THESIS WORK ABSTRACT
on the topic:
«DEVELOPMENT OF CHROMIUM-NICKEL VANADIUM STEELS WITH DISSIPATIVE PROPERTIES AND THEIR SURFACE MODIFICATION BY DEPOSITION OF NANOSTRUCTURED WEAR-RESISTANT TIN-CU COATINGS»,
submitted for the Doctor of Philosophy (PhD) degree in specialization 6D074000-«Nanomaterials and nano technology»

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The research goal is making dissipative chromium-nickel-vanadium steels and the application of nanostructured, wear-resistant TiN-Cu coatings to modify their surface

The primary goals of the research are:

- making new compositions with enhanced vibration, acoustic, and damping qualities that are alloyed with nickel, chromium, and vanadium;
- the correlation between the methods of nanostructured ceramic-metal coating deposition on the final steel substrates and their composition and structure through a series of investigations;
- investigation of the chemical and phase compositions of coatings, analysis of their physical and mechanical properties;
- investigation of the tribological properties of coatings in a wide temperature range, including under dynamic heating conditions;
- investigation of the dissipative, vibration and acoustic properties of newly developed steels with ceramic-metal nanostructured coatings deposited on their surface.

The object of the research is to create novel melted steel compositions with a layer of ceramic-metal (TiN-Cu) nanostructure.

Research methods. Numerous contemporary analytical research techniques were applied in the project, including optical microscopy, scanning and transmission electron microscopy, micro-X-ray spectral analysis, X-ray phase analysis, and X-ray photoelectron spectroscopy.

The conventional, recognized methodologies and techniques, together with current precision equipment, were utilized to determine the physical, mechanical, and tribological properties of the coatings. A thorough analysis of the acoustic and vibration characteristics of plate and tube steel samples with further modernization was used to evaluate the damping characteristics.

Fundamental Scientific Provisions (proven scientific hypotheses and other conclusions that represent new knowledge) submitted for defense :

1. EO5 steel has been developed, alloyed with nickel, vanadium, chromium with a carbon content, having increased damping properties (Q^{-1}=1,54*10^{-2}; ψ 9,66*10^{-2}; δ =4,83*10^{-2}), reduced sound emission during impact (LA = 54

dBA) and sufficient physical and mechanical properties ($\sigma_в$=1100 МПа; $\sigma_т$ 1000МПа; $\delta_5 \geq 8\%$; $5 \geq \psi \geq 40\%$; KCU ≥ 110Дж/см2;) the heat treatment of EO5 steel (quenching at 830 °C with air cooling and high tempering at 500 ° C) creates a reed-composite structure that provides optimal strength properties and an increase in the level of dissipation an increase in internal friction from (4.39×10^{-2} to 7.69×10^{-2});

2. Ceramic-metal nanostructured TiN-Cu coatings with different copper content with increased hardness (46-50 GPa) with an increased degree of elastic reduction (> 50%), with a low coefficient of friction (0.4), high adhesive strength to the substrate (> 35 N) were obtained, dependencies between the structure and phase composition of the coatings were established and their tribological characteristics over a wide temperature range;

3. The application of a ceramic-metal nanostructured coating by vacuum arc method to the surface of EO5 steel consists of grains of HCC phase of titanium nitride with an average size of 14-18 nm, and copper, being in a metallic state, is located at the intergranular boundaries of TiN, which in turn provides additional noise reduction of mechanical origin by (7-9) dB with sufficient strength of the coatings.

4. A pilot industrial inspection was carried out at the enterprises of JSC AZTM Almaty Heavy Machinery Plant and Almaty Electroshield Steel Plant EO5 (CMNC) (0.45-0.48% C; 1.0-1.2% Ni; 0.7-0.8% Mn; 0.5-1.2% Si; 0.35- 0.45% V; 0.9% Cr; 0.3-0.4% Co, the rest - Fe) LLP, a sleeve was made in the guide pipe of the lathe machine. The noise reduction was 9-16 dBA compared to 25X2NMFA steel. The expected annual economic effect amounted to 1,000,000 tenge.

An explanation of the study's primary findings.

