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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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STUDY OF VIBRATION PROPERTIES OF CERAMIC-METAL NANOSTRUCTURAL TIN-CU COATINGS WITH DIFFERENT COPPER CONTENT 7 AND 14 AT. % ON CHROMIUM-NICKEL-VANADIUM STEELS

Abstract. This paper studies the vibration properties of chromium-nickel-vanadium steels with a ceramic-metal nanostructured TIN-CU coating with different copper contents - 7 and 14at.%. Among the advantages of a nanostructure with an increased area of intergranular boundaries there is a high value of viscosity and resistance to "brittle" cracks initiation and propagation; they are able to resist fracture for a long period under conditions of an external combined stress. Therefore, the invention of new generations of ceramic-metal nanostructured coatings with an increased area of intergranular and interlayer boundaries makes it possible to increase the durability, hardness in combination with sufficient viscosity, high adhesion strength with respect to the substrate material. For increasing the dissipative properties, we consider Cr-NI-V as an alloying agent, in such a way improving the parts performance, which contribute to the damping of nuisance vibrations and vibrations in alloys. The research procedure includes the study of the acoustic and vibration characteristics of the alloys, the mathematical processing of the results obtained. The research results show that the samples under study have higher strength and impact toughness indicators than their standard analogs. The use of a JSM-6700F field emission scanning electron microscope with a JED-2300F add-on for energy-dispersive spectrometry, JEOL (Japan), is associated with high image quality and resolution, which makes it possible to conduct a quantitative morphological analysis of the microscopic structure and elements composition, showing the presence of a nanostructure with layers of different nitride phases noticeably distinguishable in contrast. The presence of a nanostructured coating reduces the level of vibration acceleration.

Key words: nanostructure, vibration acceleration, noise-level meter, scanning electron microscope.

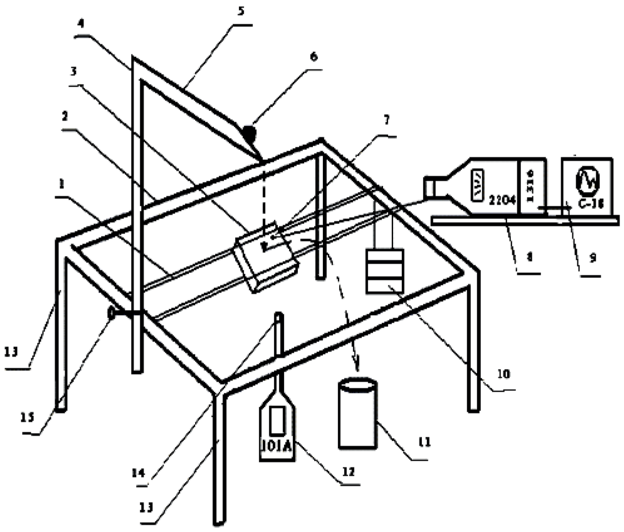
Introduction. The choice of nickel, chromium and vanadium as alloying elements in iron-carbon alloys is explained as follows. As shown by the analysis of works [1-4], alloys with increased damping properties contained chromium, nickel and vanadium as alloying elements. It should be noted that nickel is one of the most widespread elements on earth (0.09%) and is widely used in iron-based alloys with high damping properties. Nickel additions from 2% to 4% also affect the damping properties of the alloys. The choice of chromium as an alloying element is explained by the fact that this element is also widely used in high damping alloys. Chromium additions to other metals significantly change their properties and create opportunities for obtaining a wide range of various very valuable materials. Slightly hardening ferrite, chromium does not reduce its toughness and more than 3 thousand steels and alloys are known, which include chromium. Vanadium belongs to the elements that are constantly present in steels, while it has a significant effect on the composition and nature of non-metallic inclusions.

When developing high-damping alloys, one of the main criteria is the inadmissibility of a significant decrease in strength properties. Therefore, one of the reasons for choosing iron-carbon alloys of chromium, manganese and vanadium as alloying elements was that among the main alloying elements (the most frequently used), these elements harden ferrite more than others [5].

When using alloying elements in high-damping alloys, the noiselevel can be reduced if a real research result is obtained, since different classes of materials absorb the sound vibration energy differently, which depends on external factors - this is the ratio of the structure components, the type of technological treatment, etc. Information that the chemical composition of alloys affects the damping properties makes it possible to develop compositions from low alloy steels with high damping properties. When conducting research in the field of combating noise and vibration during the collision of parts of the mechanism, the noise level is reduced by changing the chemical composition, the type of heat treatment, increasing the mass of the colliding bodies and the duration of the collision of bodies.

