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COMBINED TECHNOLOGY OF STRENGTHENING THE SURFACE LAYER OF PISTON RINGS FROM STEEL 18X2H4MA

КОМБІНОВАНА ТЕХНОЛОГІЯ ЗМІЦНЕННЯ ПОВЕРХНЕВОГО ШАРУ ПОРШНЕВИХ КІЛЕЦЬ ІЗ СТАЛІ 18Х2Н4МА

In the production of engine parts, namely the cylinder-piston group, in order to improve the wear resistance and operational reliability of piston rings, there is a need to replace the material. The search for the most attractive options is to use alloyed steels of grades 18X2H4MA, 38X2H4MA, 50XФA instead of 15X2H2TPA, 20X2H4A. During chemical-thermal treatment of the surface layer of parts, the materials acquire increased properties in terms of wear resistance and corrosion resistance. The most attractive strengthening technologies include combined methods of surface layer treatment — nitriding, boriding with subsequent laser surface treatment. Nitriding allows to obtain a dense nitrided layer up to 160 microns thick on steels 18X2N4MA, 38X2N4MA, 50XFA. Laser treatment of the nitrided surface leads to the formation of complex solid phases with combined microstructures and special properties of the surface layer. Significant hardness, wear resistance is due to the presence in the surface layer of complex carbides, iron nitrides and individual components of alloy elements that are part of the chemical composition of steels [1].

***Keywords**: piston ring, nitriding, tribo system, cylinder-piston group, wear, friction surface, laser treatment.*

При виробництві деталей двигуна, а саме циліндро-поршневої групи з метою покращення зносостійкості та експлуатаційній надійності поршневих кілець виникає потреба заміни матеріалу. Пошук найбільш привабливих варіантів є використання легованих сталей марок 18Х2Н4МА, 38Х2Н4МА, 50ХФА на зміну 15Х2ГН2ТРА, 20Х2Н4А. При хіміко-термічній обробці поверхневого шару деталей матеріали набувають підвищені властивості з зносостійкості, корозійної стійкості. До найбільш привабливих технологій зміцнення можна віднести комбіновані способи обробки поверхневого шару — азотування, борування з наступною лазерною обробкою поверхні.

Азотування дозволяє на сталях 18Х2Н4МА, 38Х2Н4МА, 50ХФА отримати щільний азотований шар товщиною до 160 мкм. Лазерна обробка азотованої поверхні приводить до утворення складних твердих фаз з комбінованими мікроструктурами і особливими властивостями поверхневого шару. Значна твердість, зносостійкість обумовлена наявністю в поверхневому шарі складних карбідів, нітридів заліза та окремих компонентів легованих елементів, що входять до хімічного складу сталей [1]. Основною проблемою при обробці поверхневого шару поршневого кільця є ризик викривлення деталі в наслідок термічного впливу. Нагрів при азотуванні та лазерній обробці локальних зон призводить до викривлення кристалічної решітки металу. Тому термічну і лазерну обробку тонкостінної деталі проводять у спеціально фіксуючому пристрої, який жорстко фіксує деталь на кожній стадії термічної обробки та лазерного впливу.

***Ключеві слова**: поршневе кільце, азотування, трибо система, циліндро-поршнева група, знос, поверхня тертя, лазерна обробка.*

Problem’s Formulation

The main problem when choosing a technology for strengthening a specific part is the choice of materials and coatings of tribo-bonded pairs, which determine the nature and nature of the formation of wear-resistant structures. To solve the tasks, a comprehensive approach is required, taking into account the influence of all significant factors. These factors should take into account both the technological components for the flow of proven strengthening technologies, and the predicted results of structure formation and the selection of optimal materials for the part and coatings.

Analysis of recent research and publications

In modern automotive industry, a huge amount of experience has been accumulated in the use of modern materials and coatings, which is the result of the introduction of the latest technologies into the technological chains of production. Recently, the use of combined technologies has been observed to strengthen the surface layer of parts operated in extremely harsh conditions [1—3]. For a number of reasons (technological, safety, economic, strength), in automotive production, the replacement of the material of most component parts is observed. Replacing the material of the part also prompts the corresponding technology for strengthening the surface layer. Using the example of replacing 50ХХФА steel with 18X2N4MA steel, from which piston rings of internal combustion engines were made, it is possible to determine certain differences and similarities of some components, namely: — both are highly alloyed, well suited to nitriding, cementation, boriding, and laser processing technologies under certain conditions. The differences include chemical composition, physical and strength characteristics.

