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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
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КАЗАХСТАН
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STUDY OF DAMPING PROPERTIES OF ALLOYED STEELS WITH CERAMIC-METALLIC NANOSTRUCTURED COATING FOR CRITICAL PARTS

Abstract. In this paper the damping properties of chromium-nickel vanadium steels with TIN-CU ceramic-metal nanostructure coating with different copper content of 7 and 14 at.% were studied. The elastic properties influencing the sound pressure levels at the initial moment of impact, characterized by the duration of the maximum acoustic impulse were studied. Electrical resistance is a value that characterizes the resistance of an electric circuit to the passage of an electric current. Internal friction, showing the potential of a solid sample (substrate) to dissociate the energy of mechanical vibrations. The results of the study of the acoustic and physical-mechanical characteristics of the experimental alloys allow the following conclusions to be drawn. There is a close correlation between the internal friction and the sound level of the alloys. Experiments on investigation of amplitude dependence of internal friction allowed revealing the dislocation mechanism of attenuation in the investigated alloys. The specific electrical resistance of the experimental alloys after hot forging and further air cooling has a fairly wide range from 410^{-6} to 1110^{-6}. Normalization and quenching contribute to a decrease in the resistivity. Use of a JSM-6700F field emission scanning electron microscope with a JED-2300F energy dispersive spectrometry unit from JEOL (Japan) is associated with high image quality and resolution, which enables quantitative morphological analysis of the microscopic structure and composition of elements, showing the presence of nanostructure with layers of different nitride phases noticeably distinguishable by contrast.

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

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ЖАУАПТЫ БӨЛШЕКТЕР ҮШІН ҚЫШ-МЕТАЛЛ НАНОЖАБЫНДЫСЫ БАР ЛЕГІРЛЕНГЕН БОЛАТТАРДЫҢ ДЕМПФЕРЛЕУШІ ҚАСИЕТТЕРІН ЗЕРТТЕУ

Аннотация. Бұл мақалада мыстың құрамы 7 және 14 ат.% болатын TIN-CU қыш-металл наноқұрылымдық жабындысы бар хромникельванадий болаттарының демпферлеуші қасиеттеріне зерттеу жүргізіледі. Максималды дыбыс импульсінің ұзақтылығымен сипатталатын бастапқы соққы сәтіндегі дыбыс қысымының деңгейіне әсер ететін серпімдік қасиеттері, электрлік токтың өтуіне электрлік тізбектің кедергі келтіруін сипаттайтын электрлік кедергі, механикалық тербелістердің энергиясын қатты үлгімен ыдырату әлеуетін көрсететін ішкі үйкеліс зерттелді. Тәжірибелік үлгілердің акустикалық және физика-механикалық сипаттамаларын зерттеу нәтижелері келесі қорытынды жасауға мүмкіндік береді. Қорытпалардың ішкі үйкелісі мен дыбыс деңгейі арасында тығыз корреляциялық байланыс бар. Ішкі үйкелістің амплитудалық тәуелділігін зерттеу бойынша эксперименттер зерттелген болаттардағы дислокациялық сөну механизмін анықтауға мүмкіндік берді. Ыстық сомдау мен ауада ары қарай суытудан кейінгі тәжірибелік қорытпалардың меншікті электрлік кедергісі 4´10-6бастап 11´10-6 дейінгі ауқымға ие. JEOL (Жапония) компаниясының JED-2300F энергия-дисперсионды спектрометриясы бар JSM-6700F эмиссионды растрлық электронды микроскопты пайдалану суреттердің жоғары сапасымен байланысты, бұл түрлі нитрид фазаларының қабаттары бойынша айқындалатын наноқұрылымның бар болуын көрсете отырып, микроскопиялық құрылым мен элементтердің құрамдарына сандық морфологиялық талдау жүргізуге мүмкіндік береді.

Түйін сөздер: наноқұрылым, виброүдеу, шу өлшегіш, растрлық электронды микроскоп.

