INFLUENCE OF INCREASED SLIDING SPEED ON THE STRUCTURE AND PROPERTIES OF PISTON RINGS WITH ION-PLASMA COATING

T.S. Skoblo [1], A.I. Sidashenko[1], I.E. Garkusha[2], A.V. Taran[2], R.M. Muratov[2], T.V. Maltsev[1]

[1]Kharkiv Petro Vasilenko National Technical University of Agriculture, Kharkiv, Ukraine;
[2]National Science Center "Kharkov Institute of Physics and Technology",
Institute of Plasma Physics, Kharkiv, Ukraine

E-mail: tservis@ticom.kharkov.ua

The technology of ion-plasma hardening of oil-scraper piston rings of D100 diesel engine by multilayer TiN/CrN composition is proposed. Comparative tests for friction and wear of the piston rings have been carried out and the multiple increasing in wear resistance of the rings with ion-plasma coating is shown. An estimation of the change in their microhardness before and after the tests was performed. The nature of the change in the composition of coatings: both in the initial state and during operation by local micro-X-ray spectral analysis was established. A method for estimating the effective thickness of coatings, which is protected by a patent, is proposed.

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INTRODUCTION

The results of the authors` previous studies about determining the degree and nature of wear of the serial oil-scraper piston rings of D100 diesel engine have confirmed their low wear resistance [1]. Due to the intensive wear of these rings in operation, there is an increase in smoke emissions, carbon deposits in the engine exhaust path and oil consumption. These rings by the adopted technology are made of gray cast iron without the use of hardening technologies.

To solve this problem, ion-plasma technologies for depositing solid and super-hard films and nanocoatings are of great interest [2-6]. The analyzed results of the studies show that the single-layer ion-plasma coatings providing significant increase in the level of the working surfaces properties. However, as studies show, single-layer coatings [2-6] can not provide significant increase in performance. It should also be noted that such coatings do not imply universality and require targeted using, to ensure maximum efficiency.

Therefore, it becomes necessary to consider the possibility of using a multilayer coating of dissimilar materials with different fractions to provide higher performance characteristics of piston rings, in particular tribological, which can be widely used in the machine building industry. Thus, the above coatings of TiN and CrN system demonstrate a wide range of high performance indicators: necessary wear resistance, adhesion between the coating and the substrate, low coefficient of friction, corrosion resistance, etc. [2-6]. Therefore, such coatings can be considered sufficiently universal for a wide range of applications, including for hardening the piston rings of internal combustion engines, which are subject to heavy loads and wear.

The aim of the work is to determine the degree of wear at an increased slip speed – 1.3 m/s oil-scraper piston rings of D100 diesel engine, hardened by multilayer ion-plasma coating of the TiN/CrN system, to justify recommendations on the ratio of the share of each component.

1. THE OBJECT, MATERIALS AND METHODS OF RESEARCH

A scheme of the cross-section of the ring with a working surface of 0.2 mm high is given in [1]. It is designed to remove oil from the cylinder into the crankcase of the engine, preventing it from entering the combustion chamber.

To ensure a high wear resistance of the ring, a multilayer ion-plasma coating of the TiN/CrN system was deposited by the "Bulat" type equipment. The deposition of the coating was carried out at an arc current of I = 100 A and a bias voltage of the substrate of U = -200 V. Six layers of CrN and five layers of TiN were alternately applied, previously spraying a sublayer of pure Cr with a thickness of ~ 50 nm. The thickness of a TiN layer is 49 nm, and a CrN layer is 240 nm. The ratio of CrN/TiN was 5.8. The total thickness of the multilayer coating is 1.7 μm.

By serial production technology, these products are subjected to galvanic tinning to shorten the period of their running-in. The tin coating has a non-uniform grain structure, consisting of individual fragments and ironed sections. The serial rings were tested together with the hardened TiN/CrN ion-plasma coating for a comparative evaluation of their tendency to wear.

To assess the nature and rate of wear of such rings, bench tests were carried out on a specialized machine in conditions of sliding friction during reciprocating motion. The machine was fitted with one sample of the cylinder liner and two samples selected from each variant of the piston rings. The moving part is a sample of the cylinder liners. Samples of the cylinder liners are made of gray cast iron and subjected to phosphating (serial technology).

The scheme for testing samples is presented in [1]. The constant speed of moving the mobile samples for each variant was 1.3 m/s. The value of the specific pressure on the working edge of the ring for all samples was chosen 0.8 MPa. The supply of engine oil to the friction zone was 1…2 drops per minute.

