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Kruglyak Iryna[1], doctor of technical sciences, professor, Department of industrial engineering
Кругляк І.В., доктор технічних наук, професор, кафедра галузевого машинобудування
ORCID: 0000-0001-8872-6778
e-mail: seredabp@ukr.net

Cherneta Oleg[1], candidate of technical sciences, associate professor, department of automobiles and transport and logistics systems
Чернета О.Г., кандидат технічних наук, доцент, кафедра автомобілів та транспортно-логістичних систем
ORCID: 0000-0002-3871-6923
e-mail: OCherneta@gmail.com

Suhomlin Volodymyr[1], candidate of physical and mathematical sciences, associate professor, department of condensed matter physics
Сухомлин В.І., кандидат фізико-математичних наук, доцент, кафедра фізики конденсованого стану
ORCID: 0000-0002-3673-1353
e-mail: v_suhomlyn@ukr.net

Kubich Vadym[2], candidate of technical sciences, associate professor, Department of Automobiles, Heat Engines and Hybrid Power Plants
Кубіч В.І., кандидат технічних наук, доцент, кафедра автомобілів, теплових двигунів та гібрідних енергетичних установок
ORCID: 0000-0001-6230-9263
e-mail: schmirung@gmai.com

Yeriomina Kateryna[1], candidate of technical sciences, associate professor, department of condensed matter physics
Єрьоміна Е.А., кандидат технічних наук, доцент, кафедра фізики конденсованого стану (ФКС)
ORCID: 0000-0001-8595-5735
e-mail: eka.yeriomina@gmail.com

Bondyuk Denys[1], PhD student
Бондюк Д.М., здобувач третього (доктор філософії) рівня вищої освіти
e-mail: dbondyuk@gmai.com

Somich Andriy[1], PhD student
Сьоміч А.В., здобувач третього (доктор філософії) рівня вищої освіти
ORCID: 0009-0007-0857-8498
e-mail: Trade@azot.com.ua

[1]Dniprovsky StateTechnical University, Kamianske
Дніпровський державний технічний університет, м. Кам’янске
[2]National University “Zaporizhzhya polytechnic”, Zaporizhia
Національний університет “Запорізька політехніка”, м. Запоріжжя

STUDY OF THE MICROSTRUCTURE OF NITRIDATED STEEL 18X2N4MA AFTER LASER PROCESSING WITH MODELING OF WEAR PROCESSES

ДОСЛІДЖЕННЯ МІКРОСТРУКТУРИ АЗОТОВАНОЇ СТАЛІ 18Х2Н4МА ПІСЛЯ ЛАЗЕРНОЇ ОБРОБКИ З МОДЕЛЮВАННЯМ ПРОЦЕСІВ ЗНОСУ

Modern technologies for strengthening the surface layer of machine-building parts use the latest processing methods based on advanced research into the transformation of the microstructure of surface layers under the influence of external actions. The main factors that significantly affect the structure formation and physical and mechanical, strength, wear-resistant characteristics are the chemical composition of the material, temperature, speed, heating and cooling time. The gas environment during heat treatment is also of great importance. The combination of these factors and requirements requires appropriate technological solutions when choosing strengthening technologies together with economic calculation and the feasibility of choosing a technological method of influencing the surface of the part. In contrast to the use of expensive high-alloy materials with high indicators of strength, heat resistance, wear resistance, there are alternative options for using relatively inexpensive, most common and affordable analogues with appropriate processing.

The advantages of such a combination in combined processing are the possibility of using significant operational elements of several technological processes of hardening. Thus, preliminary nitriding of the surface layer allows to saturate the surface of 18X2N4MA steel with nitrogen, and laser processing to form the corresponding microstructure. Usually, after laser processing, a microstructure of acicular martensite with inclusions of Fe_2N, Fe_3N *nitrides is formed on the nitrided surface with accumulation. The appearance of* Fe_3N *type nitrides is the result of hardening by the secondary action of the laser beam. Nitriding of a part made of 18X2N4MA steel increases the hardness of the surface layer in comparison with the matrix center by 2 times, and laser processing up to* $H_{\mu50}$*=10000MPa.*

***Keywords**: friction surface, strengthening technologies, restoration technologies, mechanical characteristics, surface layer.*

Сучасні технології зміцнення поверхневого шару деталей машинобудівного виробництва використовують найновітніші методи обробки, що засновані на передових дослідженнях трансформації мікроструктури поверхневих шарів під впливом зовнішніх дій. Основні чинники, що суттєво впливають на структуроутворення та фізико-механічні, міцні, зносостійкі характеристики, це хімічний склад матеріалу, температура, швидкість, час нагріву та охолодження. Також визначне значення мають газове середовище при термічній обробці.