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ИССЛЕДОВАНИЕ ДЕМПФИРУЮЩИХ СВОЙСТВ ЛЕГИРОВАННЫХ СТАЛЕЙ С КЕРАМИКО-МЕТАЛЛИЧЕСКИМ НАНОСТРУКТУРНЫМ ПОКРЫТИЕМ ДЛЯ ОТВЕТСТВЕННЫХ ДЕТАЛЕЙ

Аннотация. В данной статье проведены исследования демпфирующих свойств хромоникелеванадиевых сталей с керамико-металлическим наноструктурным покрытием TIN-CU с разным содержанием меди 7 и 14 ат. %. Изучены упругие свойства, оказывающие влияние на уровни звукового давления в начальный момент соударения, характеризующийся длительностью максимального звукового импульса, электрическое сопротивление, величина которая характеризует сопротивляемость электрической цепи прохождению электрического тока, внутреннее трение, показывающая потенциал твердого образца (подложки) диссоциировать энергию механических колебаний. Результаты исследования акустических и физико-механических характеристик опытных сплавов позволяют сделать следующие выводы. Между внутренним трением и уровнем звука сплавов существует тесная корреляционная связь. Эксперименты по исследованию амплитудной зависимости внутреннего трения позволили выявить дислокационный механизм затухания в исследованных сплавах. Удельное электросопротивление опытных сплавов после горячей ковки и последующего охлаждения на воздухе имеют довольно широкий интервал от 4x10-4 до 11x10-6. Нормализация и закалка способствуют снижению удельного электросопротивления. 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.

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

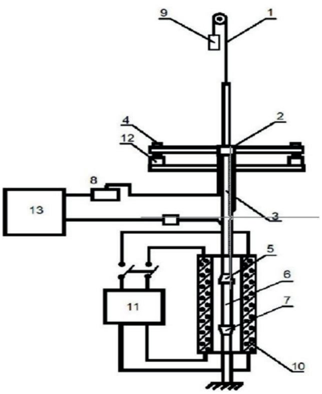
Introduction. Currently in Kazakhstan, in order to develop or maintain the competition of manufactured products in foreign and domestic markets, modern industrial production is in dire need of new progressive technologies, allowing to obtain high quality products and at the same time to reduce intensity of use of materials, energy and labor, to ensure environmental friendliness and safety for health (Suleev et al., 2006, Zhumadilova et al., 2022).

Much attention is paid to improvement of physical and mechanical properties of machine-building, machine-tool industry components, etc., in particular, those working under shock loads and intensive wear and tear, but acoustic ecology (environmental pollution by noise and vibration) is rarely paid attention to (Suleev et al., 2006,).

Noise levels in wood-cutting machines are very high. Such parts include chopping blades for production of technological and wood fuel chips, bushings for drilling and boring machines, gears for milling machines, wood-cutting tools, many machine-building industry products, etc. Known noise reduction methods (sound insulation, sound absorption, means of personal hearing protection) are ineffective and not always possible to use due to cluttering of production areas, fire hazard, increased dustiness, masking of warning signals. One of effective methods of noise reduction is noise damping at the source of noise, namely the use of damping metal materials for noise control (Utepov et al., 2000, Grishkevich et al., 2021).

The standard steel samples 20KhN, 20KhN4FA, 25Kh2NMFA (Zhuravlev et al., 1981) and melted steel samples EO3, EO4, EO5 were used as an object of investigation. And applied CMNC on the melted EO5 steel with different copper content

Materials and methods. The modulus of elasticity is one of the main physical parameters affecting the damping properties of the steels under study (Vancoille et al., 1993, GOST, 2011, Utepov et al., 2015). The shear modulus was measured on the installation, the scheme of which is shown in Fig. 1.