Chromium-nickel steels (grades 12CHN2, 12CHN3A, 12CH2N4A, 20CHN3A, 20CH2N4A, 20CHN, 20CHN4FA, 25CH2NMFA) are used after carburizing, quenching and low tempering for the manufacture of large parts of especially critical use. In this regard, for further study of the damping properties, we used steels 20KHN, 20KHN4FA, 25KH2NMFA, which experience significant shock loads during operation.

Vibration acceleration research technique. Based on the analysis of installations for the study of vibration (vibration acceleration level, general vibration acceleration level) properties of steels, a device was chosen for a comprehensive study of the vibration properties of plate and tubular steel samples with subsequent modernization [7]. The installation works as follows (Figure 15). The striking ball 6 was installed on an inclined plane 5, from which it rolls and makes a free fall to the geometric center of the plate sample 3. The striking ball 6 bounces off it and falls into the receiver of balls 11. The noise from the collision of the striking ball 6 and sample 3 is recorded by noise-level meter "OCTAVA-101A" 12. Sample (lamellar) 3, vibrating in the weave of nylon threads 1 creates vibration, which is evaluated by the device model 2204 of the company'Bruel&Kjer' 8. The tension of the sample with nylon threads 1 is always constant, since the weight 10 controls this tension. The drop height of the ball can be changed by means of the screw for fastening the striker strut 15. The entire system of fastening the sample 3 and the striking ball 6 is mounted on the frame 2, which, using struts 13, is at a certain height above the floor.



1 - nylon threads; 2 - frame; 3 - lamellar sample; 2 - frame stand; 5 - inclined plane; 6 - ball-striker; 7 - vibration sensor of the sound level meter of the company 'Bruel & Kjer'; 8 –noise-level meter of the company "Bruel & Kjer" model 2204 with octave filter model 1613; 9 - oscilloscope S-18; 10 - cargo; 11 - ball receiver; 12 –noise-level meter "Octava 101A"; 13 - frame racks; 14 - microphone of the noise-meter 'Oktava 101A'; 15 - screw for fastening the striker stand.

Fig. 1. A device for a comprehensive study of the acoustic and vibration properties of solid samples [7]:

During the measurements, we used steel (SHKH15) striking balls of the following diameters: 7 mm; 8 mm; 9 mm; 11 mm (the mass of the striking balls, respectively: 1.40; 2.09; 2.97 and 5.55 g).

Steel plate specimens (50x50x5) mm were examined on the installation.

The mass of the ball, the density of the sample, the distance from the point of impact to the sample, and the thickness of the sample are interrelated by the following formula:

$$m \langle 4{,}6 \cdot \rho \cdot l \cdot h^2 \qquad (6)$$

where m is the mass of the sample plate, g;

ρ is the density of the sample plate material, g / cm^3;

l - distance from the point of impact to the nearest edge of the sample plate, cm;

h is the thickness of the sample plate, cm.

In this case, the width and length of the sample plate should be at least 5 times its thickness. The investigated plate with dimensions 50x50x5 mm satisfies these requirements.

Sound pressure levels were investigated in octave frequency bands in the range of 31.5 - 31,500 Hz, vibration acceleration levels in the range of 31.5 - 31500 Hz. Noise level - on the “A” scale, the general level of vibration acceleration - on the “Lin” characteristic. The sound generator ZG-10 was used to calibrate the measurements of the sound signal. Correction for the change in the sound signal from atmospheric pressure was carried out using a PF-101 pistonphone. The air temperature and humidity in the laboratory were kept constant. Acoustic measurements were found as the average of five measurements [75].

Mathematical processing of the experimental results and determination of confidence intervals were also carried out in accordance with the methodology [8]. Before starting work, the measurement path was adjusted by checking the sound pressure levels of the reference sample.

Research results. Study of the chemical composition and mechanical properties of steels by standard methods for the determination of alloying elements and the tensile determination method.

The results of studies of the chemical composition and mechanical properties of standard steels 20KHN, 20KHN4FA, 25KH2NMFA are shown in Table 1.