The main characteristics of steel 18X2N4MA are given in tabl. 1, 2, 3, 4, 5, 6, 7.

Table 1. Material characteristics 18X2N4MA

Brand	18Х2Н4МА
Substitute	15Х2ГН2ТРА, 20Х2Н4А
Classification	Alloyed structural steel
Addition	Chromium-nickel-molybdenum steel
Using	In the case of cemented and improved condition, it is used for important parts that require high strength, toughness and wear resistance, as well as for parts that are exposed to high vibration and dynamic loads. The steel can be used at temperatures from –70 to +450 °C.

Table 2. Chemical composition in % of material 18X2N4MA

C	Si	Mn	Ni	S	P	Cr	Mo	Ti	Cu
0.14 - 0.2	0.17 - 0.37	0.25 - 0.55	4 - 4.4	до 0.025	до 0.025	1.35 - 1.65	0.3 - 0.4	до 0.06	до 0.3

Table 3. The temperature of the critical points of the material 18X2N4MA

Ac_1 = 700 , $Ac_3(Ac_m)$ = 810 , $Ar_3(Arc_m)$ = 400 , Ar_1 = 350 , Mn = 336

Table 4. Technological properties of the material 18X2N4MA

Weldability:	difficult to weld
Flocking sensitivity	sensitive.
Contribution to temper brittleness	does not contribute.

Table 5. Mechanical properties at *T*=20ºC of the material 18X2N4MA

Assortment	Size	$\sigma_в$	$\sigma_Т$	δ_5	ψ	KCU	Thermoforming
-	мм	МПа	МПа	%	%	кDj / м^2	-
Rod	Ø 15	1130	835	12	50	980	Hardening and tempering
Hardness of 18X2N4MA after annealing						HB 10^{-1} = 269 MPa	

Table 6. Physical properties of the material

T	E 10^{-5}	α 10^{6}	λ	ρ	C	R 10^{9}
Degree	MPa	1/Град	V/(m·deg)	кg/м^3	Dj/(кg·deg)	Om·m
20	2			7950		
100	1.65	11.7	36	7930		
200	1.41	12.2	36	7900		
300		12.7	35	7860		
400	1.39	13.1	35	7830		
500		13.5	34	7800		
600		13.9	33	7760		
700			32			
800			30			

Table 7. Foreign analogues of the material 18X2H4MA

Germany	Japan	England	Spain	Bulgaria	Poland	Czech Republic	Austria
DIN,WNr	JIS	BS	UNE	BDS	PN	CSN	ONORM
1.6657 14NiCrMo134 GX19NiCrMo4 X19NiCrMo4	SNCM815	832M13835M15	4NiCrMo131	18Ch2N4MA	18H2N4WA	16720	BOHLERM 130

Formulation of the study purpose

The wear rate of the ring material according to Goryacheva I.G. is proportional to the pressure and is determined by the formula

$$I_t = Kq, \tag{1}$$

where q — the pressure; K — is the wear rate coefficient.

The pressure at a given time is given as a series of ascents. Then the expression for the contact pressure distribution has the form

$$q'(\theta,t') = \sum_{n=1}^{\theta} B_n U_n(\theta) exp(-\lambda_n^2 t'); \tag{2}$$

$$B_1 = \frac{2\cos L_1^+ n \sin L_1^- n}{L_1^- \cos L_1^- n} + \frac{\frac{2\sin L_1^+ n}{L_1^+}}{\frac{\pi cos^2 L_1^+}{cos^2 L_1^- n}} + \frac{(3\lambda_1 -) cos^2 L_1^- \pi \sin L_1^- \pi}{\lambda_1 L_1^- cos L_1^- n} + \frac{(3\lambda_1)\sin 2L_1^+\pi}{2\lambda_1 L_1^+}, \tag{3}$$