1 - capron thread; 2 - frame; 3 - rod; 4 - electromagnets; 5,7 - collet clamps; 6 - sample; 8 - rheostat; 9 - weight; 10 - furnace; 11 - thermostat; 12 - optical system; 13 - generator

Figure 1 – Schematic of the installation for measuring the shear modulus and internal friction at free and forced oscillations (Krishtal et al., 1976)

The value of electrical resistance, expressed in ohms, is equal to the quotient of the voltage applied to an electrical circuit, in Volts, divided by the current flowing through the electrical circuit, in Amperes (Knotek et al., 1992).

Internal friction indicates the potential of a solid specimen to dissociate the energy of mechanical vibration. In most cases, the amplitude of the alloy depends on the internal friction (Suleev et al., 2002, Shtansky et al., 2004).

Results and discussions. The morphology of the formed coatings with copper content of 7 at% and 14 at% (Figure 2) is characterized by roughness (Ra) ~ 0.15 μm and cellular structure. The appearance of the cellular structure is explained by the repetition of the surface topography of the coating substrate. The relief is formed on the surface after gas-abrasive pretreatment. The end fractures and cross sections of the ceramic-metal coatings with the metal component content in the above range testify to their high density (Fig. 2 b, d). At the interface "substrate - coating" there are no cracks, pores and other discontinuities.

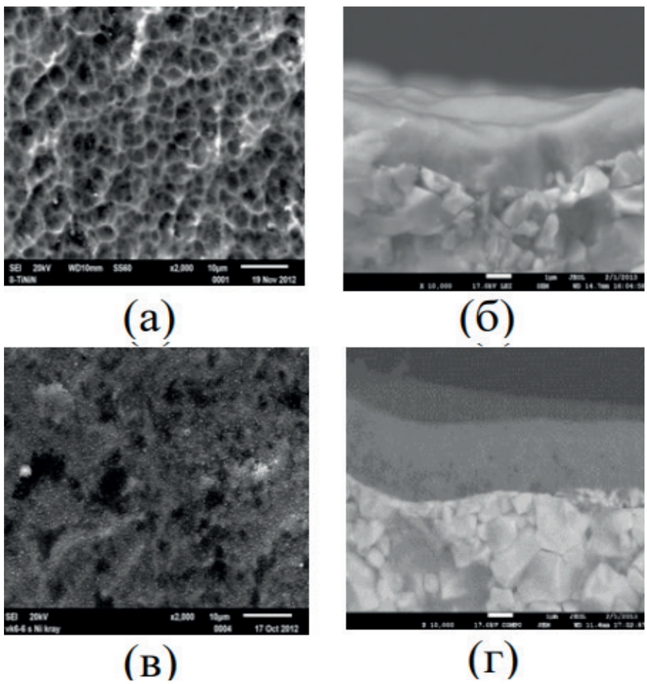


Figure 2 – Appearance of TiN-Cu coatings (а, б, в, г); with copper content: 7 at.% (а, б) and 14 at.% (в, г); (а, в) frontal image of coating; (б, г) image of coating fractures on substrate.

Figure 3 shows fractograms of ceramic-metal nanostructured coatings with different copper contents of 7 at. % and 14 at. %. As the ceramic-metallic coatings increase in copper content from 7 at. % and 14 at. %, respectively, they exhibit porosity, which increases as the amount of metal components in the composite increases.

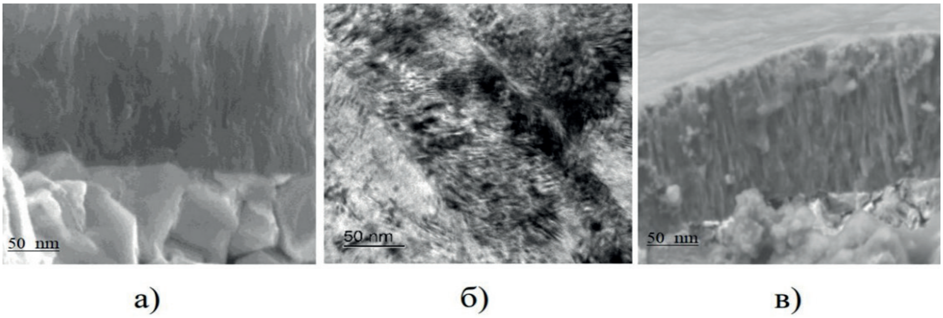


Figure 3 Fracture fractogram (a) and electron microscopic image (b) TiN-Cu 7 at. %, fracture fractogram of TiN-Cu 14 at.%

