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Study of the acoustic properties of new smelted steels alloyed with chromium, vanadium, and manganese

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Abstract. The article presents the results of a comprehensive study of the acoustic, damping, and vibration properties of newly cast steels alloyed with vanadium, chromium, and manganese. The relevance of the work is determined by the growing industrial need to reduce impact noise and vibration generated during the operation of machinery, mining, and metallurgical equipment. Increased acoustic loads lead to accelerated wear of components, reduced reliability of units, and adverse effects on workers, which makes the search for new materials particularly important. The study includes an analysis of literature data on existing noise-reduction methods and demonstrates the advantages of using alloys with enhanced internal damping compared to traditional structural materials. The experimental part was carried out by modeling impact processes using specialized measuring equipment that made it possible to record sound pressure levels, frequency spectra, and vibration decay rates. Special attention was paid to the influence of chemical composition, phase structure, and grain morphology on the acoustic characteristics of the steels. It was established that the optimal combination of alloying elements promotes the formation of a structure that provides more efficient vibration attenuation. The results obtained can be used in the development of new materials and protective components aimed at reducing industrial noise and increasing equipment durability.

Keywords: *impact noise, damping properties, acoustic properties, vanadium alloying, low-alloy steels, noise reduction.*

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1. Introduction

Reducing noise levels in the environment is one of the pressing tasks of modern science and technology. Among the various sources of acoustic impact, industrial noise occupies a special place, the level of which has increased significantly in recent years due to the widespread introduction of high-performance machines and mechanisms, as well as an increase in the operating speeds of equipment. The most common and harmful type of industrial noise is mechanical noise of impact and impulse origin, whose levels can reach 120 dB [1-5].

Impulse and impact noises are widespread in metallurgy, mechanical engineering, and transportation. Their unexpected impact can cause stress reactions, increased blood pressure, rapid breathing, arrhythmia, and decreased mental performance. Therefore, the problem of reducing impact noise is considered one of the priority areas of research related to improving the reliability and safety of machines and mechanisms.

Modern noise control methods include sound insulation, noise source shielding, sound absorption, vibration absorption, increasing structural rigidity, using damping devices and materials, and rational equipment placement. However, these approaches often involve an increase in the weight, size, and cost of machines, as well as a reduction in the manufacturability of structures. In particular, the use of non-metallic sound-absorbing materials (rubber, polyurethanes, plastics) is limited by their low strength and thermal stability, which makes them unsuitable for high temperatures and aggressive environments typical of the metallurgical and machine-building industries [2, 3].

In this regard, the use of metallic materials with enhanced damping properties that can effectively reduce the level of sound emission at its source is of particular interest. Such materials are distinguished by their simplicity of design, stability of properties when the frequency of vibrations changes, high strength, wear resistance, and a wide range of operating temperatures. Nevertheless, the damping mechanism of metal alloys has not been fully studied, and attempts to establish a functional relationship between the loss coefficient and other physical and mechanical characteristics have not yet yielded conclusive results.

The most promising for research are low-alloy structural steels used for the manufacture of critical machine parts – shafts, axles, gears, bushings, and couplings. These materials include 16Cr4 (AISI 5115), 20Cr4 (AISI 5120), 20MnCr5 (AISI 8620), and 16CrV4 (AISI 6150), which are distinguished by their combination of strength, wear resistance, and toughness after heat treatment.

This study examines the acoustic and damping properties of new low-alloy steels alloyed with manganese, chromium, and vanadium. Vanadium, being a constant component of most steels, significantly affects the nature of non-metallic inclusions and microstructure, while chromium and manganese contribute to increasing the strength and damping characteristics of the material [1, 5].

The aim of this work is to establish the patterns of influence of vanadium, chromium, and manganese alloying on the acoustic and damping properties of steels used under impact and friction loads, with the goal of developing materials that reduce impact noise in mechanical engineering.

For many decades, research into reducing industrial noise and vibration has attracted the attention of researchers in the fields of mechanical engineering, materials science, and acoustics. The problem of impulse and impact noise generated by modern high-speed equipment is particularly acute. Analysis of the literature shows that the level of impact noise in industrial conditions can reach 110-120 dB, which significantly exceeds acceptable health standards [6, 7].

According to [8-12], standard industrial sound level meters do not provide sufficient accuracy when measuring short-term sound pulses, since their integration periods do not meet the requirements for recording instantaneous peak values. To correctly measure impulse noise affecting the hearing organs, it is necessary to use devices with a constant integration time of about 20 μs, capable of recording peak sound pressure. Studies [13] have shown that even short sound pulses with an amplitude of up to 140 dB can cause damage to the hearing organs, despite their subjectively perceived lower volume.

