest influence on it is in the density of the power of radiation, with the increase of which the roughness of the surface of the part increases. This is due to the hydrodynamic effects in the melt, the change in volume during phase transitions and the partial evaporation of the material [11, 12]. The critical power density E_{cr} is an important parameter of the pulsed laser strengthening of the surface of the part. The number of factors is influenced on this. With an increase in the degree of alloying of steels, the critical density of laser processing power decreases, which results in a decrease in the depth of the laser zone when reinforced without melting. This is due to the fact that as the content of the alloying elements increases, the Solidus temperature and the thermal conductivity of the material decreases. Therefore, to melt the surface of the part requires less energy, that is, the E_{cr} decreases [4]. The composition of the deposited cam on the working surface in Table 3 is given.
The thickness of the paddle layer for further laser treatment was 2 mm.

Table 3: Composition of the claw attached to the working surface

№/№	Composition of attached	
	Glue «Supermonolit» (TU U-2406-30440956-003-02)	Bor technical (TU 6-08-374-77)
1	Chloroprene rubber	
2	Aliphatic hydrocarbons	
3	Aromatic hydrocarbons	
4	Synthetic resins	
5	Esters	

In Fig. 5 the scheme of measurements of microhardness of the corresponding zones of the restored and strengthened by a laser beaming of a cam [8] is shown. When testing on the hardness of the Vickers method, the diamond quadrilateral pyramid is pressed onto the surface of the material with a corner at an apex of 136°. Hardness is characterized by the area of the imprint. The loads of indenter is 20g. After removal of the load, with the aid of a microscope mounted on a solid measure, diagonal diagonals of the d1 and d2 marks remaining on the surface of the sample are measured to within 0.001 mm. The number of Vickers hardness HV as the ratio of the load P to the measured value of the diagonal of the imprint is calculated:

$$HV = \frac{P}{M} = \frac{2P\sin\frac{\alpha}{2}}{d_1^2} = 1{,}854\frac{P}{d_1^2}. \qquad (2)$$

Measurements of the strengthened zones were carried out with a PTM-3M according to the traditional method in three directions - from the projection of the cam to the central part and two symmetrical paths at right angles (Fig,5) [9,10]. Each sector into a zone of the surface layer, a zone of the middle of the surface and the inner layer, allotted in the scheme in different colors is conventionally divided is conventionally divided. The results of processing the received data in Fig. 6 are shown.

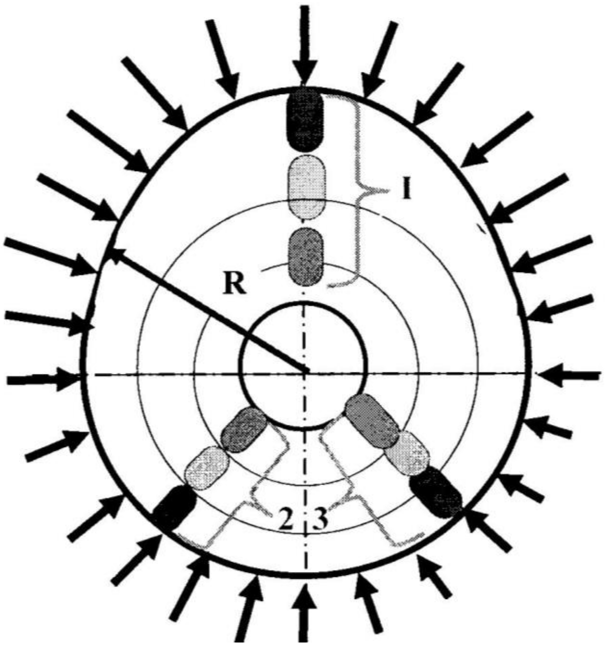


Fig. 5: Scheme of measurements of microhardness of the corresponding zones of the claw restored and strengthened by laser boring.

On Fig. 6 shows that the microhardness of the surface layer after laser boring increased three times (HV350-460) compared with the initial structure of the camshaft of eccentric shaft (HV180-260), which proves the promise of this technology of restoration and strengthening of parts.

The unevenness of the indicators of microhardness (Fig. 6, 7), several different zones on the surface and section of the body of the cam are due to the following factors:

- different composition of the alloying elements in the main material (steel 45) and the restored surface area with the following laser boring;
- forming in the surface layer of tempered structures and zones of release;
- forming in local zones during laser treatment and blotting of separate tumors (boron carbides, carbonoborates, iron borides, etc.);
- uneven pulse laser processing, where the density of the flow is limited by the diameter of the laser spot (9 mm), and the treatment with overlapping zones leads to the surface layer not only hardening but also the release of local microparticles.

