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**O. Cherneta**[1], Ph.D., Associate Professor
**B. Sereda**[1], Doctor of Technical Sciences, prof., Head of the Department,seredabp@ukr.net
**V. Kubich**[2], Ph.D., Associate Professor
[1]DniproState Technical University, Kamyanske
[2]National University "Zaporizhzhya Polytechnic", Zaporozhye

# USE OF COMBINED STRENGTHENING METHOD TO OBTAIN OPTIMAL COMPOSITION OF PHYSICO-MECHANICAL CHARACTERISTICS OF MEDIUM CARBON

*The research of the combined method of restoration and strengthening of the surface layer of the camshaft of the internal combustion engine is carried out. A comparative analysis of the physical and mechanical characteristics of coatings after the most common hardening treatments, taking into account structural transformations in the surface layers.*

*The graph of dependence of physical and mechanical characteristics of coverings at the corresponding technologies of hardening taking into account prime cost and expenses for optimization of technological ways of hardening is deduced.*

***Key words***: *hardening, drilling, laser processing, microstructural analysis, combined method, instrumental identification, technological processes of hardening.*

*В роботі проведені дослідження комбінованого способу відновлення і зміцнення поверхневого шару* кулачків *розподільного валу двигуна внутрішнього згорання. Зроблений порівняльний аналіз фізико-механічних характеристик покриттів після найбільш поширених зміцнюючи обробок з урахуванням структурних перетворень в поверхневих шарах.*

*Виведений графікзалежності фізико-механічних характеристик покриттів при відповідних технологій зміцнення з урахуванням собівартості і витрат для оптимізації технологічних способів зміцнення.*

***Ключові слова***: *зміцнення, борування, лазерна обробка, мікроструктурний аналіз, комбінований спосіб, інструментальне ідентифікування, технологічні процеси зміцнення.*

## Problem's Formulation

Modern conditions of operation and use of automotive equipment require a significant increase in loads, speed and temperature of the main components, mechanisms and units while increasing the reliability, durability and life of the car as a whole.

The main percentage of destruction of parts (30 %) is allocated to friction processes in the contact pairs of mechanisms. Therefore, special attention is paid to the condition of the surface layer of tribocontact pairs, namely hardening technologies.

The wear resistance of the surface layer, durability, reliability and service life of cars depend on the complex of the formed properties at various technological ways of strengthening.

## Analysis of recent research and publications

Over the last decades, hundreds of technologies have been introduced into the machine-building industry in the world practice to strengthen the surface layer of parts. The main criteria for choosing methods of hardening are high wear-resistant, physical and mechanical, operational properties of coatings and the total cost of the technological process, equipment, consumables, environmental friendliness and safety. The mechanisms of formation of wear-resistant structures are covered in many works of famous scientists [1—4].

The directories provide the modes of processing and the end result of the most common technological methods of processing, which is guaranteed by the sequential performance of certain operations are appropriate microstructures with specified microhardness and wear resistance on experimental steels [5—7].

A significant breakthrough in the field of strengthening treatments was the use of high-energy energy sources, which allowed to expand the range of modification of surface layers, significantly increase the strength and wear resistance characteristics [8].

**Formation of the study purpose**

Based on the analysis of the use of the latest methods of hardening to develop a method of choosing the best option for the use of wear-resistant technologies, to develop a sequence of combined methods of surface layer modification by boriding followed by laser treatment.

**Presenting main material**

The disadvantage of most methods using laser treatment with different types of coatings is the inability to control the surface roughness, structural processes, the concentration of alloying elements in the surface layers in the laser treatment zone, the heterogeneity of the treated surface, fluctuations in microhardness of local areas processing.

In industrial practice, quite often the processes of restoration and strengthening of the surface layer consist of the following successive operations: restoration of the geometry and shape of the surface by surfacing with electrodes; blade processing to ensure the geometric parameters of the product; drilling of the surface with the formation of superhard structures; laser treatment for surface modification; finishing. In fig. 1 shows a cross-sectional view of the camshaft after surfacing and hardening.