In mechanical engineering and metallurgy, the source of intense impact noise is the collision of machine parts and mechanisms, for example, in pipe rolling mills, where the sound level reaches 110-118 dB [14]. In this regard, active research is being conducted to develop materials and structures with enhanced damping properties that can effectively absorb acoustic energy.

The most widely used methods of noise reduction are sound insulation, shielding, sound absorption, and vibration damping [15-19]. However, each of these approaches has significant drawbacks: increased machine dimensions, reduced compactness of structures, increased metal consumption, and more complicated operation. The use of special damping devices increases the cost and complicates the maintenance of equipment, and the rational placement of noisy units requires significant capital investments in the reconstruction of existing workshops.

The use of non-metallic materials (rubber, plastics, polyurethanes) as sound-absorbing elements is limited by their low strength and thermal stability, which makes them unsuitable for use in high-temperature conditions and aggressive environments. Therefore, increasing attention is being paid to metal alloys with a high coefficient of internal friction, which have the ability to dissipate the mechanical energy of vibrations into heat.

The literature notes that high-damping alloys often contain chromium, manganese, and vanadium as the main alloying elements [1, 2]. Manganese increases viscosity and fatigue resistance, chromium contributes to the strengthening of ferrite without reducing plasticity, and vanadium improves the microstructure and regulates the amount of non-metallic inclusions that affect sound attenuation. According to [4], there are more than three thousand grades of steel containing chromium, which confirms its versatility as an alloying element for alloys with high damping properties.

Research [5] have examined alternative methods for improving damping characteristics, including changing the geometry of metal surfaces and creating bimetallic composite materials (45 steel-copper MT, X18H10T steel-AMGS alloy, X18H10T steel-copper M1, etc.) obtained by hot rolling and explosion welding. These materials have shown high efficiency in noise absorption, but their production is technologically complex and expensive.

Despite the results achieved, the problem of creating economical, strong, and durable materials with high internal damping remains unresolved. In particular, the damping mechanisms in low-alloy steels used in mechanical engineering, as well as the influence of vanadium alloying on their acoustic and physical-mechanical properties, have not been sufficiently studied. This circumstance determines the relevance of the present study, aimed at finding patterns that ensure a reduction in impact noise by optimizing the composition of steels and the structure of the material.

2. Materials and methods

Standard steels for castings of grades 16Cr4 – AISI 5115, 20Cr4 – AISI 5120, 20MnCr5 – AISI 8620, 16CrV4 – AISI 6150), used for shafts, axles, gears, and couplings, alloyed with chromium, manganese, and vanadium, whose mechanical characteristics are given.

Scrap metal, ferroalloys, waste from our own production, and armored iron were used as metal charge materials. A RelTEC crucible induction furnace was used for smelting. Sheet metal made of 10 steel served as the starting material. Alloying was carried out with 97.6% metallic manganese, 77.5% FeSi, and 99.98% metallic nickel. Synthetic cast iron with a carbon content of 3.9% served as a carbon-containing additive. The steel was cast into a metal mold measuring 210 x 115 x 115 mm.

Based on research into equipment for studying the acoustic proprieties (sound level, sound pressure level) of steels, a device was used for comprehensive research into the acoustic and vibration properties of plate and tubular steel samples, with further modernization. The operational scheme of the setup is shown in Figure 1.

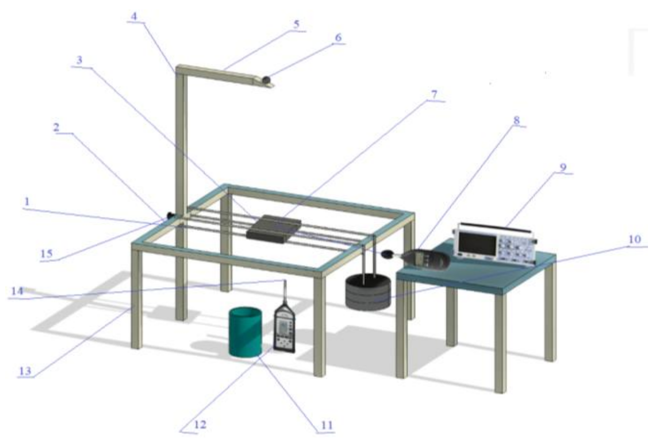

Figure 1. Device for comprehensive acoustic investigation [13]: 1 – capron threads; 2 - frame; 3 – sample plate; 4 – frame stand; 5 – inclined plane; 6 – ball impactor; 7 – vibration sensor of the Bruel & Kjer sound level meter; 8 – Bruel & Kjer sound level meter model 2204 with octave filter model 1613; 9 – S-18 oscilloscope; 10 – load; 11 – ball receiver; 12 – «Octava 101A» sound level meter; 13 – frame stands; 14 – microphone of the «Octava 101A» sound level meter; 15 – screw for securing the impactor stand