Поєднання цих факторів та вимог потребує відповідних технологічних рішень при виборі технологій зміцнення разом з економічним розрахунком і доцільністю вибору технологічного способу впливу на поверхню деталі. У відмінності з використанням дорогих високолегованих матеріалів з високими показниками міцності, термостійкості, зносостійкості є альтернативні варіанти застосування відносно недорогих, найбільш поширених та доступних аналогів з відповідною обробкою. Одним із поширених технологічних способів зміцнення є формування і модифікування мікроструктури поверхневого шару.

Це може бути як хіміко-термічна, іонна-плазмова обробка, гарт СВЧ, лазерний гарт, лазерне легування поверхневого шару та інш. або комбінована обробка,що поєднує окремі елементи технологічних операцій. Так попереднє азотування деталі із сталі 12Х2Н4МА забезпечує насичення азотом поверхневий шар, а наступна лазерна обробка формує відповідну мікроструктуру з заданими фізико-механічними та міцними характеристиками.

Звичайно після лазерної обробки на азотованій поверхні із скупченням утворюється мікроструктура голчастого мартенситу з вкрапленнями нітридів Fe_2N, Fe_3N*.*

Поява нітридів типу Fe_3N *є результатом гарту вторинної дії лазерного променя. Азотування деталі із сталі 18Х2Н4МА збільшує твердість поверхневого шару в порівнянні матричним центром у 2 рази, а лазерна обробка до* $H_{\mu50}$*=10000МПа.*

***Ключові слова**: технології відновлення, фізико-механічні характеристики, поверхневий шар, технології зміцнення, поверхня тертя.*

Problem's Formulation

Modern technologies for strengthening the surface layer of machine-building parts use the latest processing methods based on advanced research into the transformation of the microstructure of surface layers under the influence of external influences. The main factors that significantly affect the structure formation and physical and mechanical, strength, wear-resistant characteristics are the chemical composition of the material, temperature, speed, heating and cooling time. The gas environment during heat treatment is also of great importance. In contrast to the use of expensive high-alloy materials with high strength, heat resistance, wear resistance, there are alternative options for using relatively inexpensive, most common and affordable analogues with appropriate processing. One of the common technological methods of strengthening is the formation and modification of the microstructure of the surface layer.

Analysis of recent research and publications

This can be either chemical-thermal, ion-plasma treatment, microwave hardening, laser hardening, laser alloying of the surface layer, etc. or combined treatment, combining individual elements of technological operations. Thus, preliminary nitriding of a part made of 12X2N4MA steel ensures saturation of the surface layer with nitrogen, and subsequent laser treatment forms an appropriate microstructure with specified physical, mechanical and strength characteristics.

Usually, after laser treatment, a microstructure of acicular martensite with inclusions of Fe_2N, Fe_3N nitrides is formed on the nitrided surface with accumulation. The appearance of Fe_3N type nitrides is the result of hardening by the secondary action of the laser beam. Nitriding of a part made of 18XN4MA steel increases the hardness of the surface layer in comparison with the matrix center by 2 times, and laser treatment up to $H\mu_{50}$=10000MPa.

Tabl. 1—6 provide the main characteristics of 8X2N4MA steel and similar foreign steels that are close in chemical composition and physical and mechanical properties.

Table 1. Chemical composition in % of 18X2N4MA steel material (GOST 4543 – 71)

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	0.025	0.025	1.35 - 1.65	0.3 - 0.4	0.06	0.3

Table 2. The temperature of the critical points of 18X2N4MA steel

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

Table 3. Technological properties of 18X2N4MA steel

Weldability	hard-to-weld
Difficult to weld Flake susceptibility	sensitive
Sensitive Not prone to temper brittleness	not inclined.