The total test time was taken at 100 hours of which the first stage (running-in) lasts 3 hours, the second stage of the main tests lasts 25 hours and the third stage of the tests lasts 72 hours. The total length of the friction path taken by the samples was 468 km. Between the test stages, the level of weight wear, the change in microhardness, and the height of the working surfaces of the rings were fixed. After the tests, the working surface of the piston ring samples was evaluated by the change of the chemical elements fraction of the ion-plasma coating by micro-X-ray spectral analysis.

2. RESULTS OF THE RESEARCH

It should be noted that for all stages of testing, the total weight wear of the cylinder liner tested in pair with the hardened rings is 6 % lower than the serial ones (Fig. 1). During the running-in period, the wear of the cylinder liner, which was paired with the hardened rings, was three times higher than the serial ones. This is due to the presence of tin coating on serial products. At the second stage of the tests, a higher wear (in 3 times) is observed in the case of the cylinder liner, which worked in pairs with the serial rings. In the third stage, the weight wear of the cylinder liner that worked with the hardened rings was 13 % higher than the serial ones.

It should be noted that the total wear rate of the cylinder liners, paired with the hardened piston rings is also 6 % lower. The high microhardness of the rings with ion-plasma coating (Fig. 2) caused processes of local gripping of the cylinder liner surface, which caused an increased wear at the initial stage.

The insignificant gain of hardened rings of 0.001 g in the 2-nd and 3-rd stages (Fig. 3) is also associated with local gripping of individual areas of the friction surface. The evaluation results show higher wear rate of the serial rings. The results of testing rings with ion-plasma coating show the wear rate decreases by 12 times.

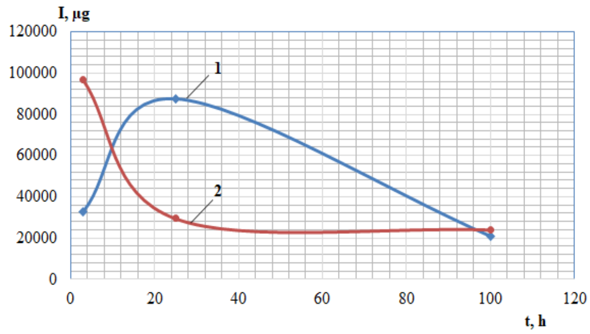

Fig. 1. Wear of cylinder liner samples worked with the TiN/CrN hardened rings (1) and with the serial ones (2)

The height of the serial rings working surfaces increased by 0.04 mm after the tests, and the height of the hardened ones increased by only 0.01 mm relative to the initial state. The observed is the result of the plastic deformation process development of the rings working surfaces, especially after the hardening. The wear rate for increasing the height of the surfaces shows that for the hardened rings it is 4 times lower.

Coating with tin ensures the stability of the indicators only during the runing-in and the difference in the degree of hardening after the second stage of testing is fixed (see Fig. 2). The initial average microhardness of the rings with TiN/CrN coating is 120 times higher than the serial ones before the tests. The microhardness of the hardened rings after the second stage of the tests on average is 3 times higher, after the third stage of the tests is twice higher relatively the serial ones at the respectively test stages. The microhardness of the rings with ion-plasma coating after the 2nd stage of testing is reduced by 3.7 times, and after the third stage is reduced by 7.8 times relative to their initial value.

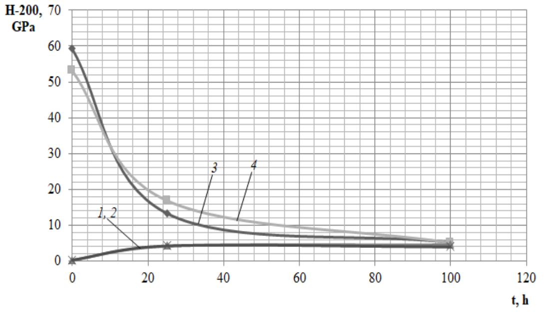

Fig. 2. Microhardness of serial ring samples (1, 2) and with ion-plasma hardening ones (3, 4)