The ball impactor 6 was placed on the inclined plane 5, down which it rolled and then freely fell onto the geometric center of the plate sample 3. The ball impactor 6 rebounds from the plate sample and is caught in the ball receiver 11. The sound generated as a result of the collision between the ball impactor 6 and the sample 3 is recorded using the «Octava-101A» sound level meter 12.

The plate sample 3, while vibrating in the capron threads 1, causes vibrations that are measured by the Model 2204 apparatus 8 from the company «Bruel&Kjer». The tension of the sample using the capron threads 1 is stable because the load 10 controls the tension force.

The height of the ball's fall is adjusted using the screw for securing the impactor stand 15. The complex consisting of the fastening of the sample 3 and the ball impactor 6 is fixed to the frame 2, which is secured by stands 3 at the required height above the floor.

For the purpose of measurement, ball impactors (SHKh15) made of steel with diameters of 7 mm (1.40 g), 8 mm (2.09 g), 9 mm (2.97 g), and 11 mm (5.55 g) were used.

The study of steel plate samples (50 x 50 x 5) mm was carried out 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 ratio:

$$m \langle 4.6\cdot\rho\cdot l\cdot h^2 , \qquad (1)$$

where m is the mass of the sample plate, g; ρ is the density of the sample plate material, g/cm^3; l is the distance from the point of impact to the nearest edge of the sample plate, cm; h is the thickness of the sample plate, cm.

The width and length of the sample plate must be 5 times greater than its thickness. An experimental plate with dimensions of 50x50x5 mm meets these characteristics.

The sound pressure levels were measured in octave frequency bands ranging from 31.5 to 31 500 Hz, and the vibration acceleration levels were measured in the range from 31.5 to 31,500 Hz. The sound level was adjusted according to the «A» scale, and the overall vibration acceleration level was adjusted according to the «Lin» characteristic.

The ZG-10 sound generator was used to calibrate the sound signal studies. Corrections for changes in the sound signal depending on atmospheric pressure were made using a PF-101 pistonphone. A constant air temperature and humidity were maintained in the laboratory. Acoustic measurements were calculated as the arithmetic mean of five measurements [13]. The sound pulse generated by the collision of the sample under study with the striker was recorded using a storage oscilloscope, after which it was photographed and the damping parameters were determined: logarithmic decrement, sound attenuation rate, relative scattering, and internal friction.

3. Results and discussion

When developing high-damping alloys, one of the main criteria is that there should be no significant reduction in strength properties. Therefore, one of the reasons for choosing chromium, manganese, and vanadium as alloying elements for iron-carbon alloys was that, among the main alloying elements (the most commonly used), these elements strengthen ferrite more than others (Table 1).

Table 1. Chemical composition and mechanical properties of the studied steels

Steel grade	Chemical composition, % by weight						Mechanical properties				
	C	Si	Mn	Cr	V	Other elements	σ_t, MPa	$\delta5$, %	ψ, %	a_n, J/cm^2	σ_y, MPa
16Cr4	0.12-0.18	0.17-0.37	0.4-0.7	0.7-1.0	-	≤0.035 S;	700	12	45	70	500
20Cr4	0.17-0.23	0.17-0.37	0.5-0.8	0.5-0.8	-	≤0.035 P;	800	11	40	60	650
20MnCr5	0.15-0.21	0.17-0.37	0.9-1.2	0.9-1.2	-	≤0.30 Cu;	900	10	40	-	750
16CrV4	0.12-0.18	0.17-0.37	0.4-0.7	0.8-1.1	-	≤0.3 Ni	750	13	50	80	550
BO-1	0.23	0.15	0.9	1.7	0.47	0.035 S;	650	12	35	70	520
BO-2	0.15	0.25	0.99	1.3	0.42	0.035 P;	720	10	40	75	580
BO-3	0.28	0.2	0.51	1.2	0.56	0.35 Cu;	810	15	45	71	680
BO-4	0.13	0.17	0.45	1.5	0.51	0.4 Ni	880	11	50	78	720

Note: σ_t is tensile strength, MPa; $\delta5$ is relative elongation after rupture on five-fold length specimens, %; ψ is relative reduction in area after rupture, %; a_n is impact strength, J/cm^2; σ_y is yield strength, MPa.

