II ТЕХНОЛОГІЇ ОТРИМАННЯ ТА ОБРОБКИ КОНСТРУКЦІЙНИХ МАТЕРІАЛІВ

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DETERMINATION OF THE OPTIMAL PARAMETERS OF LASER BORIDING TO IMPROVE THE WEAR RESISTANCE OF PISTON RINGS

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Purpose. *The goal was to determine the effect of laser heating parameters on the structure and depth of the borated layer, since the properties of piston rings depend on the depth of the latter.*

Research methods. *Microstructural and X- ray phase analyzes were used to determine the structural state of piston rings.*

Results. *Application of traditional boriding methods associated with diffusion of boron into the solid phase leads to formation of the working layer having high brittleness. The conducted studies revealed that the increase in the speed of displacement of the part in the process of laser heating reduces the depth of the borated layer. Such a dependence is observed both at 0.15 mm thickness of coating and at a thickness of 0.30 mm. For all modes of workpiece displacement speed for the used boron containing envelope with the above-specified thickness a higher thickness of the borated layer and the heat affected area corresponds to a higher thickness of coating. Increase of the spot size leads to an increase in the depth of the layer. By X- ray and metallographic diffraction there were decoded the phases and structural constituents of the borated layer.*

Scientific novelty. *An approach to solving the problem of increasing the wear resistance of piston rings without crumbling is shown. The use of laser heating during drilling ensures the formation of a new layer with special properties. However, optimal properties can be achieved only after establishing a relationship between the parameters of the process and the depth of the boron layer. X-ray and metallographic analysis determined the relationship between the rate of irradiation and the proportion of high-boron structures in the layer. It is shown that the borated layer in high-strength cast iron contains such phases as FeB, Fe_2B, α- phase, borocementite $Fe_3(B,C)$.*

Practical value. *Increased wear resistance of piston ring materials, which often limits the growth of machine productivity and their service life. Research results can be extended to other parts subject to intensive wear.*

Key words: *piston rings, borated layer, laser heating.*

Introduction

One way to improve the performance properties of cast iron piston rings, exposed to abrasion, is boriding. However, the use of traditional boriding methods associated with diffusion of boron into a solid phase leads to the formation of a working layer having high brittleness. Therefore, the actual problem is the development of a different method of surface hardening, not leading to embrittlement. Implementation of such a process can be carried out using laser heating accompanied by surface layer melting. However, this method can be offered to be used in the production only after a detailed study of the relationship between the parameters of process implementation and the depth of the layer, as well as after studying the peculiarities of structure formation under specific conditions of laser boriding. The properties of the product on which a borated layer is applied depend on the depth of the latter.

Analysis of publications shows that the technique of increasing the wear resistance of piston rings by boriding, conducted using non-traditional methods, but using the lat-est technologies has not been developed so far. In sources [1–3] they proposed to increase durability by either tradi-tional borating, or laser treatment. However, there is no as-sociation of these two technological processes.

Implementation of such a process can be carried out by establishing the interrelation between the parameters of laser heating and the depth of the borated layer.

The objective of this work was to determine the influ-ence of laser action parameters into the depth of the borated layer and revealing the features of structure formation of such layers.

Purpose

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Material and methods of the experiment

The research material applied was ductile iron containing C = 3.47 %, Si = 2.15 %, Mn = 1.36 %. After pretreatment, it had a ferrite-perlite structure (85-90% perlite). The size of nodule corresponds to 3 points.

Laser treatment was carried out using the continuous CO_2 laser. At a constant irradiation power they varied the speed of movement of the sample in the range of 2–4 mm/s. The thickness of coating boron was 0.15 mm and 0.30 mm. Conditional defocusing (F_{cond}) allowed to change the irradiation spot diameter from 2 to 4 mm. A mixture of amorphous boron with acetone and zapon varnish was used as a coating material.

The structure, phase composition, the depth of the borated layer was studied by optical microscopy, using conventional and staining etching as well as X-ray structural analysis.

Findings

With the help of etching by a 4 % nitric acid solution, revealing the entire layer structure, it was established that the change in the metal structure as a result of doping occurs only in the melting zone. Study of the profile of the reflow zone boundary indicates that a deeper penetration of the metal matrix occurs near the graphite inclusions that confers the border in waves.

Fig. 1 shows the dependence of the depth of the borated layer on the speed of workpiece displacement for two cases – with a coating thickness of 0.15 and 0.30 mm (curve 1 and 2 respectively).