Table 1 - Chemical composition and mechanical properties of known metallic materials

Steel marking	Chemical composition, %								Mechanical properties				
	C	Ni	Mn	Si	V	Cr	Fe	Other elements	$\sigma_в$	$\sigma_т$	δ_5	ψ	KCU
									MPa		%		$\frac{J}{cm^2}$
20KHN	0.17-0.23	1.00-1.40	0.40-0.70	0.17-0.37	-	0.45-0.75	Res.	≤0.035 S; ≤0.035 P; ≤0.30 Cu;	780	590	11	40	66
20KHN4F	0.17-0.24	3.75-4.15	0.25-0.55	0.17-0.37	0.10-0.18	0.70-1.10	Res.		880	685	9	40	83
25KH2NMFA	0.23-0.27	1.30-1.60	0.40-0.70	0.17-0.35	0.05	1.80-2.20	Res.		657	520	14	40	49

The results of studies of the chemical composition and mechanical properties of the melted steels are shown in Table 2.

Table 2 - Chemical composition and mechanical properties of melted steels

Steel marking	Chemical composition, %									Mechanical properties				
	C	Ni	Mn	Si	V	Cr	Co	Fe	Other elements	$\sigma_в$	$\sigma_т$	δ_5	ψ	KCU
										MPa		%		$\frac{J}{cm^2}$
EO3	0.22	1,2	0.7	0.30	0.35	0.8	0.1	Res.	0.035 S; 0.035 P; 0.35 Cu; 0.02 = Al 0.01 = Bi	1100	980	11	48	120
EO4	0.35	2.5	0.8	0.20	0.40	0.8	0.2	Res.		1050	950	10	45	100
EO5	0.45 -0.48	1.0 -1.2	0.7-0.8	0.5 - 1,2	0.35 - 0.45	0.9	0.3 - 0,4	Res.		1100	1000	8	40	110

Comparative analysis of the data given in Tables 4 and 5 shows that the melted steels EO3, EO4 and EO5 with comparable plastic properties (relative elongation δ5 and relative contraction ψ) have higher strength and toughness values than standard counterparts. Thus, the ultimate tensile strength σv of these alloys is 1.19-1.25 times higher than that of the most durable standard analogue 20KHN4FA, the ultimate strength σt is 1.39-1.46 times, and the impact toughness KCU is 1.20 -1.33 times. The results obtained were achieved due to additional alloying of steel with small additions of Co and an increased amount of V, as well as optimization of the content of C, Ni, Cr, Si and Mn in steel.

Transverse fracture images 2 show that the coatings have a columnar structure with transverse grain sizes

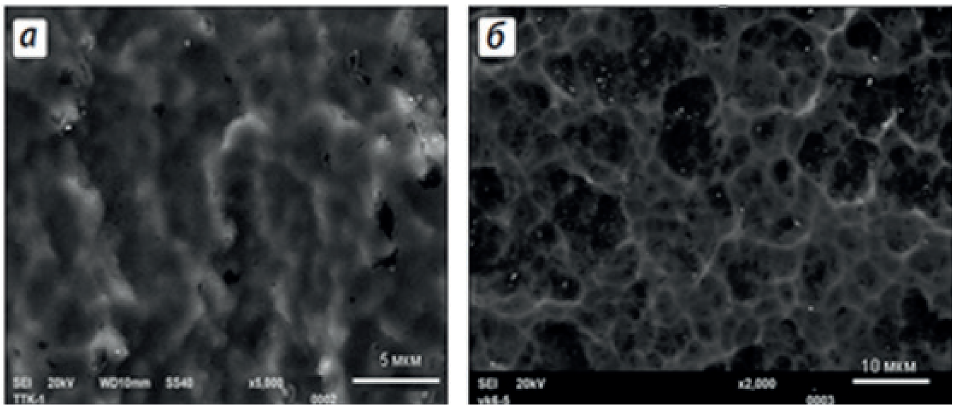


Fig. 2.Appearance of TiN-Cu coatings with copper content: a) 7 at% б) 14 at%

The thickness of the deposited CMNP was approximately 120 nm and was controlled by the deposition time. The study of the structure of the coatings on the end section using a high-resolution SEM shows that the coating is a nanostructure with layers of different nitride phases noticeably distinguishable by contrast (see Figure 3). The assessment of the thicknesses of individual layers in the coating, carried out on them, indicates that their values correspond to the sizes determined in the analysis of the distribution of elements in the coating by the X-ray PS method with its layer-by-layer etching, and are 5 nm.