Table 4. Mechanical properties at T=20ºC of 18X2N4MA steel

Assortment	Size	$\square_{в}$	$\square_{T}$	$\square_{5}$	$\square$	KCU	Heat treatment.
-	mm	MPa	MPa	%	%	kJ/m^2	-
Wire	Ø 29	1130	835	12	50	980	Hardening and tem-
Hardness 18X2H4MA after annealing, GOST 4543-71						HB 10^{-1} = 269 МПа	

Table 5. Physical properties of 18X2N4MA steel

T	E 10- 5	$\square$ 10^{6}	$\square$	$\square$	C	R 10^{9}
Degree	MPa	1/ Degree	W/(m•degrees)	kg/m^3	J/(kg•degree	Om•m
20	2			7950		
100	1.65	11.7	36	7930		

Continue of the table 5

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 6. Foreign analogues of steel 18X2N4MA

Germany	Japan	England	Spain	Bulgaria	Poland	Czech Repub-lic	Austria
DIN,WNr	JIS	BS	UNE	BDS	PN	CSN	ONORM
1.6657 14NiCrMo134 GX19NiCrMo4 X19NiCrMo4	SNCM815	832M13 835M15	14NiCrMo131	18Ch2N4MA	18H2N4WA	16720	BOHLERM130

Formulation of the study purpose

The main goal of the research is to study and select optimal technological methods for strengthening the surface layer using combined technologies that allow the formation of wear-resistant structures with increased strength characteristics of the surface layers.

Presenting main material

Using a Scanning electron microscope (REM 106 fig. 1), the microstructures of the surface layer of nitrided steel 18X2N4MA with subsequent pulsed laser treatment were investigated [1—3]. In the photographs of Fig. 2, 3, three zones are clearly distinguished, which record the dynamics of structure

Fig. 1. Scanning electron microscope (REM 106I)

formation in different layers of the surface. The surface layer itself (zone 3) is characterized by a dense structure, which is a consequence of nitriding with subsequent hardening and laser exposure. Accumulations of Fe_2N nitrides after hardening due to laser treatment are partially transformed into Fe_3N nitrides on a martensitic structure [3—6].