The appearance of porosity can be associated with poor wettability of titanium nitride with copper (Lifshits et al., 1950, Blinkov et al., 2015) (contact angle of wetting Θ ~134°-130° for stoichiometric TiN). Thus in the process of deposition of ceramic-metallic coatings formation of insular films of a metallic phase on the formed crystallites of titanium nitride is possible. As the copper content increases, these islands merge and the area of their contact with TiN grains decreases with the subsequent collapse of the resulting pores. Their presence is manifested in the structure of these coatings along with porosity in the form of light spherical inclusions of size ~ 20-25 nm.

The studied relative strain amplitude locus of the sample (6.9-51.8)x106 depends on the internal friction in the amplitude-independent and amplitude-dependent regions, according to Figure 4. In the second example, internal friction not only causes separation of dislocations from defects, but also moves dislocations to other regions. In order to fix the dislocations there, the atoms of the alloy's impurities need to change their positions. Figure 4 shows the kinks in the curves resulting from dislocation disruption and dislocation movement. If unstabilized carbon in the form of graphite is present in the steel composition, the amplitude curve of internal friction is accompanied by the maximum slope angle of the curve (tgα). Moreover, it has no locus of amplitude independence, where the distance between dislocations does not change. In other words, this sample, even if a minimum deformation-inducing force is applied to it, causes dislocation disruption and displacement, which dampens the sound energy.

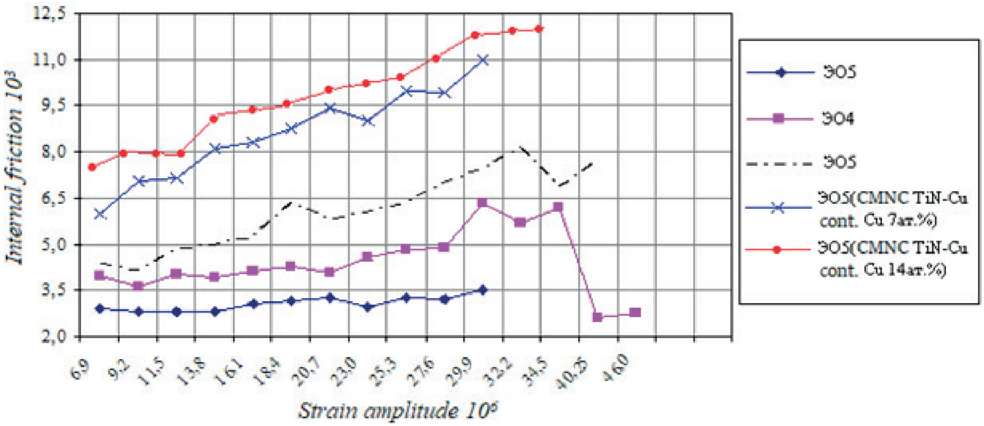


Figure 4 – Amplitude dependence of internal friction of the samples under study

The internal friction of this sample became almost 2 times greater with increasing amplitude of deformation, and increased from $6x10^{-3}$ to $11x10^{-3}$. Parameters of internal friction depending on amplitude of deformation can be seen in Table 1.

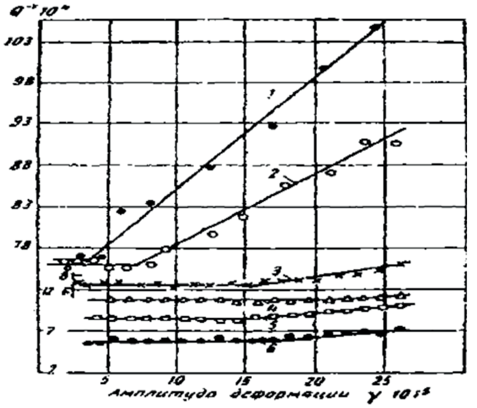
Table 1 – Amplitude dependence of internal friction of the samples under study.