The lack of modern acoustic equipment capable of measuring peak values of impulse sound signals was an obstacle to solving this problem. In this study, sound pressure levels were studied during impact excitation of various alloys using a modern Octava-101A sound level meter, which allows measuring the peak value of a pulsed sound signal that characterizes the initial impact effect with a maximum sound pressure duration of $T = 20$ μs. The secondary effect of the collision was recorded on the «Impulse» scale with an integration time of $T = 35$ ms. This time characterizes the average time of sound perception by human auditory organs. To determine the time of registration of the impact sound pulse, the sound pressure levels and sound levels were studied on the same alloys with an integration time of 7-35 ms and a peak sound pulse delay of 20 μs. Table 2 shows the sound levels and sound pressures of alloys at different integration time constant values of the equipment used.

As can be seen from Table 2 when measuring a sound signal with a duration of $T = 20$ μs, which practically characterizes the instantaneous value of the impact sound pulse, the sound pressure levels for all the alloys studied are close to each other regardless of the chemical composition and type of heat treatment of the samples.

The sound levels of all alloys at this integration time are the same and amount to 125 dBA. Exceedance of peak sound pressure levels above the values on the «Impulse» scale was detected across the entire frequency range and averaged 15 dB, with a difference in sound levels of 13 dBA. However, Table 4 shows that the sound pressure levels at $T = 35$ ms for alloys BO-1 and BO-2 at a frequency of 8.16 kHz do not differ from the peak values of the sound signal at $T = 20$ μs. The reason for this is apparently the increased elastic modulus values for these steels.

Table 2. Average values of sound levels and sound pressure levels of experimental alloys after various types of heat treatment and at different sound pulse integration times

Alloy number	Integration time	Sound pressure levels, dB, in octave bands with geometric mean frequencies, Hz						Type of heat treatment	Sound level, dBA
		500	1000	2000	4000	8000	16000		
BO-1	35 ms	62	67	63	88	112	112	normalization	111
BO-1	20 µs	76	85	97	105	121	120	normalization	125
BO-2	35 ms	56	63	68	87	112	113	normalization	112
BO-2	20 µs	77	84	97	105	120	119	normalization	125
BO-3	35 ms	70	73	75	79	98	102	normalization	109
BO-3	20 µs	76	84	96	105	119	125	normalization	125
BO-4	35 ms	56	63	64	81	110	97	quenching, low tempering	100
BO-4	20 µs	76	84	97	107	113	113	quenching, low tempering	125
16Cr4	35 ms	50	69	73	78	107	112	quenching	110
16Cr4	20 µs	77	84	97	105	121	119	quenching	125
20Cr4	35 ms	68	69	77	91	110	107	normalization	113
20Cr4	20 µs	82	86	97	107	125	121	normalization	125

While the chemical composition and type of heat treatment had virtually no effect on peak sound and sound pressure levels, changing the thickness of the sample from 5 to 4 mm contributed to an average increase in these properties of 3 dB.

Based on the results of the experiment, it can be concluded that the sound pressure levels 35 ms after collision characterize the dissipative properties of the colliding parts. The attenuation of sound vibrations in metal materials in our experiment over 35 ms ranges from 3.5 to 17.5 dBA at a sound attenuation rate of 100 to 750 dB/s, respectively. The acoustic properties were measured on a newly created setup.

Figure 2 show the average values of sound levels and sound pressure levels in octave bands of geometric mean frequencies of the studied steels after normalization.