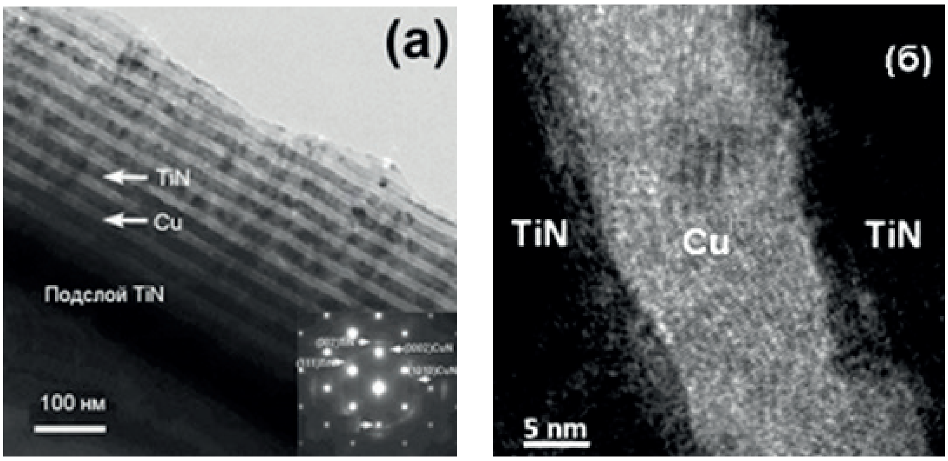


Fig. 3.SEM image of the cross-section of the coatingsTiN-Cu(a and b)

Evaluation of vibration of samples under shock excitation. The vibration characteristics of the investigated steels (20KHN, 20KHN4FA and 25KH2NMFA) are presented in

Table 3 shows the vibration characteristics of samples (plates with a size of 50x50x5 mm) made of steels EO3, EO4, EO5 and EO5 (CMNP) after collision with striking balls with diameters d = 7 mm, d = 8 mm, d = 9 mm and d = 11 mm.

Table 3 - Vibration characteristics of the developed steels EO3, EO4, EO5 and EO5 (CMNP)

Steel grade	Striking ball diameter, d, mm	Vibration acceleration levels, dB, in octave bands with geometric mean frequencies, Hz											OVAL, dB
		31.5	63	125	250	500	1000	2000	4000	8000	16000	31500	
EO3	7	88	107	89	68	67	69	65	67	68	70	75	112
	8	102	118	98	81	58	57	55	54	54	58	57	122
	9	92	120	92	71	62	60	56	58	87	87	69	121
	11	90	122	91	72	62	60	63	96	98	94	96	125

EO4	7	87	105	88	69	68	69	67	66	67	69	78	117
	8	85	117	87	84	71	70	69	68	55	76	79	119
	9	88	120	85	80	65	72	67	70	83	82	72	123
	11	87	119	91	70	67	74	73	72	93	85	93	127
EO5	7	84	100	83	65	61	66	62	60	67	58	57	94
	8	82	110	81	77	67	65	52	72	52	58	59	99
	9	82	113	81	68	63	57	59	62	79	56	59	103
	11	80	107	82	61	58	55	56	65	80	77	87	110
EO5 (CMNPTiN-Cu with Cu7at.%)	7	77	93	77	59	58	57	61	59	60	57	56	75
	8	79	104	80	75	70	60	50	69	52	57	56	96
	9	78	98	78	65	60	55	57	61	70	53	57	72
	11	74	99	76	56	54	53	53	60	61	70	72	91
EO5 (CMNPTiN-Cu with Cu14at.%)	7	75	91	75	58	56	55	60	58	58	55	54	74
	8	77	102	78	73	67	58	48	67	50	55	55	95
	9	75	97	77	66	58	53	52	60	68	50	55	70
	11	72	96	75	55	52	51	50	58	60	68	70	88

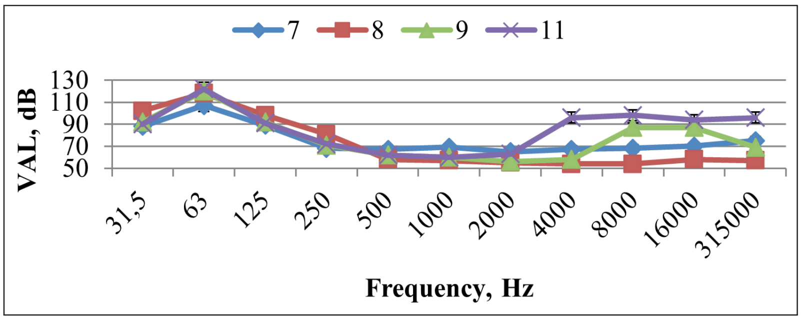
The nature of the vibration acceleration curves (VAC) of the developed steels is as follows:

- the vibration acceleration levels of the investigated samples vary in the range 56 - 125 dB;
- the maxima are observed at frequencies 63 and 125 (102 - 125 dB);
- the minima of the vibration acceleration levels of the samples are typical for frequencies of 1000 Hz, 2000 Hz, 16000 Hz and 31500 Hz (56 - 58 dB);
- the maximum values of the vibration acceleration levels of the compared samples are typical for collisions with a ball-striker with a diameter of d = 9 mm;
- the minimum values of the vibration acceleration levels of the compared samples are typical for collisions with striking balls with diameters d = 7 mm and d = 9 mm;
- the maxima of the vibration acceleration levels according to the “Lin” characteristic for samples EO3, EO4 and EO5 are observed when they collide withstrikingballs with diameters d = 9 mm and d = 11 mm (72 - 130 dB).