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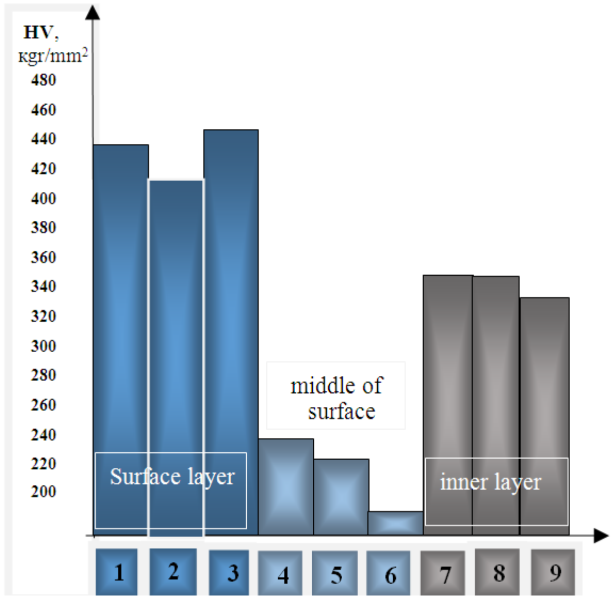

Fig. 6: Microhardness of the surface layer from the largest projection to the center of the body of the cam (zone I).

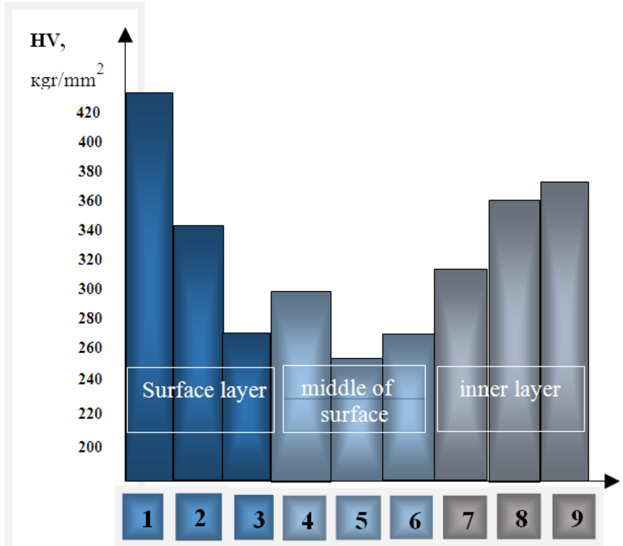

Fig.7: Microhardness of the surface layer from symmetrical paths 2-3 to the center of the body of the claw.

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- forming in local zones during laser treatment and blotting of separate tumors (boron carbides, carbide-borides, iron borides, etc.);
- uneven pulse laser processing, where the density of the flow is limited by the diameter of the laser spot (9 mm), and the treatment with overlapping zones leads to the surface layer not only hardening but also the release of local micro particles.

On Fig. 8 graphic dependences of the values of microhardness of steel 45 up to and after restoration with subsequent reinforcement by laser boring are constructed. By the nature of the distribution of values, it can be make that the largest microhardness is observed in the surface layers of the sample. In these layers, as shown by microstructural and X-ray diffraction studies, martensitic structures with a small concentration in them (up to 4-5%) of borides and iron carbides were formed.

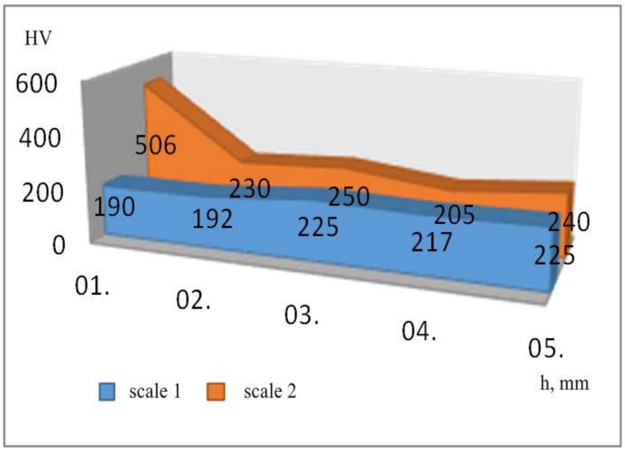

Fig. 8: Microhardness of sample 1 before and after 2 laser boring.

3. Conclusion

The research of restored and strengthened surfaces of samples of cams of operational camshaft with the help of laser boring was carried out. It is determined that the strengthened surface layer has a complex structure and generally contains a martensitic base with thin layers of borides and carbides. It was established that the microhardness of the processing zone increases in 3-4 times (H_m 6500-7000 MPa). The obtained results indicate that the microhardness of the surface layer of samples from steel 45 with laser boring is almost three times greater than the main material without laser treatment. Taking into account the on increasing the wear-resistance of the material with increasing the hardness of its surface layers, it can be stated in advance that the new structures formed will have greater resistance to fracture during mechanical interaction with another surface, for example, in the tribo-coupling of the gas-distributing shaft of the "cam-pusher" engine. But this is one of the components of further research in the stated direction.

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