де

$$B_n = \left(\frac{2sh\Lambda_n^- \cos\Lambda_n^+ n}{\Lambda_n^- ch\Lambda_n^- \pi}\right) + \frac{2sin\Lambda_n^+ n}{\Lambda_n^+} / \left[\frac{\pi cos^2 \Lambda_n^+ n}{ch\Lambda_n^- n} + \frac{(3\lambda_n - 2) cos^2 \Lambda_n^- n}{\lambda_n \Lambda_n^- ch\Lambda_n^- n} + \frac{(3\lambda_n + 2) sin 2\Lambda_n^+ n}{2\lambda_n \Lambda_n^+} + \pi\right]; \tag{5}$$

$$L_1^+ = \sqrt{1 \pm \lambda_1}; \Lambda_n^+ = \sqrt{\lambda_n \pm 1}; \tag{6}$$

$$U_1(\theta) = cos L_1^+ \theta + \frac{cos L_1^+ \pi cos L_1^- \theta}{cos L_1^- \pi}; \tag{7}$$

$$U_n(\theta) = cos\Lambda L_1^+ \theta + \frac{cos\Lambda_1^+ \pi ch\Lambda_1^- \theta}{ch\Lambda_1^+ \pi}; \tag{8}$$

$$t' = \frac{K'EJt}{r^4}; q'(\theta, t') = \frac{q(\theta,t)r^3}{EJ}, \tag{9}$$

Де θ — angular coordinate (for piston ring lock $\theta = \pm\pi$); E—modulus of elasticity of the ring; t — current time; r — radius of curvature of the ring; q — pressure.

Presenting main material

18X2H4MAhigh-quality nitrided steel, heat-resistant, relaxation-resistant. This is a reliable and load-resistant material, which contains up to 2 % chromium, and the content of molybdenum and aluminum in it is no more than 1 %. Such steel is resistant to wear and fatigue, it is easy to cut (while the surface is without defects), when hardened it is practically not deformed. The heat resistance of this steel is up to 450 degrees.

In the cemented and improved condition it is used for critical parts that require high strength, toughness and wear resistance, as well as for parts subject to high vibration and dynamic loads. The steel can be used at temperatures from –70 to +450 °C.

In the cemented and improved condition it is used for critical parts that require high strength, toughness and wear resistance, as well as for parts subject to high vibration and dynamic loads. The steel can be used at temperatures from –70 to +450 °C. A combined technology for strengthening the surface layer of piston rings was first tested on 50XFA steel. The technological process of strengthening consists of two consecutive stages: nitriding in well furnaces at a temperature of 650°C in an environment of nitrogen-containing substances with a holding time of 96 hours and subsequent pulsed laser processing on the GOOS1001 device[3—7]. Samples in the form of washers with a diameter of 30 mm and a thickness of 5 mm were prepared for testing.

The prepared samples were placed in open containers in the chamber of the nitriding furnace at a temperature of 650°C. Then, nitrogen-containing gas was supplied under pressure for 96 hours.

The next stage of combined processing is pulsed laser radiation on the GOOS1001 device at the following modes (accumulation energy 15 kJ, distance to the target — 290 mm, laser spot diameter 11 mm, interval between shots 3 minutes). Fig. 1, 2 show a scheme for preparing samples of 18X2N4MA steel for tribological tests.

To fully perceive the dynamics of the hardening processes using the combined technology, half of the sample was subjected to laser processing with overlapping zones of influence without melting the surface layer. The geometric parameters of the samples with the combined hardening technology did not change.

At the same time, as a result of laser processing, the surface roughness parameters changed — the microrelief after melting changed. The tops of microroughness after melting with a laser beam were smoothed.

As a result of technological operations of strengthening by combined technology, the surface layer of the part made of 18X2N4MA steel acquired certain changes in the microstructure from the surface to the center of the matrix material.

The multicomponent content of alloying elements provoked the formation of complex forms of carbonitrides and nitrides in the predominantly martensitic matrix of the surface, which has high indicators of strength, hardness ($H\mu_{50}$=11000 MPa) and wear resistance.

