UDC 621.793

INVESTIGATION OF PECULIARITIES OF PISTON RINGS LASER BORATING

BOLSHAKOV V. I.[1], *Dr. Sc. (Tech.), Prof.,*
GLUSHKOVA D. B.[2*], *Cand. Sc (Tech)., Ass. Prof.,*
VORONOVA Ye. M.[3], *Cand. Sc. (Tech), Ass. Prof.*

[1] Department of Materials and Materials Processing, State Higher Educational Establishment «Prydneprovs'ka State Academy of Civil Engineering and Architecture», 24-A, Chernyshevskogo str., Dnipropetrovsk 49600, Ukraine, Tel. +38 (0562) 745-23-72, e-mail: bolshakov@mail.pgasa.dp.ua, ORCID ID: 0000-0003-0790-6473
[2*] Department of Technology of Metals and Material Science, Kharkiv National Automobile and Highway University (KhNAHU), 25, Petrovsky str., Kharkiv 61002, Tel. +38(057)707-37-92.
[3] Department of Foreign Languages № 1, Kharkiv National Automobile and Highway University (KhNAHU), 25, Petrovsky str., Kharkiv 61002, Tel. +38(057)707-37-21.

Abstract. Problem formulation. Piston rings are subject to wear while in operation. Insufficient wear resistance of materials limits the growth of machines productivity as well as the terms of their exploitation. The required complex of properties of piston rings made of cast iron cannot be always reached by applying traditional methods of heat treatment or chemical heat treatment processing. Thus, application of traditional borating methods associated with diffusion of boron into the solid phase leads to the formation of the working layer exhibiting high brittleness. Therefore, the problem of increasing the wear resistance of piston rings without embrittlement is challenging. The use oflaser heating during borating provides the formation of a new layer with special properties. However, the optimum properties can be achieved only after determining the relationship between the parameters of running a process and the depth of the borated layer. ***Goal of research.*** To determine the influence of laser heating parameters on the depth of the borated layer, as the properties of piston rings depend on the depth of the latter. ***Conclusions.*** Increase in the speed of displacing parts during laser heating reduces the depth of the borated layer, and increase of the spot diameter enhances the depth of the layer. The phases and structural components of the borated layer were interpreted by means of X-ray and metallographic methods. The results of investigations can be applied to other machine parts, which are subject to intensive wear.

Key words: *piston rings, borated layer, depth, structure, laser heating*

ДОСЛІДЖЕННЯ ОСОБЛИВОСТЕЙ ЛАЗЕРНОГО БОРУВАННЯ ПОРШНЕВИХ КІЛЕЦЬ

БОЛЬШАКОВ В. І.[1], *д. т. н., проф.,*
ГЛУШКОВА Д. Б.[2*], *к. т. н., доц.,*
ВОРОНОВА Є. М.[3], *к. т. н., доц.*

[1] Кафедра матеріалознавства та обробки матеріалів, Державний вищий навчальний заклад «Придніпровська державна академія будівництва та архітектури», вул. Чернишевського, 24-а, 49600, Дніпропетровськ, Україна, тел. +38 (0562) 745-23-72, e-mail: bolshakov@mail.pgasa.dp.ua, ORCIDID: 0000-0003-0790-6473
[2*] Кафедра технології металів та матеріалознавства, Харківський національний автомобільно-дорожній університет», вул. Петровського, 25, 61002, 61002, Харків, Україна, тел. +38(057)707-37-92.
[3] Кафедра «Іноземних мов № 1», Харківський національний автомобільно-дорожній університет (ХНАДУ), вул. Петровського, 25, 61002, Харків, Україна, тел. +38 (057) 707-37-21.

Анотація*. *Постановка проблеми. Поршневі кільця у процесі експлуатації зношуються. Недостатня зносостійкість матеріалів затримує зростання продуктивності машин і терміну їх експлуатації. Не завжди потрібний комплекс властивостей поршневих кілець, виготовлених із чавуну, може бути досягнутий традиційними методами термічної або хіміко-термічної обробки. Так, застосування традиційних способів борування, пов'язаних із дифузією бору в тверду фазу, зумовить формування робочого шару, щомаєвисокукрихкість. Тому актуальною є проблема 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. ***Мета дослідження.*** Встановити вплив параметрів лазерного нагріву на глибину шару борування, так як властивості поршневих кілець залежать від глибини останнього. ***Висновки.*** Збільшення швидкості переміщення деталі в процесі лазерного нагріву зменшує глибину шару борування, а підвищення діаметру плями сприяє зростанню глибини шару. Рентгенографічним і металографічним методами росшифровано фази і структурні складові шару борування. Результати досліджень можуть бути поширені і на інші деталі, що підлягають інтенсивному зношуванню.