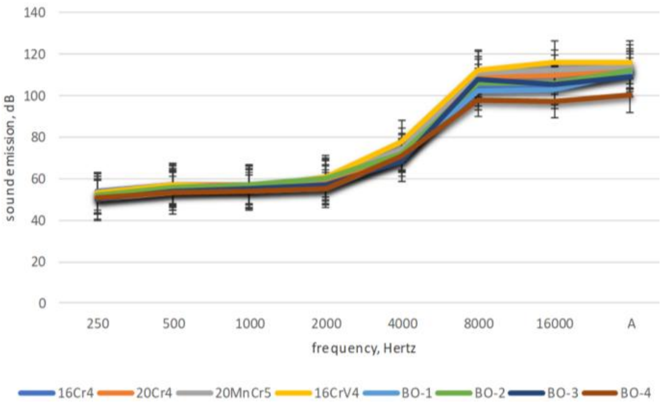

Figure 2. Average values of sound levels and sound pressure levels of the investigated steels after normalization

As can be seen from Figure 2, the peak of the SPL is at frequencies of 8000 and 16000 Hz (112-116 dB). The minimum of the SPL is at a frequency of 250 Hz (50-54 dB).

The sound levels of the alloys studied vary between 110 and 116 dBA. The «loudest» alloys during collisions are 16Cr4 (116 dBA), 18ХГ (114 dBA), and 20Cr4 (113 dBA). The BO-4 damping alloy stands out from all other alloys due to its low sound level (100 dBA) and relatively low sound pressure levels. The reason for the high damping properties of the BO-4 alloy (0.13% C; 0.17% Si; 0.45% Mn; 1.5% Cr; 0.51% V, the rest being iron) after normalization is structural damping due to the formation of large metal grains.

The above-mentioned alloys, after cementation and subsequent quenching and low tempering, exhibit increased damping properties compared to normalization. As can be seen in Figure 3, the maximum sound pressure levels in the octave bands of mean geometric frequencies are also at 8000 and 16000 Hz (95-110 dB). The minimum levels are at 250-500 Hz (50-58 dB).

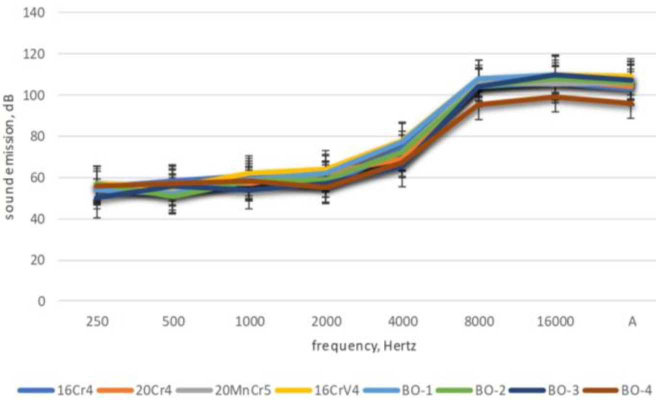

Figure 3. Average values of sound levels and sound pressure levels of the investigated steels after carburizing, quenching, and low tempering

Figure 3 clearly shows how the sound pressure levels change after normalization, carburizing followed by quenching, and low tempering. After carburizing followed by quenching and low tempering, the sound pressure levels of the alloys decrease by 4–8 dBA compared to normalization.

The BO-4 alloy is characterized by minimum sound levels (96 dB(A)) and sound pressure levels in octave frequency bands.

After cementation followed by quenching and low tempering, the sound pressure levels of the alloys decrease by (4-8 dBA) compared to normalization.

Figure 4 shows the microstructures of samples BO-3 and BO-4, respectively, after thermomechanical treatment for three cycles.

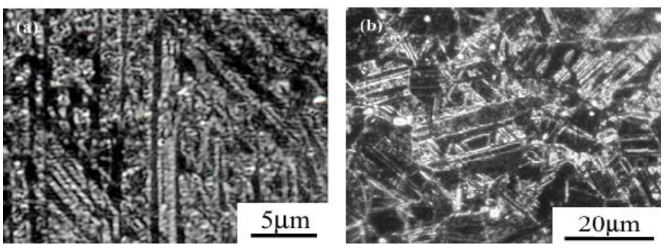

Figure 4. Microstructure of samples BO-3 (a) and BO-4 (b)

The effect of manganese content within the range of 0.5-1.0% on the acoustic properties of alloys is not noticeable. Although according to data, manganese and manganese-based alloys have high damping capacity at low and high deformation amplitudes ($\varphi = 7$-40%), in Fe-Mn alloys -C alloys, the damping capacity is mainly determined by the carbon content and the influence of manganese on phase transformations.