In accordance with Figure 4, the maximum effect of amplitude-dependent damping was found at a frequency of 8000 Hz when the EO3 sample collided with a strikingball with a diameter of d = 7 mm, VAL = 91 dB, and when the EO3 sample collided with a strikingball with a diameter d = 9 mm, VAL = 61dB. The ADD effect = 20 dB.

At a frequency of 125 Hz, when the EO3 sample collides with a strikingball with a diameter of d = 8 mm, the VAL = 90 dB, and when the EO3 sample collides with a strikingball with a diameter of d = 11 mm, VAL = 60. The ADD effect = 30 dB.

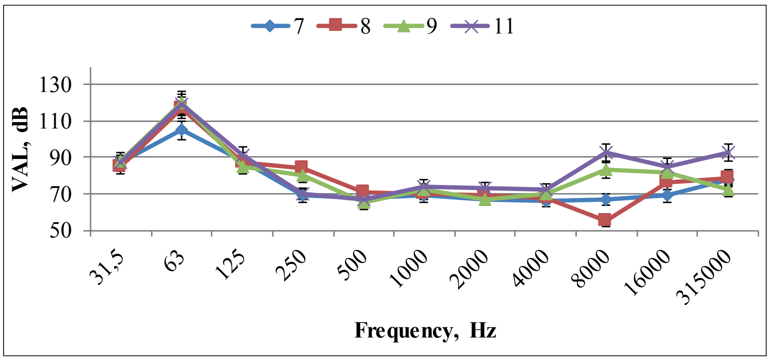
At a frequency of 31.5 Hz, when the EO3 sample collides with a striking ballwith a diameter of d = 8 mm, the VAL = 85 dB, and when the EO3 sample collides with a striking ballwith a diameter of d = 11 mm, the VAL = 71 dB. The ADD effect = 14 dB.



d = 7 ÷ 11 mm – diameters of ball strikers

Fig.4.Characteristics of vibration accelerations of the sample EO3 upon impact

In accordance with Fig. 5, the maximum effect of amplitude-dependent damping was found at a frequency of 63 Hz when the EO4 sample collided with a strikingball with a diameter of d = 9 mm VAL = 125 dB, and during the collision of an EO4 sample with a strikingball with a diameter d = 11 mm, VAL = 106 dB. TheADDeffect = 21 dB.

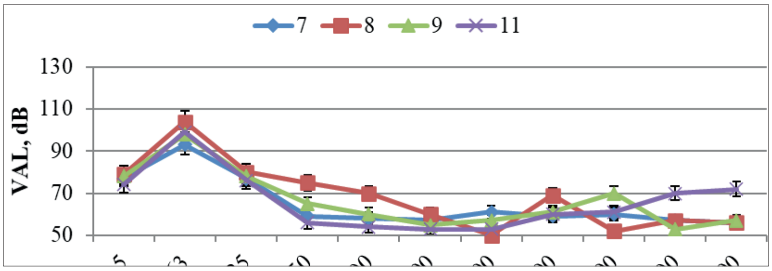


d = 7 ÷ 11 mm – diameters of ball strikers
Fig.5.Characteristics of vibration accelerations of the EO4 sample upon impact.

In accordance with Fig. 6, the maximum effect of amplitude-dependent damping was found at a frequency of 63 Hz when the EO5 sample collided with a striking ball with a diameter of d = 11 mm,VAL = 124 dB, and when the sample EO5 collided with a striking ball with a diameter d = 8 mm, VAL = 84 dB. The ADD effect = 40 dB.