Combined method of modification by drilling and laser treatment, including pre-drilling in the furnace in the environment of boron-containing substances and followed by pulsed laser treatment at storage energy E = 28 kJ, Ø = 8 mm — diameter of the laser beam with a coefficient of overlap of 15 % with a pulse duration of $1\cdot10^{-3}$—$2\cdot10^{-3}$s and a distance of 70 mm from the target (fig. 1) allows you to get on steel 45stable layer of borides and boboboroids type carboborodi Fe (CB), $Fe_2$ (CB).

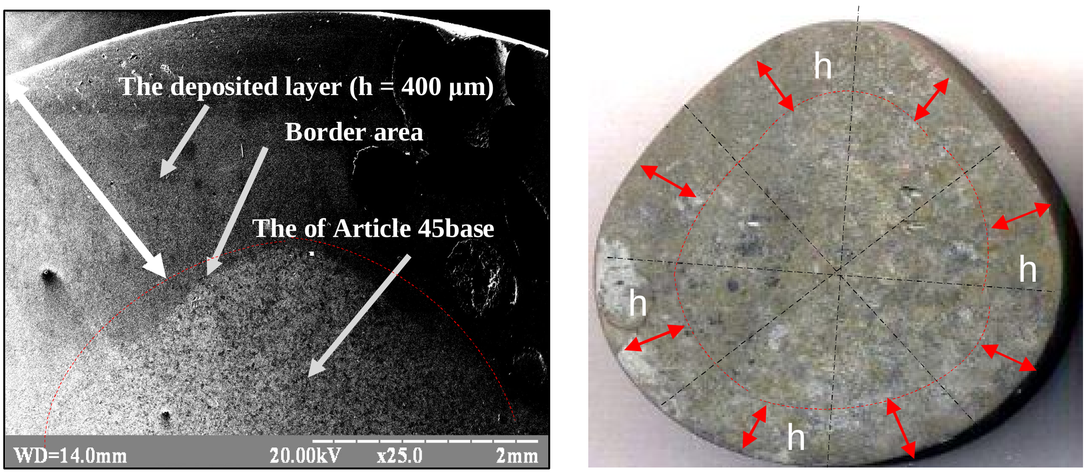



*Fig.1.* Photo of the cross section of the camshaft after surfacing and hardening

The technological process is based on the task of improving the combined method of surface modification by combining two consecutive operations — saturation of the surface layer with boron in the furnace with the formation of high-strength phases FeB, $Fe_2B$ with microhardness $H_{\mu50}$ = 16000 MPa on steel 45 at a depth of 25 microns. The disadvantage of superhard structure is its fragility and susceptibility to cracking. To eliminate these defects, a second cycle of processing using laser pre-drilled surfaces of the part is proposed. The needle microstructure of the surface boron layer is destroyed by laser irradiation. The crystal needles of the microstructure are crushed and new quenching structures appear in the surface layers such as Fe (CB) and $Fe_2$ (CB) carboborides. Decreased by 20 % above the high stresses of the crystal lattice and the microhardness $H_{\mu50}$ = 14000 MPa in the surface layer.

Modes of laser processing are developed with the following parameters at: accumulation energy E = 28 kJ, Ø = 8 mm — diameter of laser beam with coefficient of overlap of processing zones 15 %, with pulse duration $1\cdot10^{-3}$—$2\cdot10^{-3}$ s and with distance to target 70 mm. When boriding in the combined method in the furnace is the saturation of the surface layer with boron to a depth of 25 mcm. The next stage in surface modification is pulsed laser treatment of a homogeneous boron-saturated surface with preservation of geometric parameters. The implementation of the combined method according to the prototype leads to partial recrystallization of the microstructures of the borated layer. The superhard needle-shaped boron layer after laser treatment is transformed into smaller formations, and the accumulation of FeB and Fe2B borides is transformed into carboborides of the Fe (CB), $Fe_2$ (CB) type with a 15—20 % reduction in the surface layer hardness. This proportionally increases the ductility of the material, which has a positive effect on the overall characteristics of strength and durability.