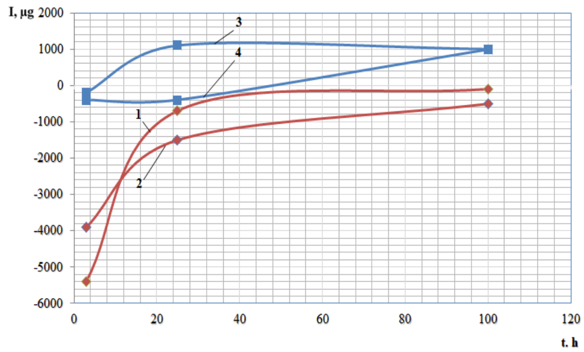

Fig. 3. Degree of wear/weight gain of the serial piston ring samples (1, 2) and with ion-plasma hardening ones (3, 4)

Tables 1 and 2 present the results of local micro-X-ray spectral analysis surfaces of serial rings and hardened with TiN/CrN coating ones respectively. Table 1 shows the initial chemical composition of the serial ring surface and after the tests (spectrum 1 and 2 respectively). Fig. 4 shows the zones for determining the chemical composition of the initial surface (spectrum 1) and the friction zone (spectrum 2) of the serial ring and Fig. 5 presents the similar zones chemical composition determining of the hardened one.

It should be noted that tin on the serial ring samples, due to their complete wear was not detected.

At the same time, the plastic deformation is revealed, which breaks the integrity of the coating with tin of the inclined plane (the initial surface), which is adjacent to the friction surface (see Fig. 4). This is due to the Saint-Venant principle [7], accompanied by the localization of the stress-strain state of the nearby material zone (the contact zone of the inclined surface of the ring to the working one). The change of the macrorelief in the contact zone of the inclined plane to the working surface corresponds to a value close to the height of the working one (~ 0.45…0.5 mm).

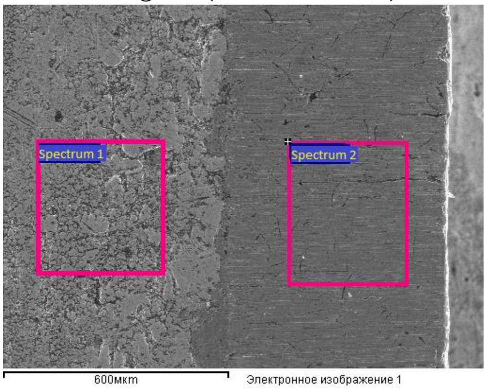

Fig. 4. Zones for determining the chemical composition of the initial surface (spectrum 1) and the friction zone (spectrum 2) of the serial ring

Table 1

Chemical composition of the initial (spectrum 1) surface and friction zone (spectrum 2) of the serial piston ring

Zone	C	O	Al	Si	Mn	Fe	Sn
Spectrum 1	1.09	–	0.29	0.29	–	1.14	97.21
Spectrum 2	2.69	–	0.23	1.86	1.25	94.20	–

The friction surface is characterized by the formation of longitudinal bands on the working surfaces of both variants of the rings. There is also the formation of a graphite mesh in the working surfaces of the serial rings, which are also represented in the form of separate, chaotically located and oriented oblong inclusions of black color (see Fig. 4), which corresponds to the original metal.

The results of the initial surface analysis of tested samples of oil-scraper piston rings with multilayer TiN/CrN ion-plasma coating demonstrate that the initial ratio of the Cr/Ti coating component fraction was 5.77. The fraction of the components in the coating after the tests was 3 % in total, and the fraction of the base metal (C, O, Si, Mn, Fe) increased up to 95.67 %, which indicates about significant wear of the deposited coating at this sliding speed. At the same time, the Cr/Ti ratio decreased to 2.75, where the Cr fraction decreased 38 times, and the Ti ratio decreased 18 times. According to the previously proposed calculation method [8], the residual thickness of the TiN/CrN coating after the tests is 50 nm. The appearance of P (0.59 %) is associated with its partial transfer from the surface of the phosphated cylinder liner during testing, and the appearance of Al (0.55 %) and Ca (0.2 %) is possible due to friction under lubrication conditions, which contribute to the weight gain of the hardened rings on 2-nd and 3-rd stages of tests.

Simultaneously, the fact of pronounced structuring of the tin coating in the initial area with a length of ~ 0.45…0.5 mm was revealed (see Fig. 4). This also indicates about the degradation of the base metal and its low resistance to cyclic action. Moreover, similar structuring of the inclined surface for rings with the ion-plasma coating is not observed (see Fig. 5), which is explained by the high degree of the coating resistance to the development and deformations propagation.