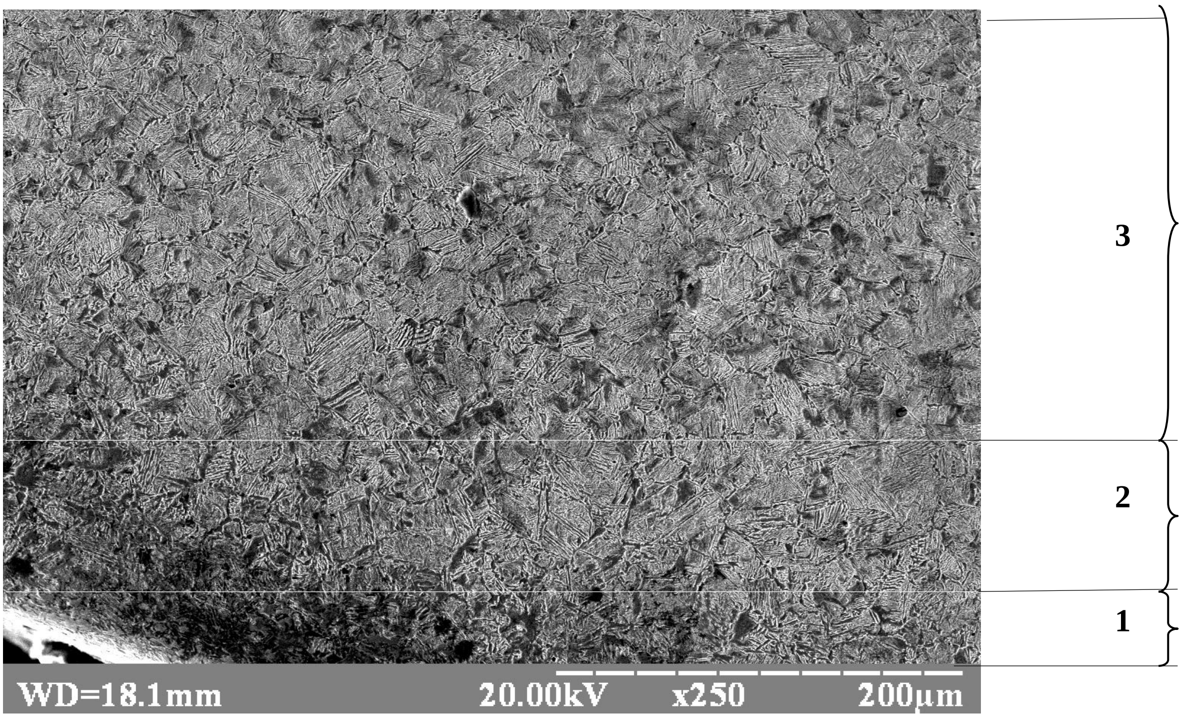


Fig. 2. A multilayer complex microstructure of сталі 18Х2Н4МА steel (x1000)

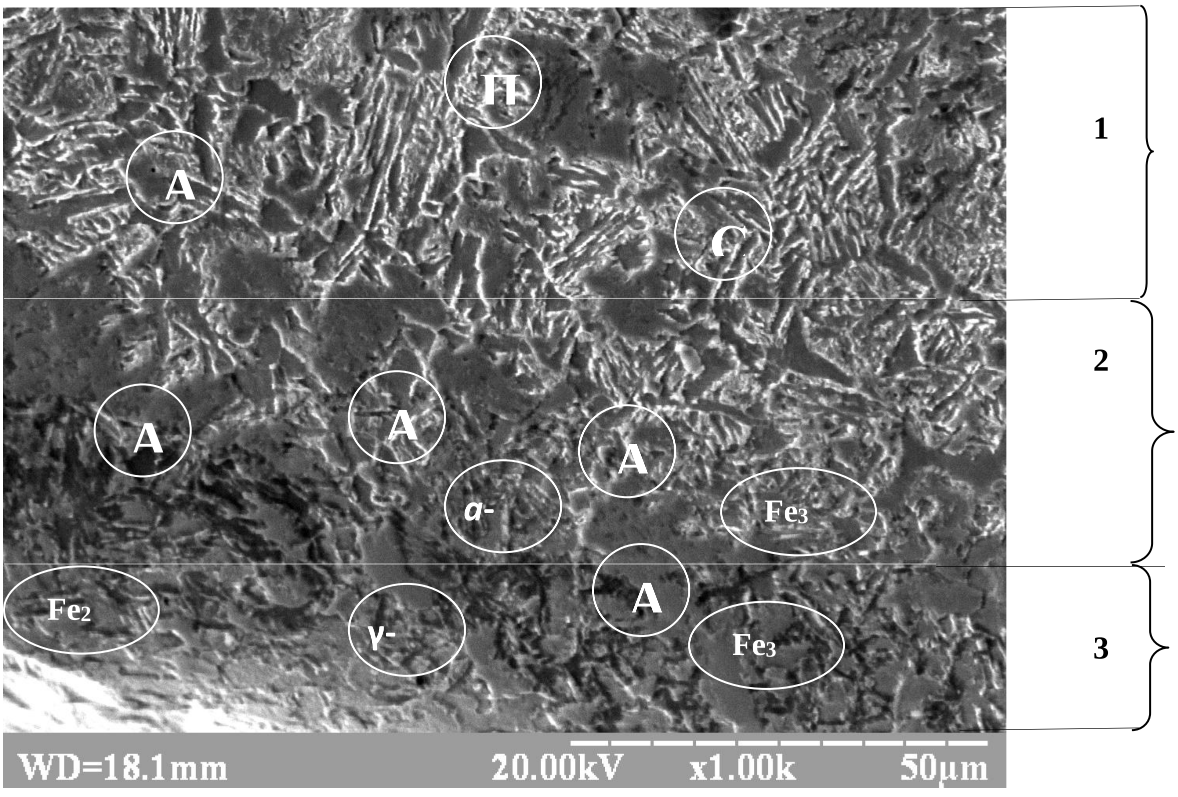
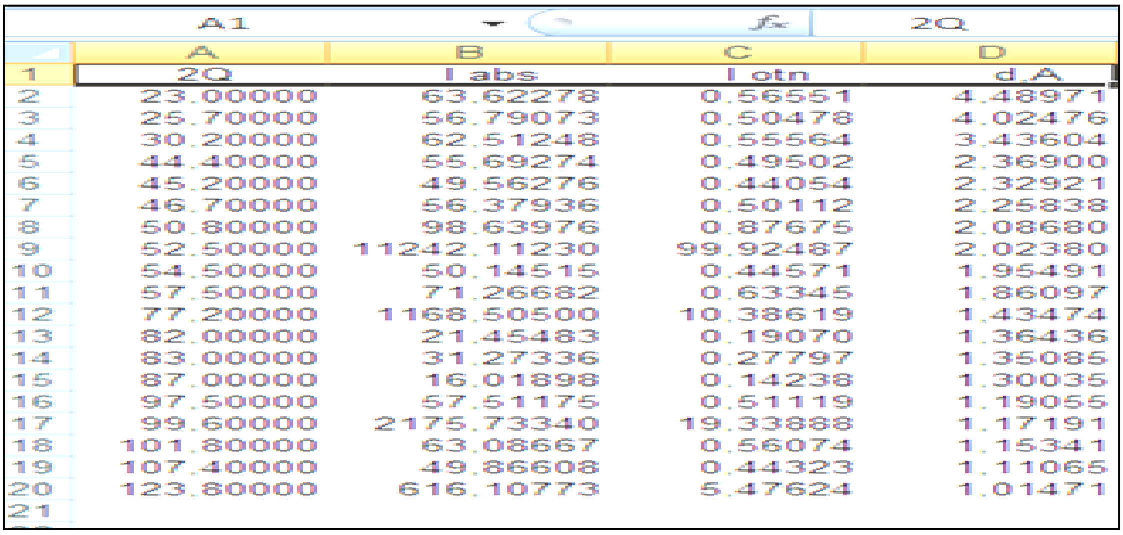