The specified modes of boriding and laser processing provide recrystallization of surface layer structures. Modes of combined processing are developed: drilling at a temperature of 850°C with endurance of 7 hours of processed details in the environment of boron-containing substances and the subsequent laser processing at energy of accumulation E = 28 kJ, Ø = 8 mm — diameter of a laser beam with coefficient of overlapping $1 \cdot 10^{-3}$—$2 \cdot 10^{-3}$s and from a distance of 70 mm to the target. Fluctuations in the values of energy accumulation less than E = 28 kJ leads to incomplete recrystallization of the surface layer structures, the presence of zones without the influence of laser radiation. When using energies greater than E = 28 kJ leads to uncontrolled melting of local areas, violation and destruction of the microgeometry of the surface layer, the emergence of craters and other defects of the surface layer. When the coefficient of overlap fluctuates less than 10 %, some local areas do not fall under the zone of laser exposure, and more than 30 % to the imbalance of components and boron layer and uncontrolled processes of hardening and double hardening. Fig. 2 shows a schematic diagram of the proposed combined method of strengthening the surface layer. The boron hardening process is as follows. The prepared surface of the part 1 in a special container is loaded into an electric furnace 2 for chemical-heat treatment (boriding). Electric heating device 3 provides temperature maintenance in the furnace T = 850° with a holding time of 7 hours in the environment of boron-containing substances. The second stage of the hardening process is associated with laser treatment (solid-state pulsed laser 3 GOS-1001) of the boriding layer according to the given modes at storage energy E = 28 kJ, Ø = 8 mm — diameter of the laser beam with overlap coefficient of 15 % pulse $1 \cdot 10^{-3}$—$2 \cdot 10^{-3}$s and with a distance to the target of 70 mm. After completion of the combined method of hardening, the surface of the part is cleaned of soot and oxidation products.