For the first time were developed the following types of steel (0.22% C; 1.2% Ni; 0.7% Mn; 0.30% Si; 0.35% V; 0.8% Cr; 0.1% Co, remainder - Fe), EO4 (0.35% C; 2.5% Ni; 0.8% Mn; 0.2% Si; 0.4% V; 0.8% Cr; 0.2% Co, remainder. - Fe), EO5 (0.45-0.48% C; 1.0-1.2% Ni; 0.7-0.8% Mn; 0.5-1.2% Si; 0.35- 0.45% V; 0.9% Cr; 0.3-0.4% Co, the rest - Fe), alloyed with Cr , Ni , V , which have increased dissipative, acoustic, vibration properties and an approach has been proposed to further increase their damping properties properties due to the deposition of coatings on their surface. Considering the investigation of the oscillogram of the attenuation of a sound pulse, the developed alloys EO5 Q^{-1}=1,54*10^{-2}; Ψ 9,66$10^{-2}$;Δ =4,83*10^{-2}; have increased sound attenuation rates and dissipative characteristics compared to standard 20KhNI steels Q^{-1}=0,79*10^{-2}; Ψ =4,9*10^{-2}; Δ =2,48*$10^{-2}$for grade 20KhN4FA (Q^{-1}=0,72*10^{-2}; Ψ =4,52*10^{-2}; Δ =2,26*10^{-2}); for brand 25X2NMFA (Q^{-1}=0,58*10^{-2}; Ψ =3,64*10^{-2}; Δ =1,82*10^{-2}). The resulting troostobainite structure of the EO5 sample makes it possible to suppress noise from contact interaction and obtain increased dissipativity. The vibrations of the smelted steels EO3, EO4 and EO5 are (16 - 23) dB lower than those of the known steels 20XH, 20XH4ФA and 25X2HMBA. The acoustic characteristics of the smelted steels are (3 - 13) dBA lower than those of the known ones.

The findings of investigations into the structural and phase formation processes of the (TiN)-Cu coating, which was produced using the ion-plasma vacuum-arc sputtering technique on melted EO5 steels in the specified concentration range of 7% and 14% copper. Transmission and scanning electron microscopy were used to examine the phase composition and structure of the TiN-Cu coating. When using scanning electron microscopy to examine transverse chips. The resultant coatings were layered in architecture and had a thickness of 2.5 μm. Pits of fibrous-banded fracture form in the microrelief together with ductile fracture symptoms associated with a coating fracture. Analysis of the coating structure using TEM demonstrates the presence of a nanostructure. Based on microdiffraction analysis of the obtained dark-field images, it can be concluded that the crystallites of the coatings are titanium nitride δ–TiN. Crystallite sizes for TiN-Cu coatings are in the range of 15–30 nm; the average crystallite size is 14-18 nm. Applying transmission electron microscopy (TEM) it was established that coatings formed by Ti–14 at.% Cu consist of randomly oriented crystallites relative to each other. This is evidenced by pronounced diffraction rings in electron diffraction patterns.

TiN-Cu CMNCs with a copper concentration of 7 at.% are found to contain exclusively titanium nitride, according to X-ray and electron diffraction patterns. In both electron and X-ray diffraction patterns, there are no diffraction lines for phases that include copper. This suggests that they are amorphous to X-rays. The X-ray diffraction patterns of the TiN-Cu coating show X-ray diffraction lines of the copper-containing phase at copper concentrations of more than 10 at.%, or 14 at.%. There was no evidence of columnar structure in the coatings; instead, they are continuous and devoid of micropores and microcracks. The formation of titanium nitride crystallites is impeded during the vacuum-arc process of manufacturing a TiN-Cu coating because of the surrounding copper layers.

EO5 with CMNC is 14 dBA lower than that of 25Kh2NMFA steel. The nanostructured coating reduces the level of vibration acceleration by (7 - 9) dB (steel 25Kh2NMFA) and by 19 dB (steel EO5).

The results of a study by nanoindentation of nitride coatings obtained by the vacuum-arc method with a copper concentration of 7 to 14 at.% are presented, as well as, for the purpose of comparison, TiN. It has been established that with an increase in the concentration of copper in the evaporated cathode (7-14.%), the hardness increases from 46 to 50 GPa, while the hardness of the TiN coating is ≈ 2 times lower and amounts to 23 GPa. The degree of elastic recovery of TiN-Cu coatings is ≈ 2 times higher than that of TiN coatings. The adhesive strength of coatings on substrates of smelted steel EO5 is measured by scratch testing on a Revetest device. Before the onset of adhesive failure, practically no cracks, chips or local cohesive failures were observed on the surface of the coatings. The critical load L_{c3} for the coating, however, was significantly lower than for the coating with a copper content of 7 at.%. For the coating, the critical load was $L_{c3} \approx 35$ N.

Shear pressures are thought to be the primary cause of destruction based on the type of delaminations. With further indentation of the coating into the substrate material, compressive and tensile stresses around the margins of the scratch start to play a key part in the destruction of the coatings, which occurs primarily along the scratch as the load increases. This is explained by the nano-sized structure of the coatings under study, which helps to restrain the growth of cracks by a branched network of grain boundaries, as well as by maintaining the viscosity of the CMNP material.