Fig. 3. A multilayer complex microstructure of 18Х2Н4МА steel (x250)

Zone 2 is a transition zone with a concentration of austenite, Fe3N nitrides, and individual cementite inclusions on a troostite-sorbite matrix. The maximum depth of nitrogen penetration corresponds to 60—80 μm. Zone 1 is a matrix material with a pearlite component.

The presence of the corresponding phases, which were obtained on the DRON-3 diffractometer, Fig. 4, is confirmed by X-ray diffraction patterns., Fig. 5, Fig. 6.

Fig. 4. DRON-3 X-ray diffractometer



1	2Q	I abs	I otn	d,A
2	23.00000	63.62278	0.56551	4.48971
3	25.70000	56.79073	0.50478	4.02476
4	30.20000	62.51248	0.55564	3.43604
5	44.40000	55.69274	0.49502	2.36900
6	45.20000	49.56276	0.44054	2.32921
7	46.70000	56.37936	0.50112	2.25838
8	50.80000	98.63976	0.87675	2.08680
9	52.50000	11242.11230	99.92487	2.02380
10	54.50000	50.14515	0.44571	1.95491
11	57.50000	71.26682	0.63345	1.86097
12	77.20000	1168.50500	10.38619	1.43474
13	82.00000	21.45483	0.19070	1.36436
14	83.00000	31.27336	0.27797	1.35085
15	87.00000	16.01898	0.14238	1.30035
16	97.50000	57.51175	0.51119	1.19055
17	99.60000	2175.73340	19.33888	1.17191
18	101.80000	63.08667	0.56074	1.15341
19	107.40000	49.86608	0.44323	1.11065
20	123.80000	616.10773	5.47624	1.01471
21				

Fig. 5. Tabular data X-ray diffractogram of the sample 5L-A 18X2H4MA Co-K*a* radiation

Depending on the concentration of the corresponding phases in the depth, the hardness of the flood layer also changes. If on the surface of the nitrided layer with subsequent laser processing values up to Hμ=8000 MPa were recorded, then in the core of the matrix material Hμ=3500 MPa.

X-ray phase analysis was performed on a DRON-3 X-ray diffractometer in monochromatized Co-K α = 1.7902A. λ radiation. Identification of compounds (phases) was performed by comparing interplanar distances (d,A) and relative intensities (I_{otn}-I/I0) of the experimental curve with data from the PCPDFWIN electronic file. The shooting was carried out at angles of 10—90 degrees. Phase analysis step 0.1 degrees. Duration 5 s. Structural analysis step 0.01 degrees. Duration 5 s. Anode voltage –30 kV. Voltage current –20 mA.