Steel grade	Strain amplitude	Internal friction, $Q^{-1}x10^3$	Dispersion, $S^2 x10^3$
1	2	3	4
EO3	6,9	2,90	0,055
	9,2	2,83	0,041
	11,5	2,80	0,041
	13,8	2,82	0,018
	16,1	3,07	0,077
	18,4	3,18	0,138
	20,7	3,25	0,060
	23,0	2,96	0,020
	25,3	3,24	0,155
	27,6	3,22	0,182
	29,9	3,53	0,127
EO4	6,9	3,97	0,032
	9,2	3,63	0,153
	11,5	4,00	0,272
	13,8	3,94	0,088
	16,1	4,11	0,055
	18,4	4,26	0,062

	20,7	4,07	0,013
	23,0	4,55	0,014
	25,3	4,81	0,229
	27,6	4,90	0,000
	29,9	6,36	0,543
	32,2	5,71	0,031
	34,5	6,21	2,709
	32,2	2,62	0,065
	34,5	2,74	0,047
	40,25	2,64	0,052
	46,0	2,70	0,011
EO5	6,9	4,39	0,350
	9,2	4,13	0,063
	11,5	4,85	0,153
	13,8	4,98	0,348
	16,1	5,23	0,180
	18,4	6,33	1,435
	20,7	5,80	0,123
	23,0	6,04	0,029
	25,3	6,35	1,833
	27,6	7,01	0,147
	29,9	7,45	1,036
	32,2	8,13	2,040
	34,5	6,86	0,724
	40,25	7,69	8,297
EO5(CMNCTiN-Cucont. Cu7at.%)	6,9	5,988	0,089
	9,2	7,059	0,390
	11,5	7,154	0,057
	13,8	8,122	0,128
	16,1	8,335	0,019
	18,4	8,769	0,320
	20,7	9,432	0,129
	23,0	9,029	0,330
	25,3	9,963	0,738
	27,6	9,949	0,593
	29,9	10,973	0,178
EO5(CMNCTiN-Cu cont. Cu 14at.%)	6,9	7,154	0,089
	9,2	7,909	0,390
	11,5	7,980	0,057
	13,8	8,001	0,128
	16,1	9,029	0,019
	18,4	9,332	0,320
	20,7	9,732	0,129
	23,0	9,929	0,330
	25,3	9,863	0,738

	27,6	10,873	0,593
	29,9	10,873	0,178
	32,2	11,732	2,040
	34,5	11,929	0,724

The study of Figure 2 demonstrates that the silent sample EO5 (CMNC TiN-Cu with 14 at. % cont. Cu) is characterized by the highest vibration transmission abilities when compared with samples EO3, EO4 and EO5. The index of internal friction of sample EO5 (CMNC) indicates spontaneous dislocation disruption. Most likely, in the range of strain amplitudes, the dissipation of vibrational energy occurs when dislocations are released from atmospheric atoms of embedding against the background of applied force. Coating of ceramics and metal increases the damping qualities due to the change of sound velocity in the area of the junction of metal and nanostructure. The hypotheses are confirmed (Vetter et al., 1994., Utepov et al., 2017).



Temperature, °C: 1-470; 2-450; 3-400; 4-70; 5-350; 6-100

Figure5 – Correlation of Fec internal friction with amplitude during temperature changes (Vetter et al., 1994., Utepov et al., 2017)

The correlation of the acoustic pressure level from the internal friction established by the method of torsional undulation in the range of low frequencies (4 Hz) was revealed. Figure 5 confirms that the greater the index of internal friction, the higher the relaxation properties of acoustic wave energy. Increasing the internal friction from 0.5 to 1.7×10-3 induces a sound level change of 10 dBA. The results of the internal friction study can be seen in Table 2. Figure 4 shows the correlation of the acoustic level at contact interaction with the index of internal friction.