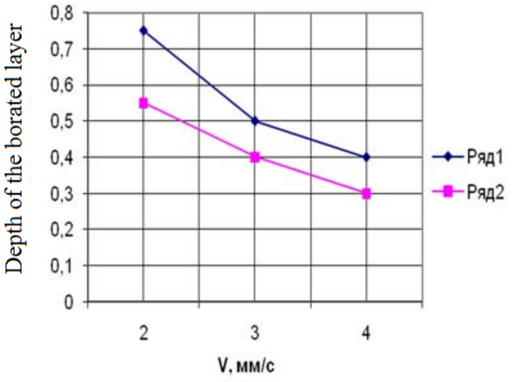

Fig. 1. Dependence of the depth of the borated layer on the rate of workpiece displacement: 1 – 0.3 mm thickness of coating; 2 – 0.15 mm thickness of coating

The graph shows that with an increase in the velocity of sample movement the depth of the borated layer decreases. Such dependence is observed both at 0.15 mm thickness of coating and at a thickness of 0.30 mm. Over a full range of speeds of workpiece movement for the applied boron containing coating with the specified thickness a greater thickness of the borated layer and HAZ corresponds to greater thickness of coating.

Fig. 2 shows a histogram of the depth of the borated layer with a thickness of 0.3 mm and the workpiece velocity of 2 mm/s for the spot diameter 2 and 4 mm, and Fig. 3 presents the same histogram in case of specimen velocity of 4 mm/s.

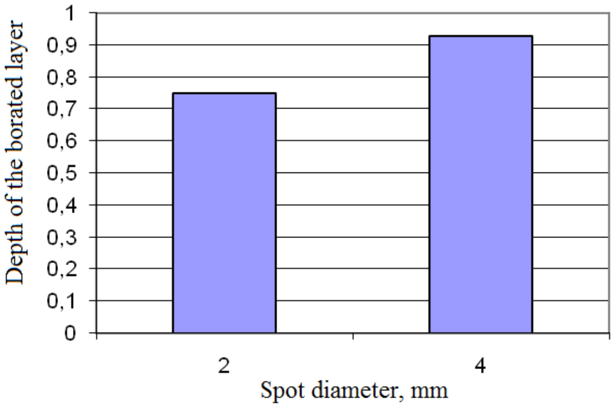

Fig. 2. Histogram of the borated layer depth with a thickness of 0.3 mm and specimen velocity of 2 mm/s for different diameter of the spot

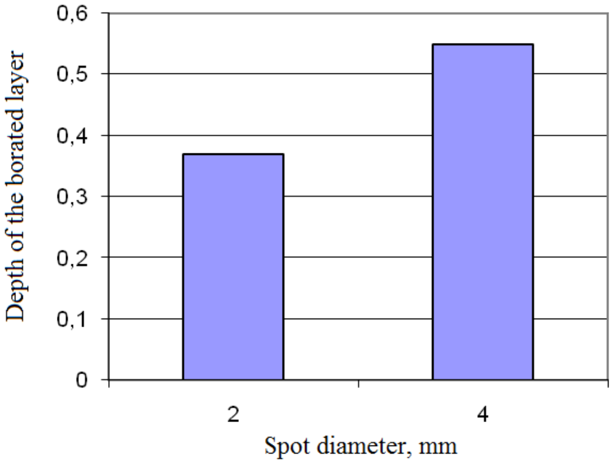

Fig. 3. Histogram of the depth of the borated layer with a thickness of 0.3 mm and specimen velocity of 4 mm/s for different spot diameter

The above histograms show that the variation of defocusing conditions, the consequence of which is the change of the spot diameter irradiation, results in a noticeable change in the depth of the layer of laser doping. Thus, reducing the defocus, ceteris paribus, the result of which there is a decrease in spot diameter, it causes a decrease in the depth of laser irradiation.

It can be assumed that the resulting effect is due to a significant increase in the surface temperature resulting in intense evaporation of the coating layer, increasing the energy costs for evaporation.

X-ray analysis showed that the borated layer in the ductile iron contains such phases as Fe_B, $Fe2_B$, α- phase, borocementite Fe_3 (B, C).

A comparison of microscopic and X-ray analysis with diagrams of state Fe-B and Fe-Fe_2B-Fe_3C revealed that these phases at crystallization of melt can form throughout the volume of the molten layer various structural compo-

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nents: a mixture of peritectic type (FeB + Fe_2B), hypereutectic, eutectic and hypoeutectic structures.

Differentiation of phases in various structures is carried out by the method of coloring etching; by the analysis of primary crystals forms.