Ключові слова*: поршневі кільця, шар борування, глибина, структура, лазерний нагрів*

ИССЛЕДОВАНИЕ ОСОБЕННОСТЕЙ ЛАЗЕРНОГО БОРИРОВАНИЯ ПОРШНЕВЫХ КОЛЕЦ

БОЛЬШАКОВ В. И.[1], *д. т. н., профессор,*
ГЛУШКОВА Д. Б.[2*], *к. т. н., доцент,*
ВОРОНОВА Е. М.[3], *к. т. н., доцент*

[1] Кафедра материаловедения и обработки материалов, Государственное высшее учебное заведение Приднепровская государственная академия строительства и архитектуры, ул. Чернышевского, 24-а, 49600, Днепропетровск, Украина, тел. +38 (0562) 745-23-72, e-mail: bolshakov@mail.pgasa.dp.ua, ORCIDID: 0000-0003-0790-6473

[2*] Кафедра «Технологии металлов и материаловедения», Харьковский национальный автомобильно-дорожный университет», ул. Петровского, 25, 61002, Харьков, Украина, тел. +38(057)707-37-92.

[3] Кафедра «Иностранных языков № 1», Харьковский национальный автомобильно-дорожный университет (ХНАДУ), ул. Петровского, 25, 61002, Харьков, Украина, тел. +38(057)707-37-21.

Аннотация*. *Постановка проблемы. Поршневые кольца в процессе эксплуатации подвергаются износу. Недостаточная износостойкость материалов лимитирует рост производительности машин и сроков их эксплуатации. Не всегда требуемый комплекс свойств поршневых колец, изготовленных из чугуна, может быть достигнут традиционными методами термической или химико-термической обработки. Так, применение традиционных способов борирования, связанных с диффузией бора в твердую фазу, приводит к формированию рабочего слоя, обладающего высокой хрупкостью. Поэтому актуальной является проблема повышения износостойкости поршневых колец без охрупчивания. Применение лазерного нагрева при борировании обеспечивает образование нового слоя с особыми свойствами. Однако оптимальные свойства могут быть достигнуты только после установления взаимосвязи между параметрами проведения процесса и глубиной борированного слоя. ***Цель исследования.*** Установить влияние параметров лазерного нагрева на глубину борированного слоя, так как свойства поршневых колец зависят от глубины последнего. ***Выводы.*** Возрастание скорости перемещения детали в процессе лазерного нагрева уменьшает глубину борированного слоя, а увеличение диаметра пятна увеличивает глубину слоя. Рентгенографически и металлографически расшифрованы фазы и структурные составляющие борированного слоя. Результаты исследований могут быть распространены и на другие детали, подвергающиеся интенсивному износу.

Ключевые слова: *поршневые кольца, борированный слой, глубина, структура, лазерный нагрев*

Problem formulation. One of the ways to improve the performance properties of cast iron piston rings that are subject to wear isboriding. However, the use of traditional boridingmethods associated with the diffusion of boron into the solid phase leads to the formation of the active layer exhibiting high friability. Therefore, the problem of developing a different method of hardening the surface that would not result inembrittlement is challenging. Implementation of such a process may be carried out, using laser heating withsurface layer melting. However, the use of such a method may be offered to be used in production only after a detailed study of the relationship between the parameters of conducting the process and the depth of the layer, as well as the study of features of structure formation under specific conditions of laser boriding. The properties of the product that the borated layer was deposited on depend on the depth of the latter.

Analysis of publications shows that there have not been developed any techniques of increasing the wear resistance of piston rings by boriding conducted without using traditional methods, but applying recent technologies. In sources [1-3] it is proposed to increase the durability either by conventional boriding, or by laser treatment. However, there is no association of these two processes.

Implementation of such a process may be carried out by determining the relationship between the parameters of laser heating and the depth of the borated layer.

Goal. The objective of this work was to determine the influence of laser-exposure parameters onthe depth of the borated layer, and to reveal the characteristics of structure formation of such layers.

Materials and methods of research. The material of study was high-strength cast iron containing C = 3,47%, Si = 2,15%, Mn = 1.36%. After preliminary treatment it had a perlite-ferrite structure (85-90% perlite). The spheroidal graphite size corresponds to 3 points.

The laser treatment was conducted using the continuous CO2 laser. At constant irradiation ratethe speed of sample displacementvaried in the range of 2-4 mm/s. The thickness of the boron wash was 0.15 mm and 0.30 mm. Conditional defocus (Fcond) allowed changing the diameter of the spot of irradiation from 2 to 4 mm. A mixture of amorphous boron with acetone and zapon varnish was used as a wash.

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

Research findings and on-judgment. By etching with 4% solution of nitric acid, revealing the structure of the entire layer, it was established that the change in the structure of the metal as a result of boron doping occurs only in the reflow zone.Study of the profile of the reflow zone band edge indicates that a deeper penetration of the metal matrix occursaroundgraphite encrusting matter that stirs up waves around the border.