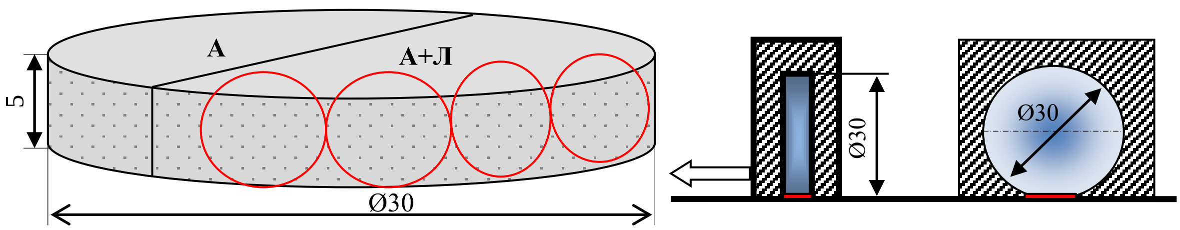
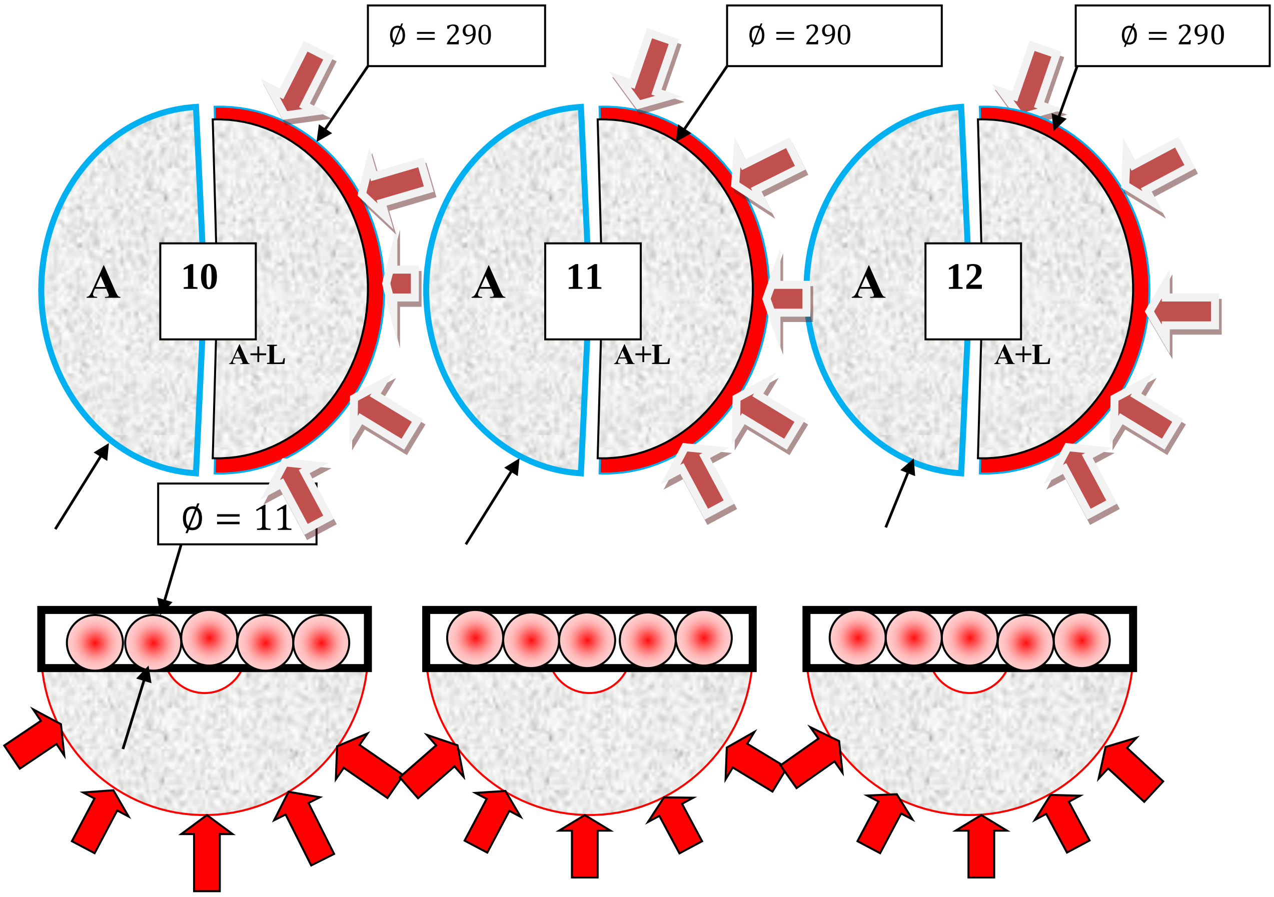


Fig. 1. Scheme of preparation of samples of 18X2H4MA steel for tribological tests



$Fig.2.$ Scheme of preparation of samples of 18Kh2N4MA steel for laser processing $L\emptyset = 11mm$E=15 KDj; L_{Φ}=290 mm

Conclusions

A technology for combined processing of high-alloy steel 18X2N4MA has been developed based on medium-temperature nitriding in an annotation furnace at a temperature of 650°C with a holding time of 96 hours and subsequent laser processing on a GOOS1001 laser device with an accumulation energy of 15 kJ, a distance to the target of 290 mm, a laser spot diameter of 11 mm and an interval between shots of 3 minutes.