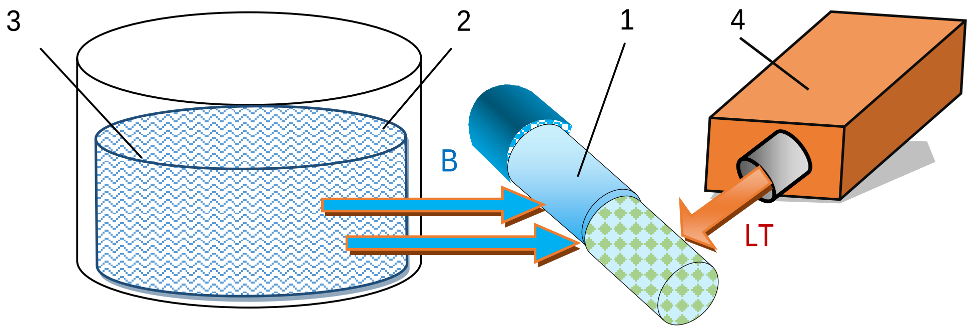
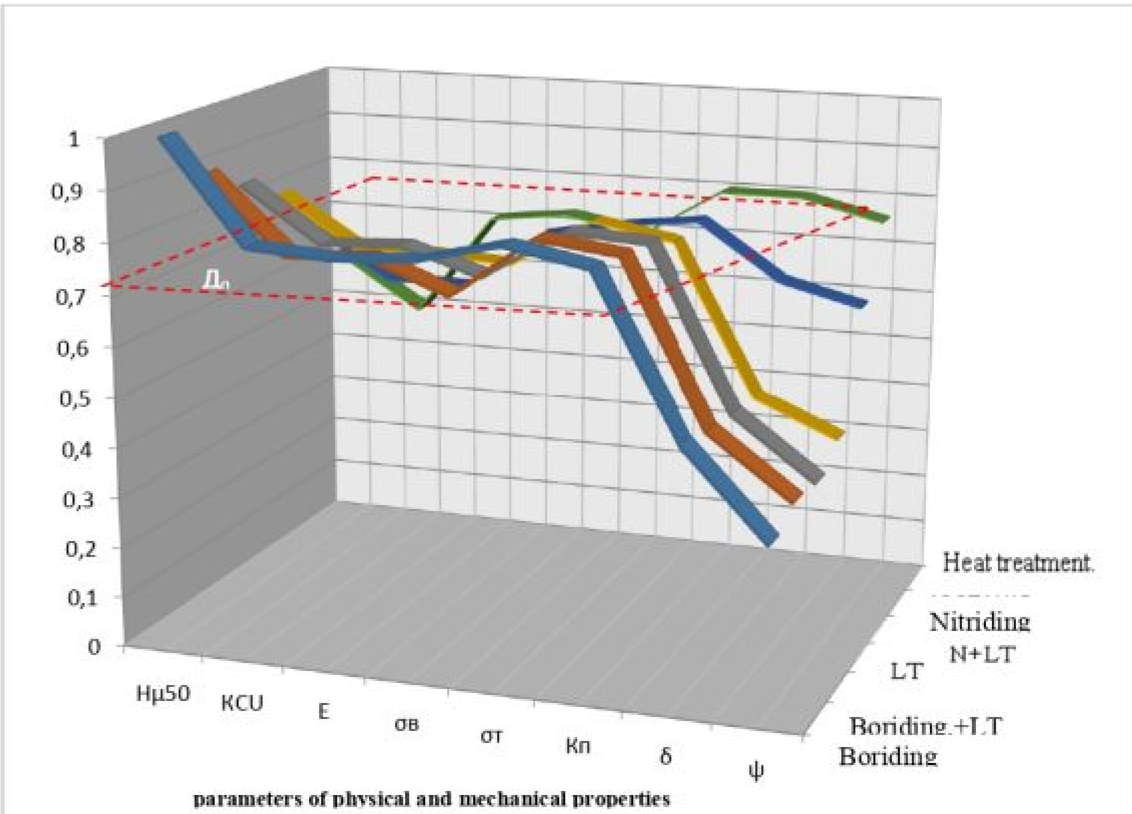



*Fig. 2.* Scheme of implementation of the combined method of hardening – boriding + laser treatment

For determination of vibrations of physical and mechanical properties of superficial layer (parameters of Hμ, KCU, E, $\sigma_b$, $\sigma_т$, Kп δ, ψ) of steel 45 after the different methods of strengthening (boriding, boriding +of LT, laser treatment (LT), nitriding + of LT, nitriding, heat treatment) used the method of instrumental authentication by means of device of "Micron-gamma" [9, 10]. On results measuring the graphic chart of vibrations of physical and mechanical properties of steel 45 (Fig. 3) after the different methods of strengthening.




| №/№ | Hµ50 | KCU | E | σв | σт | Kп | δ | ψ |
|---|---|---|---|---|---|---|---|---|
| Boriding | 1 | 0,8 | 0,79 | 0,8 | 0,84 | 0,81 | 0,5 | 0,33 |
| Boriding+LT | 0,9 | 0,75 | 0,76 | 0,7 | 0,82 | 0,8 | 0,48 | 0,36 |
| LT | 0,85 | 0,74 | 0,75 | 0,7 | 0,8 | 0,79 | 0,47 | 0,35 |
| N+LT | 0,8 | 0,7 | 0,7 | 0,69 | 0,79 | 0,76 | 0,46 | 0,39 |
| Nitriding | 0,7 | 0,6 | 0,6 | 0,72 | 0,75 | 0,77 | 0,66 | 0,62 |
| Heat treatment. | 0,6 | 0,5 | 0,71 | 0,73 | 0,7 | 0,8 | 0,8 | 0,76 |

*Fig. 3*. Graphic diagram of fluctuations of physical and mechanical properties of steel 45 after different methods of hardening (boriding, boriding + LT, laser treatment (LT), nitriding + LO, nitriding, heat treatment

The method of the dynamic squeezing out is based on automatic registration of loading (P) on an indenter and depths of his squeezing (h). Result is given as a diagram of loading, treatment of that allows to investigate micro hardness, study the features of microstrain after kinetics of squeezing to the indenter, to registration microcreep and to measure the resiliency of materials. Methodical bases of determination of hardness and module of resiliency after the diagrams of squeezing are based on the method of Oliver W.C., Pharr G. and international standard (ISO/FDIS 14577-1: 2002) accepted in quality.