Table 2 – Internal friction levels and experience dispersion of alloys in the initial state (forging) 10^{-2}

Steel grade	Sound level, dBA	Internal friction , Q^{-1}	Dispersion, S^2*10^4
20KhN	74	$0.58*10^{-2}$	0,7124
20KhN4FA	72	$0.72*10^{-2}$	0,1655
25KhN2NMFA	70	$0.79*10^{-2}$	0,1154
EO3	67	$0.94*10^{-2}$	0,5248
EO4	65	$1.28*10^{-2}$	0,2924
EO5	56	$1.54*10^{-2}$	0,7255
EO5 (CMNC)	54	$1.72*10^{-2}$	0,4824

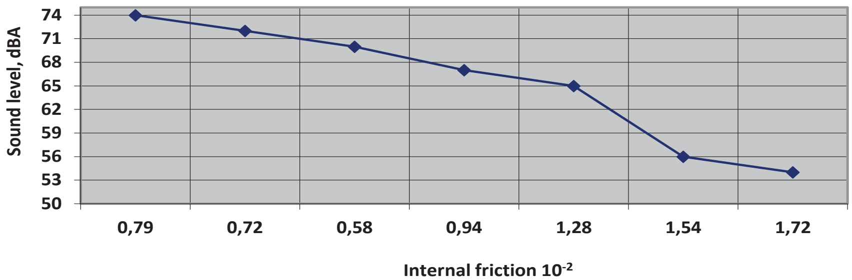


Figure 5 – Correlation of the acoustic level at contact interaction depending on the index of internal friction in the state (forging)

Analyzing the results, we can conclude that the information about internal friction can be used to study the damping properties of the samples under study. The acoustic level correlates with the internal friction.

The next physical structural-sensitive parameter of the damping characteristics of the steel investigated in the framework of the study was the specific electrical resistance (ρ), which was identified on the initial models, models after normalization and hardening. The results are shown in Tables 3-4. The interval of ρ readings increases from $6,7x10^{-6}$ to $14,6x10^{-6}$ Ohm*m during hot rolling followed by air cooling. The same interval becomes smaller after annealing. Quenching and tempering lower the resistivity of the alloys. This relationship can be seen in the correlation plots of acoustic level and resistivity in Figures 7-8.

Table3–Specific electrical resistance of the studied normalized samples

Steel grade	Average value of electrical resistance of the sample, Ohm	Specific electrical resistance p, Ohm*m, $x10^6$	Sound level, dBA
1	2	3	4
20KhN	255	6,4	70

20KhN4FA	185	10,3	72
25KhN2NMFA	265	6,2	74
EO3	186	8,5	67
EO4	171	10,1	65
EO5	325	5,1	56
EO5 (CMNC)	120	12,8	54

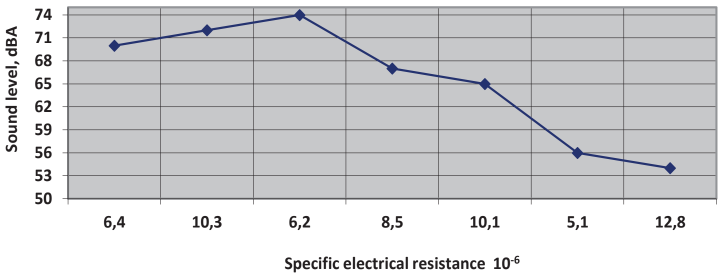


Figure7 – Specific electrical resistance of the studied normalized samples

Table4 – Specific electrical resistance of the studied hardened samples after low tempering