Excess α- phase is formed from γ- phase primary crystals according to the martensitic mechanism. Borocementite Fe_3 (B, C) and borides FeB, Fe_2B differ by metallography – by excess crystals form and the behavior during staining etching.

Primary borocementite crystals present plate-clustering – flat dendrites, which in cross sections are perpendicular to the surface, are detected in the form of thin strips.

In accordance with the ternary diagram borocementite can be formed not only by direct crystallization from a liquid solution, but also as a result of peritectic transformation [2].

Structurally-free crystals of borides Fe_2B are observed in the form of rodlet crystals having in the cross-section the shape of squares, rhombus, triangles, i.e. of all possible cross-sections of the tetragonal prism.

Eutectic components of structures in the borated layer are characterized by a definite structure diversity and dispersion.

The eutectic point in different layers and within the same layer is different by both different dispersion ability and various quantitative relation between the phases.

Comparing the patterns of layers with the comparable depth illustrates the effect of coating depth on the structure. For example, a three-zone layer with predominance of eutectic and hypoeutectic structures can become dual-zone with hypereutectic and eutectic zones with a predominance of the first one when changing the thickness of coating from 0.3 to 0.15 mm.

With increasing the exposure rate, under otherwise equal conditions of treatment there is a decrease in the depth of the layer, i.e. the volume of the molten metal bath decreases and consequently- the amount of boron dissolved in it increases therein. The data of X- ray diffraction and microscopic analysis reveal a change in the layer composition. X-ray diffraction shows an increase in the intensity of borocementite lines with the growth of irradiation rate, and microstructurally it is revealed by an increase in the share of structures with a high content of boron.

Conclusions

1. It was established that when conducting laser boriding with an increase in RMS-velocity of sample movement the depth of the borated layer decreases.
2. The histograms of the borated layer indicate the increase of the latter with an increase of the irradiation spot diameter from 2 to 4 mm.
3. X-ray and metallographic diffraction detected the phases and structural composition of the borated layer.
4. The effect of coating thickness on the structure is established.
5. X-ray and microstructural diffraction analysis revealed a connection between the RMS-irradiation growth and the share of high-boron structures in the layer.
6. The results of the research can be recommended for implementation in production of both piston rings and other parts made of ductile iron subjected to wear during operation.

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ВИЗНАЧЕННЯ ОПТИМАЛЬНИХ ПАРАМЕТРІВ ЛАЗЕРНОГО БОРИДУВАННЯ ДЛЯ ПІДВИЩЕННЯ ЗНОСОСТІЙКОСТІ ПОРШНЕВИХ КІЛЕЦЬ

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Мета роботи. *Встановити вплив параметрів лазерного нагріву на склад та глибину шару борування, так як властивості поршневих кілець залежать від глибини останнього.*

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Методи дослідження. *Для визначення структурного стану поршневих кілець використовували мікроструктурний та рентгенофазовий аналізи.*

Отримані результати. *Використання традиційних способів борування, пов'язаних з дифузією бору в тверду фазу, приведе до формування робочого шару, що має високу крихкість. В результаті проведених досліджень встановлено, що збільшення швидкості переміщення деталі в процесі лазерного нагріву зменшує глибину шару борування. Така залежність спостерігається як при товщині обмазки 0,15 мм, так і при товщині 0,30 мм. При всіх швидкостях переміщення зразка для використаної обмазки, що містить бор, із вказаними товщинами більша товщина борованого шару та зони термічного впливу відповідає більшій товщині обмазки. Збільшення діаметру плями сприяє зростанню глибини шару. Рентгенографічним і металографічним методами розшифровані фази і структурні складові шару борування.*

Наукова новизна. *Показано підхід до вирішення проблеми підвищення зносостійкості поршневих кілець без окрихчування. Використання лазерного нагріву при боруванні забезпечує утворення нового шару з особливими властивостями. Однак оптимальні властивості можуть бути досягнуті тільки після встановлення зв'язку між параметрами проведення процесу і глибиною борованого шару. Рентгенографічним і металографічним аналізом визначений зв'язок між швидкістю опромінення і часткою високобористих структур в шарі. Показано, що борований шар в високоміцному чавуні містить такі фази, як* FeB, Fe_2B, *α- фазу, бороцементит* $Fe_3(B,C)$.

Практична цінність. *Підвищена зносостійкість матеріалів поршневих кілець, що часто обмежує зростання продуктивності машин і терміну їх експлуатації. Результати досліджень можуть бути поширені і на інші деталі, що підлягають інтенсивному зношуванню.*

Ключові слова: *поршневі кільця, шар борування, лазерний нагрів.*

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