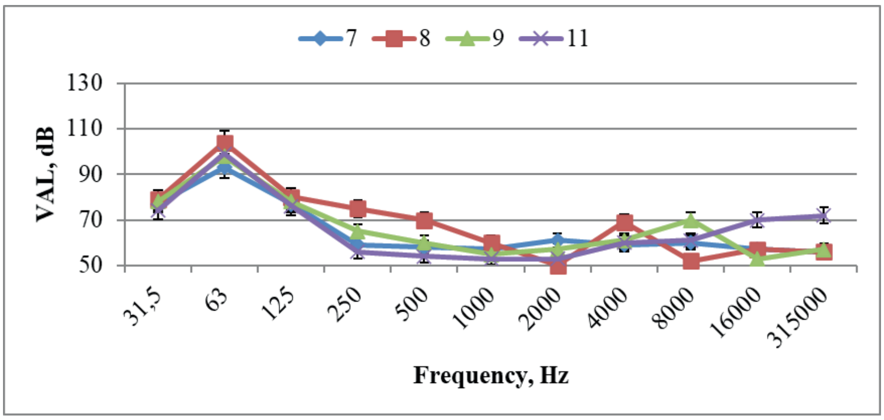
At a frequency of 31500 Hz, when the EO5 sample collides with a striking ball with a diameter of d = 7 mm, the VAL = 57 dB, and when the EO5 sample collides with a striking ball with a diameter of d = 11 mm, the VAL = 87 dB. The ADD effect = 30 dB.

At a frequency of 125 Hz, upon collision of the EO5 sample with a striking ball with a diameter of d = 7 mm, the VAL = 76 dB, and upon collision of the EO5 sample with a striking ball with a diameter of d = 9 mm, the VAL = 94 dB. The ADD effect = 18 dB.



d = 7 ÷ 11 mm – diameters of ball strikers
Fig.6.Characteristics of vibration accelerations of the EO5 sample upon impact

Figure 7 shows the levels of vibration acceleration of the sample EO5 (CMNP). The vibration levels of a sample with a nanostructured coating have their own characteristics: the general levels of vibration acceleration are lower than those of samples EO5, EO3, EO4. The minimum values of the VAL are observed in the frequency range of 500, 1000, 2000, 4000, 8000, 16000, 31500 Hz. The VALs are somewhat different when struck by a striker with a diameter of 11 mm.



d = 7 ÷ 11 mm – diameters of ball strikers
Fig.7. Characteristics of vibration accelerations of the EO5 (CMNP) sample upon impact.

Conclusion. Analysis of vibration accelerations of the investigated steels makes it possible to determine the following:

- vibrations of the melted steels EO3, EO4 and EO5 are (16 - 23) dB lower than that of the well-known steels 20KHN, 20KHN4FA and 25KH2NMFA;
- the nanostructured coating reduces the level of vibration accelerations by (7 - 9) dB (steel 20KHN4FA) and by 19 dB (steel EO5).

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ХРОМНИКЕЛЬВАНАДИЙ БОЛАТТАРЫНДАҒЫ 7 ЖӘНЕ 14 АТ.% ҚҰРАМДЫ МЫСПЕН TIN-CU ҚЫШ МЕТАЛЛ НАНОҚҰРЫЛЫМДЫҚ ЖАБЫНДЫЛАРДЫҢ ВИБРАЦИЯЛЫҚ ҚАСИЕТТЕРІН ЗЕРТТЕУ

Аннотация. Бұл мақалада мыс мөлшері 7 және 14 ат.% болатын TIN-CU керамика-металл наноқұрылымы бар хром-никель-ванадий аралас болаттардың тербелу қасиеттерінің зерттеулері келтірілген. Түйірлер арасындағы шекаралар ауданы үлкейтілген наноқұрылымның артықшылықтарының бірі – оның шұбаландығының жоғары мәнінде және «осал» жарықтардың пайда болуы мен дамуына төзімділігінде, олар ұзақ уақыт бойы күрделі, қиын жағдайларда бұзылуға қарсы тұра алады. Сондықтан түйірлер мен қабаттар арасындағы шекаралар ауданы үлкейтілген керамика-металл наноқұрылымдық жаңа жабындарын жасау материалдың ұзаққа төзімділігін, жеткілікті тұтқырлығын, қаттылығын, субстрат материалына қатысты адгезияның жоғары беріктігін арттыруға мүмкіндік береді. Диссипациялық қасиеттерді арттыру үшін Cr-NI-V түріндегі қалайылаушы элементті таңдаған жөн, бұл қорытпалардағы зиянды тербелістер мен дірілдің жойылуына ықпал ететін тетіктердің сенімділігін арттыра түседі. Зерттеу әдістемесі қорытпалардың акустикалық және діріл сипаттамаларын зерттеуден, алынған нәтижелерді математикалық өңдеуден тұрады. Зерттеу нәтижелері зерттелген үлгілердің стандартты ұқсас үлгілермен салыстырғанда беріктігі мен тұтқырлығы жоғары екенін көрсетеді. JEOL (Жапония) компаниясының JED-2300F энергиялық-дисперсиялық спектрометриясына арналған қондырмасы бар JSM-6700F далалық эмиссиялық растрлық электрондық микроскопын пайдалану кескіннің жоғары сапасына және ажыратымдылығына байланысты, бұл микроскопиялық құрылым мен элементтердің сан құрамына морфологиялық талдау жүргізуге мүмкіндік береді, әртүрлі нитридті фазалардың қабаттарының контрастымен айтарлықтай ерекшеленетін наноқұрылымның бар екенін көрсетеді. Наноқұрылымдық жабынның болуы тербелудің үдеу деңгейін төмендетеді.