References

[1] Cherneta, O. G. (2024). Strengthening of automobile transport parts by combined laser processing: monograph. Kamianske. DDTU. [in Ukrainian].
[2] Sereda, B.P. & Cherneta, O.G, & Kubich,V.I. & Ocheretyanuy, M. & Scorohod M. (2023). Mathematical modeling of car parts loading processes and choice of optimal materials, coatings and methods of their strengthening. Математичне моделювання: Науковий журнал. Кам'янське: ДДТУ. No 1(48) [in Ukrainian].
[3] Cherneta, O.G. & Kubich, V.I. & Voloshchuk, R.V. & Sasov, O.O., Korzhavin, Yu.A. (2018) Conditions for the Formation of Wear-Resistant Structures When Strengthening the Surface Layers of Parts. International Journal of Engineering & Technology, (UAE), 7 [in Ukrainian].
[4] Kubich, V.I. & Cherneta, O.G. & Yurov, V.M. (2021) INFLUENCE OF BORINATION, BORON CEMENTATION OF STEEL 45 AND VISCOSITY OF A LUBRICANT ON THE PARAME-

TERS OF ADHESION BOND IN THE STEEL 45-40X SYSTEM". O.G. Cherneta, // EURASIAN PHYSICAL TECHNICAL JOURNAL, , Vol.18, 2(36)
[5] Popov, S. V. & Buchynskyi, M. Ya. &, Hnytko, S. M. & Chernyavskyi A. M. (2019) Theorya mechanismov technologichnih machin: a textbook for students of mechanical specialties of higher education in stitutions. Kharkiv: NTMT.[in Ukrainian].
[6] Cherneta, O. & Kubich, V. & Voloshchuk, R. & Averyanov, &V. Shmatko, D. (2018) Strengthening of the Restored Surface Layers of Steel Parts 45 by Laser Boring. International Journal of Engineering & Technology, (UAE), 7 (4.3)

Список використаної літератури

1. Cherneta O. G. Strengthening of automobile transport parts by combined laser processing: monograph.Kamianske: DDTU, 2024. 147 p. ISBN 978-966-175-252-7
2. Borys Sereda. Mathematical modeling of car parts loading processes and choice of optimal materials, coatings and methods of their strengthening Sereda B., Cherneta O., Kubich V., Ocheretyanuy M., Scorohod M. Математичне моделювання: Науковий журнал. Кам'янське: ДДТУ, 2023. No 1(48). С. 62–68.
3. Cherneta O., Kubich V., Voloshchuk R., Sasov A., Korzhavin Yu. Conditions for the Formation of Wear-Resistant Structures When Strengthening the Surface Layers of Parts. International Journal of Engineering & Technology, (UAE), 7 (4.3) (2018) P. 76–80
4. Kubich V.I. INFLUENCE OF BORINATION, BORON CEMENTATION OF STEEL 45 AND VISCOSITY OF A LUBRICANT ON THE PARAMETERS OF ADHESION BOND IN THE STEEL 45-40X SYSTEM". V.I.Kubich, O.G. Cherneta, V.M. Yurov // EURASIAN PHYSICAL TECHNICAL JOURNAL,2021, Vol.18, 2(36) Pp. 67–76
5. Popov S. V., Buchynskyi M. Ya., Hnytko S. M., Chernyavskyi A. M. Theory of mechanisms of technological machines: aextbook for students of mechanical specialties of higher education institutions. Kharkiv: NTMT, 2019. 268 p.
6. Cherneta O., Kubich V., Voloshchuk R., Averyanov V., Shmatko D. Strengthening of the Restored Surface Layers of Steel Parts 45 by Laser Boring. International Journal of Engineering & Technology, (UAE), 7 (4.3) (2018) P. 71-75. DOI1O.14419/ijet.v7*14.3.19554* http://orcid.org/0000-0002-3871-6923.https://www.scopus.com/record/display.uri?eid=2-s2.0-85053319425&origin=resultslist

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