The excellent feature of device is the use of differential sensor of the small moving, principle of work of that consists in bathymetry of squeezing to the indenter in relation to the surface of pre-production model. authentication is by means of device of "Micron-gamma" [9, 10]. On results measuring the graphic chart of vibrations of physical and mechanical properties of steel 45 (fig.3) after the different methods of strengthening.

## Conclusions

Worked out methodology of determination of optimal methods and technologies of strengthening of superficial layer of details from steel 45 on the criterion indexes of efficiency. The defined basic values of base indexes that fold $Д_0$ are a zero level that is taken for an optimal variant forstrengthening of surfaces at corresponding technologies.

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## ВИКОРИСТАННЯ КОМБІНОВАНОГО СПОСОБУ ЗМІЦНЕННЯ ДЛЯ ОТРИМАННЯ ОПТИМАЛЬНОГО СКЛАДУ ФІЗИКО-МЕХАНІЧНИХ ХАРАКТЕРИСТИК СЕРЕДНЬОВУГЛЕЦЕВИХ СТАЛЕЙ

**Чернета О.Г., Середа Б.П., Кубич В.І.**

**Реферат**

Механізми утворення зносостійких структур висвітлені в багатьох працях і широко застосовуються у виробничих процесах машинобудівних галузях. Відпрацьовані режими обробок, де гарантовано при послідовному виконанні певних операцій отримуються відповідні мік-

роструктури з заданими показниками мікротвердості і зносостійкості на дослідних сталях. Значним проривом у сфері зміцнюючих обробок стало використання високоенергетичних джерел енергії, що дозволило розширити спектр модифікування поверхневих шарів, значно підвищити міцницькі і зносостійкі характеристики. У виробничий практиці доволі часто процеси відновлення і зміцнення поверхневого шару складаються із наступних послідовних операцій: відновлення геометрії і форми поверхні за рахунок наплавлення електродами; лезвійна обробка для забезпечення геометричних параметрів виробу; борування поверхні з утворенням надтвердих структур; лазерна обробка для модифікування поверхні; фінішна обробка. Комбінований спосіб модифікації за допомогою борування і лазерної обробки, що включає попереднє борування в печі в середовищі боровміщуючих речовин із наступною обробкою імпульсним лазером при енергії накопичення Е=28 кДж, Ø=8 мм – діаметром лазерного пучка з коефіцієнтом перекриття зон обробки 15 %, з тривалістю імпульсу$1\cdot10^{-3}$— $2\cdot10^{-3}$с і з відстанню до мішені70 мм дозволяє отримати на сталі 45 стабільний шар боридів і кабоборидів типу карбоборидами Fe(CB), $Fe_2$(CB). Для визначення коливань фізико-механічних властивостей поверхневого шару (параметри $H_\mu$, KCU, E, $\sigma_в$, $\sigma_т$, $K_п$, δ, ψ) сталі 45 після різних способів зміцнення (борування, борування + ЛО, лазерна обробка (ЛО), азотування + ЛО, азотування, термообробка) використовували метод інструментального ідентифікування за допомогою приладу «Micron-gamma». За результатами вимірів побудована графічна схема коливань фізико-механічних властивостей сталі 45після різних способів зміцнення. Розроблена методика визначення оптимальних способів і технологій зміцнення поверхневого шару деталей із сталі 45 за критеріальними показниками ефективності. Визначені основні значення базових показників, що складають Д — нульовий рівень і обов’язково необхідні для зміцнених поверхонь при відповідних технологіях.

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