Steel grade	Average value of electrical resistance, Ohm	Specific electrical resistance p, Ohm*m x10^6	Dispersion of experiment, S^2 (Ohm·m)^2, x10^{-6}	RMS deviation, Ohm·m, 10^6	Sound level, dBA
20KhN	250	6,7	0,206	0,454	71
20KhN4FA	174	11,6	0,671	0,819	74
25KhN2NMFA	248	7,4	0,623	0,789	76
EO3	158	9,4	0,312	0,558	68
EO4	160	11,7	0,541	0,735	70
EO5	300	6,4	0,637	0,798	72
EO5 (CMNC)	110	14,6	0,432	0,657	74

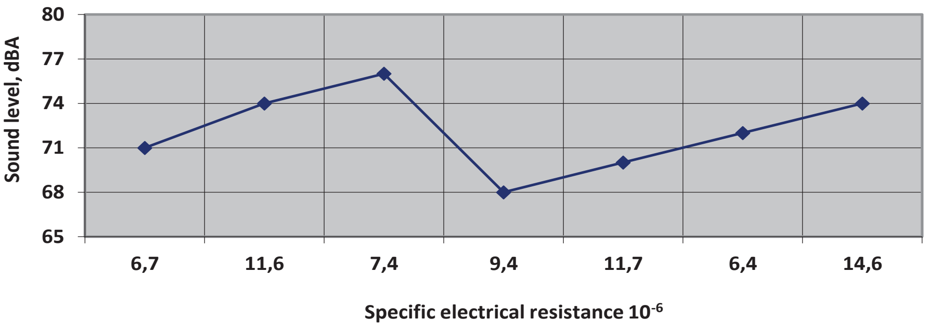


Figure 8 – Specific electrical resistance of the studied steels after quenching and low tempering

Table 5 shows the elastic properties of the studied alloys.

Table 5–Elastic properties of the studied alloys

Steel grade	Oscillation period, T, s	T^2, s^2	Shear modulus, Gx10^{10,} Pa	Young's modulus, Ex10^{10,} Pa
20KhN	0,1924	0,0370	8,108	19,945
20KhN4FA	0,1925	0,0371	8,086	19,891
25KhN2NMFA	0,1946	0,0379	7,915	19,471
EO3	0,1939	0,0375	8,000	19,680
EO4	0,1949	0,0379	7,915	19,471
EO5	0,1988	0,0395	7,595	18,683
EO5(CMNCTiN-Cu cont. Cu 7at.%)	0,1990	0,0396	7,575	18,635
EO5(CMNCTiN-Cu cont. Cu 14at.%)	0,1993	0,0398	7,555	18,605

As we know, sound also turns into heat when it is attenuated. The goal of the work was to find the correlation between electrical resistance and sound attenuation. As can be seen from Table 5, as the electrical resistivity increases, the sound level decreases, i.e. the damping increases.

The analysis of Table 1-5 shows that the damping and acoustic properties of the steels studied depend significantly on the type of heat treatment: quenching increases the damping properties, tempering, normalization and annealing reduce the dissipative properties. Steels after quenching with low and high tempering are of interest because their strength properties and hardness meet the requirements of impact parts. Comparison of dissipative properties of the known 20KhN, 20KhN4FA and 20KhN4FMA steels with the melted EO3, EO4 and EO5 steels shows that the damping properties of the melted steels are much higher than those of the known ones. The acoustic characteristics of the melted steels are also preferable compared to the known steels.

Conclusion. The results of the study of acoustic and physical-mechanical characteristics of the experimental alloys allow the following conclusions to be made. There is a close correlation between the internal friction and sound levels of the alloys. Experiments on investigation of amplitude dependence of internal friction allowed to reveal the dislocation mechanism of attenuation in the investigated alloys. The specific electrical resistance of the experimental alloys after hot forging and subsequent air cooling has a fairly wide range from 4x10-6 to 11x10-6. Normalization and quenching contribute to a decrease in the resistivity.

Thus, there is a weak directly proportional relationship between the sound level and the electrical resistivity. The modulus of elasticity affects the sound level only at the initial moment of impact, characterized by the duration of the maximum acoustic impulse τ = 20μs. At τ = 35 ms, the modulus of elasticity has no effect on the sound emission of steels.

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