Түйінді сөздер: наноқұрылым, дірілдің үдеуі, шу өлшегіш, растрлық электронды микроскоп.

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ИССЛЕДОВАНИЕ ВИБРАЦИОННЫХ СВОЙСТВ КЕРАМИКО-МЕТАЛЛИЧЕСКИХ НАНОСТРУКТУРНЫХ ПОКРЫТИЙ TIN-CU С РАЗНЫМ СОДЕРЖАНИЕМ МЕДИ 7 И 14 АТ.% НА ХРОМОНИКЕЛЕВАНАДИЕВЫХ СТАЛЯХ

Аннотация. В данной статье проведены исследования вибрационных свойств хромоникелеванадиевых сталей с керамико-металлическим наноструктурным покрытием TIN-CU с разным содержанием меди 7 и 14 ат.%. Одним из преимуществ наноструктуры с увеличенной площадью межзерновых границ является высокое значение вязкости и устойчивости к зарождению и развитию «хрупких» трещин: они способны длительное время сопротивляться разрушению в условиях сложнонапряженного внешнего воздействия. Поэтому создание новых поколений покрытий с керамико-металлическим наноструктурным покрытием с увеличенной площадью межзерновых и межслойных границ дает возможность увеличить долговечность, твердость в сочетании с достаточной вязкостью, высокой прочностью адгезии по отношению к материалу субстрата. Для повышения диссипативных свойств рассматривается выбор легирующего элемента в виде Cr-NI-V, тем самым повышая надежность работы деталей, которые способствуют затуханию вредных колебаний и вибраций в сплавах. Методика исследования включает в себя исследование акустических и вибрационных характеристик сплавов, математическую обработку полученных результатов. Результаты исследований показывают, что исследуемые образцы обладают более высокими показателями прочности и ударной вязкозти, чем их стандартные аналоги. Использование полевого эмиссионного растрового электронного микроскопа JSM-6700F с приставкой для энерго-дисперсионной спектрометрии JED-2300F компании JEOL (Япония) связано с высоким качеством изображения и разрешения, что дает возможность проведения количественного морфологического анализа микроскопической структуры и состава элементов, показывая наличие наноструктуры с заметно различимыми по контрасту слоями различных нитридных фаз. Наличие наноструктурного покрытия снижает уровень виброускорений.

Ключевые слова: наноструктура, виброускорение, шумомер, растровый электронный микроскоп.

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МАЗМҰНЫ-СОДЕРЖАНИЕ-CONTENTS

Abuova R.Zh., Ten E.B., Burshukova G.A.
STUDY OF VIBRATION PROPERTIES OF CERAMIC-METAL NANOSTRUCTURAL TIN-CU COATINGS WITH DIFFERENT COPPER CONTENT 7 AND 14 AT. % ON CHROMIUM-NICKEL-VANADIUM STEELS....6

Abetov A., Kudaibergenova S.
INTEGRATED RESEARCH OF SUFFOSION AND KARST PROCESSES AT THE KOGCF BY GEOLOGICAL AND GEOPHYSICAL AND GEODESIC METHODS....14

Amangeldykyzy A., Kopobayeva A.N., Bakyt A., Ozhigin D.S., Blyalova G.G.
MINERALOGY AND GEOCHEMISTRY OF THE SHUBARKOL DEPOSIT JURASSIC COALS....23

Dikanbayeva A.K., Auyeshov A.P., Satayev M.S., Arynov K.T., Yeskibayeva Ch.Z.
RESEARCHING OF SULFURIC ACID LEACHING OF MAGNESIUM FROM SERPENTINES....32

Duisen G.M., Aitzhanova D.A.
NATURAL RESOURCE POTENTIAL OF KAZAKHSTAN AND CENTRAL ASIAN COUNTRIES: PROSPECTS OF USE....39