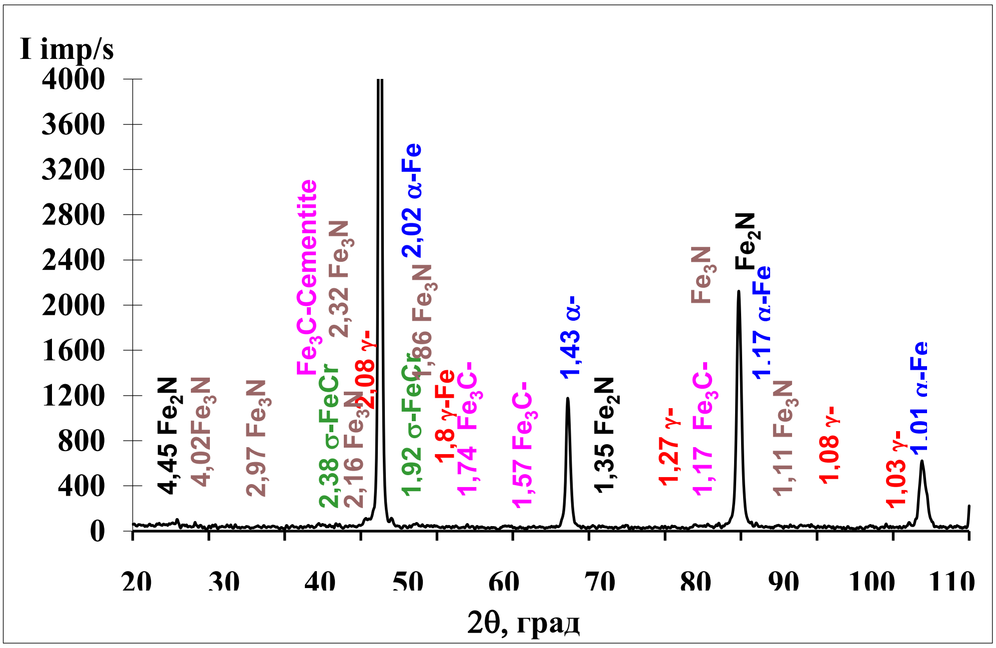


Fig. 6. X-ray diffractogram of the sample 5L-A 18X2H4MA Co-K *a* radiation

Dynamic equilibrium for a continuous flow of lubricating fluid [7—9], which is present in the friction nodes of working mechanisms and is a distribution medium between two contacting surfaces, we have the Navier-Stokes equation for the conservation of mass over time *dt* in the elements *dx, dy, dz:*

$$dp/dt + d(pu)/dx + d(pv)/dy + d(pw)/dz = 0, \tag{1}$$

where p — is the density of the lubricating fluid; u, v, w — are the velocity components in the direction of the coordinate axes x, y, z; t — is the time.

Under the assumptions made ($dp/dx=0$, $h/l=h/b=10\text{-}3$), the Navier-Stokes equation takes the form:

$$dp/dx=d(\eta du/dz)dz\ ; \tag{2}$$

$$dp/dy=d(\eta du/dz)dz,$$

where η is the dynamic viscosity.

After integration, we obtain the velocity gradients in the form

$$du/dz=z/\eta\cdot dp/dx+A/\eta$$

$$dv/dz=z/\eta\cdot dp/dy+C/\eta, \tag{3}$$

where A and C are constants.

After integration at the average viscosity value over the film thickness, corresponding to η, it has the form

$$u=z^2/2\eta\cdot dp/dx+Az/\eta+B$$

$$v= z^2/2\eta\cdot dp/dy+Cz/\eta+D \tag{4}$$

$$u =-z(h\text{-}z/2\eta)\cdot dp/dx+u_b(h\text{-}z)/h+u_a\cdot z/h$$

$$v =-z(h\text{-}z/2\eta)\cdot dp/dy+v_b(h\text{-}z)/h+v_b\cdot z/h. \tag{5}$$

Conclusions

The microstructure of a nitrided part made of high-alloy steel 18X2N4MA was investigated, followed by laser processing using combined technology on a pulsed laser type GOOS1001 with a storage energy of 15—16 kJ, a distance to the target of 294 mm, a laser spot diameter of 10 mm and an interval between shots of 5 minutes without surface melting. Calculations of the formation of a lubricating film on friction surfaces and its effect on wear are presented.

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