Fig. 1 shows the dependence of the borated layer depth on the speed of sample displacement for two cases - at wash thickness 0.15 and 0.30 mm (curve 2 and 1 respectively).

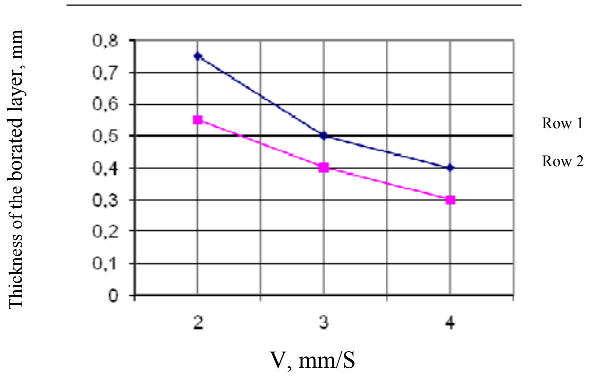

Fig. 1. Dependence of the borated layer depth on the speed of sample displacement:
1 – thickness of wash 0.3 mm;
2 – Thickness of wash 0,15 mm.

The graph shows that with the increase in the velocity of sample displacement the depth of the borated layer decreases. Such a dependence is observed both at 0.15 mm thickness of wash, and at thickness of 0.30 mm. With all the speed of sample displacement for the used boron containing wash with the specified thickness the grater thickness of the borated layer and HAZcorrespond to a greater thickness of wash.

Fig. 2 shows a histogram of the borated layer depth with wash thickness of 0.3 mm and the speed of sample displacement 2 mm/s for the spot diameter 2 and 4 mm, and Fig. 3 - the same histogram in case of sample displacement speed 4 mm/sec.

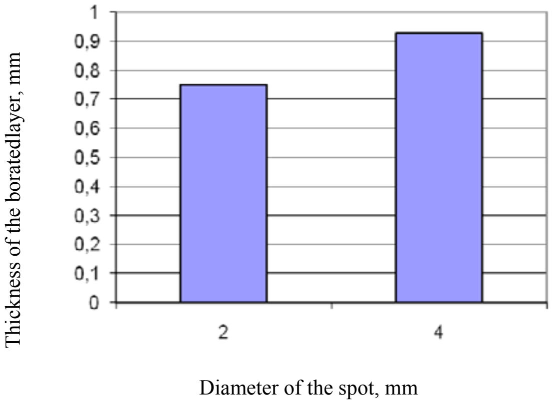

Fig. 2 Histogram of the borated layer depth with the thickness of wash 0.3 mm and the speed of sample displacement 2 mm/s for a different spot diameter size

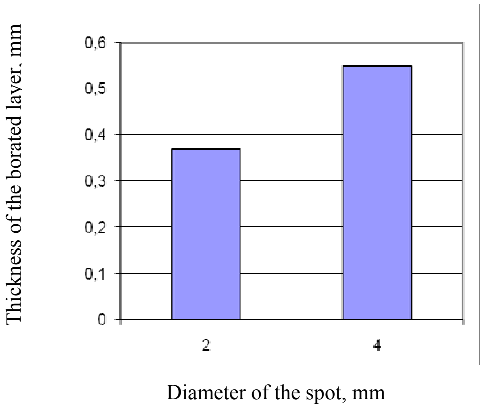

Fig. 3 Histogram of the borated layer depth with the thickness of wash 0.3 mm and the speed of sample displacement 4 mm/s for different spot diameter.

Fig. 3 Histogram of the borated layer depth with the thickness of wash 0.3 mm and the speed of sample displacement 4 mm/s for different spot diameter.

From these histograms it follows that varying of conventionaldefocusing, resulting in the change of irradiation spot diameter, leads to a considerable change of the laser doping layer depth. Thus, decrease of defocusing under otherwise equal conditions, which results in the reduction of the spot diameter, causes a decrease in the depth of laser irradiation.

It can be assumed that the obtained effect is due to a significant increase insurface temperature that caused intense evaporation of the wash layer and increase of energy input for evaporation.

X-ray analysis showed that the borated layer in ductile iron comprises such phases as FeB, Fe2B, α-phase, boric carbide of iron Fe3 (B, C).

A comparison of the microscopic and X-ray analysis with the phase diagram of Fe-B and Fe-

Fe2B-Fe3C made it possible to reveal that these phases at solidification of the melt can formdifferent structural components throughout the volume of the melted layer: a mixture of peritectic type (FeB + Fe2B), hypereutectic, eutectic and hypoeutectic structures.

The differentiation of phases in different structures was carried out bythe method of staining etching, by analysis ofthe primary crystalsform.