Edygenov E.K., Vassin K.A.
ELECTROMAGNETIC VEHICLE WITH AUTOMATED CONTROL SYSTEM FOR SURFACE MINING OPERATIONS....47

Ismailov B.A., Dossaliev K.S.
TECHNOLOGICAL REGULATIONS OF CONDITIONS IN PRODUCTION OF FERTILIZER MIXTURES "ZHAMB-70"....54

Issagaliyeva A.К., Istekova S.A., Aliakbar M.M.
GEOPHYSICAL DATA COMPLEX INTERPRETATION TECHNIQUES FOR STUDIES OF THE EARTH CRUST DEEP HORIZONS IN THE NORTH CASPIAN REGION....61

Mekhtiyev A.D., Soldatov A.I., Neshina Y.G., Alkina A.D., Madi P.Sh.
THE WORKING ROOF ROCK MASSIF DISPLACEMENT CONTROL SYSTEM....68

Mustafayev Zh.S., Kozykeeva A.T., Tursynbayev N.A., Kireychev L.V.
APPLIED MODEL OF ENVIRONMENTAL SERVICES - DEVELOPMENT OF ECOLOGICAL AND ECONOMIC DRAINAGE SYSTEM OF TRANSBOUNDARY RIVER BASINS (on the example of the Talas river basin)....77

Petr Hajek, Baimaganbetov R.S.
GEOSTABILIZATION OF ECOLOGICAL EQUILIBRIUM AS A RESULT OF FOREST FIRES....84

Salikhov N.M., Pak G.D., Shepetov A.L., Zhukov V.V., Seifullina B.B.
HARDWARE-SOFTWARE COMPLEX FOR THE TELLURIC CURRENT INVESTIGATION IN A SEISMICALLY HAZARDOUS REGION OF ZAILIYSKY ALATAU....94

Saukhimov A.A., Ceylan O., Baimakhanov O.D., Shokolakova Sh.K.
REDUCING POWER AND VOLTAGE LOSSES IN ELECTRIC NETWORKS OF OIL FIELDS USING THE MOTH FLAME OPTIMIZATION ALGORITHM....................................103

Soltanbekova K.A., Assilbekov B.K., Zolotukhin A.B., Akasheva Zh.K., Bolysbek D.A.
RESULTS OF LABORATORY STUDIES OF ACID TREATMENT OF LOW-PERMEABILITY ROCK CORES..113

Surimbayev B., Bolotova L., Shalgymbayev S., Razhan E.
RESEARCH OF THE COMPLEX STAGE-BY-STAGE SCHEME OF GRAVITY SEPARATION OF GOLD ORE..124

Temirbekov N.M., Los V.L., Baigereyev D.R., Temirbekova L.N.
MODULE OF THE GEOINFORMATION SYSTEM FOR ANALYSIS OF GEOCHEMICAL FIELDS BASED ON MATHEMATICAL MODELING AND DIGITAL PREDICTION METHODS..137

Tileuberdi N., Zholtayev G.ZH., Abdeli D. Zh., Ozdoev S.M.
INVESTIGATION OF DRAINAGE MECHANISM OF OIL FROM PORES OF OIL SATURATED ROCKS USING NITROGEN AT THE LABORATORY CONDITION........146

Tleulesov A.K., Suyundikov M.M., Shomanova Zh.K., Akramov M.B., Suiindik N.M.
ASSESSMENT OF QUALITATIVE AND QUANTITATIVE ELEMENTAL COMPOSITION OF WASTE IN THE TERRITORY OF SLUDGE COLLECTOR OF PAVLODAR ALUMINIUM PLANT..153

Turgumbayev J.J., Turgunbayev M.S.
PREDICTION OF THE CUTTING RESISTANCE FORCE OF THE SOIL CONTAINING STONY FRACTIONS..161

Uakhitova B., Ramatullaeva L., Imangazin M., Taizhigitova M., Uakhitov R.
ON THE STATE OF INDUSTRIAL INJURIES OF WORKERS IN INDUSTRIAL ENTERPRISES OF THE AKTUBINSK REGION..170

Sherov K.T., Sikhimbayev M.R., Absadykov B.N., Karsakova N.Zh. Myrzakhmet B.
METROLOGICAL ENSURING ACCURACY OF MEASUREMENT OF ANGLES V-SHAPED SURFACES GUIDE PARTS OF MACHINES FOR PETROCHEMICAL AND GEOLOGICAL EXPLORATION INDUSTRY..176

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