It`s been proven that TiN-Cu CMNC coatings with a copper content of 7 at. % had a relatively low friction coefficient when paired with a counterbody (Al_2O_3) at the level of 0.3 – 0.4. CMNC TiN-Cu coatings with a copper content of 14 at. % on the contrary, they had the highest values of the coefficient of friction and reduced wear paired with all counterbodies in the range of 0.6 – 1.0, which is typical for coatings based on titanium nitride. When synthesizing TiN-Cu coatings using the vacuum-arc method, the growth of titanium nitride crystallites is inhibited due to their surrounding by amorphous layers of copper. The crystallite size remains in the range of 15-25 nm.

EO5 with CMNC is 14 dBA lower than that of 25Kh2NMFA steel. The nanostructured coating reduces the level of vibration acceleration by (7 - 9) dB (steel 25Kh2NMFA) and by 19 dB (steel EO5).

Rationale for the significance and originality of the findings:

New steel compositions alloyed with Cr, Ni, and V were created for the first time, and a method was suggested to further improve the steels' damping qualities by applying coatings to their surface. These steel compositions had improved dissipative, acoustic, and vibration capabilities.

The formation of nanocomposite coatings in the TiN - Cu system exhibits unique structural characteristics that are dependent on the concentration of copper (7% and 14%). This is manifested in a decrease in the size of titanium nitride phase crystallites as the coatings' copper content increases.

The correlations between the nanostructured TiN-Cu coatings' physical-mechanical, tribological, dissipative, vibrational, and acoustic properties were discovered for the first time on newly created steels.

The adherence to government initiatives or scientific development guidelines.

The thesis work was carried out in the priority direction of scientific development: mechanical engineering , metals and alloys with special properties, nanotechnology and nanomaterials.

The correlation of the thesis work with research plans. The work was carried out in accordance with the research plan of the Kazakh National Research Technical University named after K.I. Satpayeva. Registration number AR08956794 Topic: “Study of the physical and mechanical properties of damping alloys with a nanostructured coating for critical parts of automobile transport”

Author's own input.

The evaluation and interpretation of the body of research on the thesis work subject, as well as hands-on execution of the work's experimental component. The processing, interpreting, and extrapolating the data; additionally, actively contributing to the development and drafting of articles and abstracts; and attending national and international conferences.

A description of the of the PhD student contribution in the production of

each publication.

16 printed works were published as a result of the thesis work; these included 5 articles that had an impact factor of more than zero in the Scopus database, 7 articles that were suggested by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, and 5 abstracts of reports from international conferences that were both scientific and practical.

The thesis work author is the corresponding author of the main scientific articles written based on the results of the work performed.

16 printed publications were published using the thesis work materials; three of these were published in international peer-reviewed scientific journals that are listed in the Scopus/Web of Science database:

1. Utepov E.B., Ten E.B., Zhumadilova Zh.O., Smailova G.A., Shevcova V.S., Isahanova A.B., **Abuova R.Zh**. Damping Metallic Materials with a Nanostructured Coating // Metallurgist, Vol. 60 (9-10), January 2017, pp.961-966, Publisher: Springer New York LLC ISSN: 0026-0894 (print), ISSN:1573-8892 **(online) Citescore: 0,23, Percentile: 36**

2. UtepovE.B, PotoskiiE.P., ShevcovaV.S., **Abuova R.Zh** Kattabekov E.N, Berkinbaeva A.S. Damping Steels for Sheet Stacker Components During Sheet Rolling // Metallurgist, Vol. 63 (3-4), July 2019, pp.286-294 Publisher: Springer New York LLC ISSN: 0026-0894 (print), ISSN:1573-8892 (online)**Citescore: 0.40**

3. **Abuova R.Zh,** E.B. Ten, G. Burshukova Study of vibration properties of ceramic-metal nanostructural TIN-CU coatings with different copper content 7 and 14 at. % on chromium-nickel-vanadium steels // News of the national academy of sciences of the republic of Kazakhstan series of geology and technical sciences. Volume 5, number 449 (2021), pp.6-13 **Percentile: 40**

4. **Abuova R.Zh**, D.K. Suleyev, G.A. Burshukova Study of damping properties of alloyed steels with ceramic-metallic nanostructured coating for critical parts // News of the national academy of sciences of the republic of Kazakhstan series of geology and technical sciences ISSN 2224-5278 Volume 3, Number 453 (2022), 52-65 https://doi.org/10.32014/2022.2518-170X.179 (Print) **Percentile: 43**

5., G.A. Burshukova A.Ye. Kanazhanov **Abuova R.Zh** A.A. Zholdasov Analysis of using Damping Alloys to Improve Vibration and strength Characteristics in the Automotive Industry // Evergreen, June 2023 ISSN:2189-0420 **Percentile: 56**