Excess α-phase is formed from γ-phase primary crystalsaccording tothe martensitic mechanism. Boric carbide of iron Fe3 (B, C) and boridesFeB, Fe2B differ metallografically–by the form of excessive crystals and behavior at stain etching.

The primary crystals of boric carbide of ironpresent sheet-like formations - flatdendrites, which are in sections perpendicular to the surfaceare revealed in the form of thin strips.

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

Structurally-free crystals of borides Fe2B are observed in the form of rod-postglacial crystals having a cross-sectional shape of squares, diamonds, triangles, i.e. all possible cross-sections of the tetragonal prism.

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

The eutectics in different layers and within a layer is characterized both by different dispersion, and various quantitative relations between the phases.

Comparison of the structures of layers withsimilar depths illustrates the effect of the wash thickness on the structure. For example, the three-zone layer with a predominance of eutectic and hypoeutectic structures can be a dual-zone layer with hypereutectic and eutectic zones and with domination of the first one when the wash thickness ranges from 0.3 to 0.15 mm.

With increasing the speed of irradiation under otherwise equal conditions of treatment the layer depth is reduced, i. e. the volume of molten metal bath reduces and consequently there increases the amount of boron dissolved therein. Thedata of X-ray and microscopic analyses record the changes in the layer composition. X-ray diffraction is shown in the increasing intensity of lines of boric carbide of ironwith an increasing rate of irradiation, and microstructurally it is shown in the increaseof the share of high-boron structures.

Conclusions

1. It has been established that during laser boriding with increase of the speed of sample displacement the depth of the borated layer decreases.
2. The constructed histograms of the borated layer depth indicate an increase in the latter with enlargementof the irradiation spot diameter from 2 to 4 mm.
3. X-ray and metallographicmethodsmade it possible to reveal the phases as well as the structural components of the borated layer.
4. The effect of the wash thickness on the structure is established.
5. X-ray diffraction and micro-structural analysis allowed revealing an association between the rate of irradiation and the proportion of high boron structures in the layer.
6. The results of research can be recommended for implementation in manufacture of not only piston rings, but other machine parts made of ductile iron that are subject to wear while in operation.

REFERENCES

1. Gladkyj I.P., Moschenok V.I., Tarabanova V.P., Lalazarova N.A. and Glushkova D.B. *Tehnologija konstrukcionnyh materialov i materialovedenie* [Technology of construction materials and materials science]. Har'k. nac. avtomob.-dorozh. un-t. Charkov: HNADU, 2011, 459 p.
2. Grygoryants A.G. *Osnovy lazernoj obrabotki materialov* [Fundamentals of laser materials processing]. Moskva: Mashinostroenie, 1989, 304 p.
3. Matveev Y.I. *Povyshenie dolgovechnosti detalej sudovyh dizelej s ispol'zovaniem plazmennogo napylenija i lazernoj obrabotki: dis. d-ra tehn. nauk: 05.08.04* [Rise of longevity of marine diesel parts using plasma spaying and laser treatment. Dissertation of Dr. Sc. (Tech.)]. Nizhniy Novgorod, 2003, 329 p.
4. Dzyuba Y.N., Lyubtchenko A.P., Glushkova D.B., Moschenok V.I. and Tarabanova V.P. *Uprochnenie izdelij iz vysokoprochnogo chuguna*. [Hardening of high-test cast iron prodacts]. *Remont, vosstanovlenie, modernizacija* [Repair, restoration, modernization]. 2009, no. 5, pp. 11-14.

ИСПОЛЬЗОВАННАЯ ЛИТЕРАТУРА

1. Технология конструкционных материалов и материаловедение : учеб. пособие для студ. ВУЗов, обучающихся по направлению "Инженерная механика" / И. П. Гладкий, В. И. Мощенок, В. П. Тарабанова, Н. А. Лалазарова, Д. Б. Глушкова ; Харьк. нац. автомоб.-дорож. ун-т. – Харьков : ХНАДУ, 2011. – 459 с.
2. Григорьянц А. Г. Основы лазерной обработки материалов / А. Г. Григорьянц. – Москва : Машиностроение, 1989. – 304 с.
3. Матвеев Ю. И. Повышение долговечности деталей судовых дизелей с использованием плазменного напыления и лазерной обработки : дис. ... д-ра техн. наук : 05.08.04 / Матвеев Ю. И. – Нижний Новгород, 2003. – 329 с.
4. Упрочнение изделий из высокопрочного чугуна / Ю. Н. Дзюба, А. П. Любченко, Д. Б. Глушкова, В. И. Мощенок, В. П. Тарабанова // Ремонт, восстановление, модернизация. – 2009. – № 5. – С. 11-14.

Рецензент: д-р т. н., проф. В. С. Вахрушева
Надійшла до редколегії: 07.10.2015 р. Прийнята до друку: 09.10.2015 р.