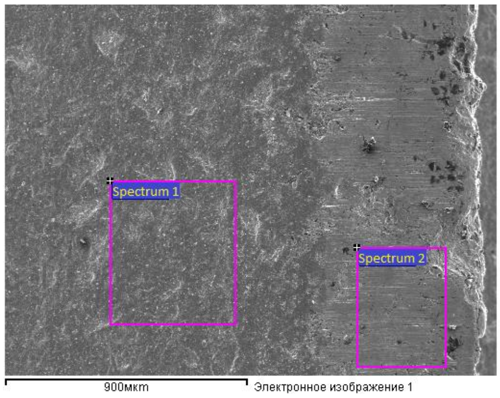

Fig. 5. Zones of local chemical analysis of the sample surface of a TiN/CrN coated ring after testing

Table 2

Chemical composition of the friction surface the TiN/CrN coated ring

Zone	C	O	Al	Si	P	Ca	Ti	Cr	Mn	Fe
Spectrum 1	0.8	0.13	–	0.16	–	–	14.5	83.77	–	0.63
Spectrum 2	3.59	–	0.55	1.77	0.59	0.20	0.80	2.20	1.28	89.03

CONCLUSIONS

The technology of hardening of piston rings by multi-layer ion-plasma coating TiN/CrN is proposed. The deposition of the coating was carried out at an arc current of I = 100 A and a bias voltage of the substrate of U = -200 V. Six layers of CrN and five layers of TiN were alternately applied, previously spraying a sublayer of pure Cr with a thickness of ~ 50 nm. The thickness of a TiN layer is 49 nm, and a CrN layer is 240 nm. The ratio of CrN/TiN was 5.8. The total thickness of the multilayer coating is 1.7 μm.

It is established that wear takes place both by weight and by increasing the height of the working surface. The results of the oil-scraper piston rings tests with multilayer ion-plasma coating revealed that the weight wear rate as a result of hardening is reduced by 12 times. The height of the working surface in such rings remains more stable to the original size. This changed the fraction of constituent phases: coating – up to 3 %, and the base metal – up to 95.67 %. In this case, the fraction of Cr after the tests decreased by 38 times, and the proportion of Ti – in 18. Therefore, in order to increase the wear resistance of such coatings, it is recommended to increase the fraction of the TiN solid phase by introducing additional or increasing its individual layers.

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ВЛИЯНИЕ ПОВЫШЕННОЙ СКОРОСТИ СКОЛЬЖЕНИЯ НА СТРУКТУРУ И СВОЙСТВА ПОРШНЕВЫХ КОЛЕЦ С ИОННО-ПЛАЗМЕННЫМ ПОКРЫТИЕМ

Т.С. Скобло , А.И. Сидашенко, И.Е. Гаркуша, А.В. Таран, Р.М. Муратов, Т.В. Мальцев

Предложена технология ионно-плазменного упрочнения маслосъемных поршневых колец дизель-генератора Д100 многослойной композицией TiN/CrN. Проведены сопоставительные испытания на трение и износ и показано многократное повышение износостойкости поршневых колец с ионно-плазменным покрытием по сравнению с серийными. Выполнена оценка изменения их микротвердости до- и после испытаний. Микрорентгеноспектральным анализом установлен характер изменения состава покрытий как в исходном состоянии, так и в процессе эксплуатации. Предложен метод оценки эффективной толщины покрытий, который защищён патентом.

ВПЛИВ ПІДВИЩЕНОЇ ШВИДКОСТІ КОВЗАННЯ НА СТРУКТУРУ ТА ВЛАСТИВОСТІ ПОРШНЕВИХ КІЛЕЦЬ З ІОННО-ПЛАЗМОВИМ ПОКРИТТЯМ

Т.С. Скобло, О.І. Сидашенко, І.Є. Гаркуша, А.В. Таран, Р.М. Муратов, Т.В. Мальцев

Запропоновано технологію іонно-плазмового зміцнення маслоз'ємних поршневих кілець дизель-генератора Д100 багатошаровою композицією TiN/CrN. Проведено порівняльні випробування на тертя і знос і показано багаторазове підвищення зносостійкості поршневих кілець з іонно-плазмовим покриттям у порівнянні з серійними. Виконано оцінку зміни їх мікротвердості до- і після випробувань. Мікрорентгеноспектральним аналізом встановлено характер зміни складу покриттів: як в початковому стані, так і в процесі експлуатації. Запропоновано метод оцінки ефективної товщини покриттів, який захищений патентом.