Manganese, dissolving in ferrite and combining with carbon to form carbides, increases the hardness and strength of steel. Due to the fact that in the presence of manganese, transformations shift to lower temperatures and eutectoid forms at lower carbon concentrations, the structure of manganese steels is less differentiated. By causing significant supercooling and increasing the stability of austenite during isothermal transformation and in the upper and lower martensite temperature ranges, manganese contributes to the formation of large amounts of residual austenite and the possibility of a-phase formation. Since manganese forms carbides that are easily soluble in austenite, the steels under study, even with slight overheating (900-950°C, 1 hour in the furnace), had large and coarse grains, both in hypoeutectoid and hypereutectoid steel. However, the formation of large coarse grains led to an improvement in the damping capacity of the steel.

4. Conclusions

Based on experimental studies of the acoustic properties of alloyed steels, it has been established that sound pressure levels during impact excitation depend mainly on the structure and thickness of the sample, while the chemical composition and type of heat treatment have less influence on peak sound values. When measuring peak pulses with a duration of 20 μs, the sound pressure levels for all the steels studied are practically the same and amount to about 125 dBA, which corresponds to the instantaneous effect of collision.

Measurements taken at an integration time of 35 ms showed that the sound pressure values obtained characterize the dissipative (damping) properties of the alloys. The attenuation of sound vibrations in metallic materials over 35 ms is 3.5-17.5 dBA at an attenuation rate of 100-750 dB/s, which reflects the difference in the ability of alloys to absorb acoustic energy.

The alloy BO-4 (0.13% C; 0.17% Si; 0.45% Mn; 1.5% Cr; 0.51% V, the rest being iron), which exhibited the lowest sound level of 96-100 dBA after normalization and cementation followed by quenching and low tempering. The increased acoustic resistance of this alloy is explained by structural damping caused by the formation of a coarse-grained microstructure.

It has been shown that alloying steels with vanadium, chromium, and manganese improves their elastic and damping characteristics without significantly reducing their strength properties. It has also been established that increasing the manganese content within the range of 0.5-1.0% does not have a noticeable effect on acoustic characteristics, but contributes to the formation of residual austenite and improves viscosity.

Thus, the developed and researched vanadium-containing low-alloy steels have an optimal combination of strength and damping properties, which allows them to be recommended for use in mechanical engineering in the manufacture of parts subject to shock and vibration loads (gears, axles, shafts, couplings, etc.).

Author contributions

Conceptualization: RZA, GAB; Data curation: RZA, AVB, GAB; Formal analysis: GAB; Funding acquisition: RZA, GAB; Investigation: RZA; Methodology: RZA, GAB; Project administration: RZA; Resources: RZA, GAB; Software: AVB, GAB; Supervision: GAB, RZA; Validation: RZA, GAB; Visualization: AVB, GAB; Writing – original draft: RZA, AVB, GAB; Writing – review & editing: RZA, AVB, GAB. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Хром ванадий марганецпен легирленген жаңа балқытылған болаттардың акустикалық қасиеттерін зерттеу

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Аңдатпа. Мақалада ванадий, хром және марганец элементтерімен легірленген жаңа балқытылған болаттардың акустикалық, демпферлік және дірілдік қасиеттерін кешенді зерттеу нәтижелері келтірілген. Жұмыстың өзектілігі өнеркәсіптің машина жасау, тау-кен және металлургия жабдықтарын пайдалану кезінде туындайтын соққы шуы мен діріл деңгейін төмендету қажеттілігінің артуына байланысты. Акустикалық жүктемелердің жоғарылауы бөлшектердің тез тозуына, қондырғылардың сенімділігінің төмендеуіне және жұмысшыларға жағымсыз әсерлерге әкеледі, бұл жаңа материалдарды іздеуді ерекше сұраныcқа ие етеді. Зерттеу барысында шуды болдырмаудың қолданыстағы әдістері бойынша әдеби деректерге талдау жүргізілді және дәстүрлі құрылымдық материалдармен салыстырғанда ішкі демпфері жоғары қорытпаларды пайдаланудың артықшылықтары көрсетілді. Эксперименттік бөлік дыбыс қысымының деңгейін, жиілік спектрін және тербелістердің ыдырау жылдамдығын түсіруге мүмкіндік беретін арнайы өлшеу жабдығын қолдана отырып, соққы процестерін модельдеу негізінде орындалды. Химиялық құрамның, фазалық құрылымның және астық морфологиясының болаттардың акустикалық сипаттамаларына әсеріне ерекше назар аударылады. Легирлеуші элементтердің оңтайлы үйлесімі тербелістерді тиімдірек сөндіруді қамтамасыз ететін құрылымның қалыптасуына ықпал ететіні анықталды. Алынған нәтижелер өндірістік шуды азайтуға және жабдықтың беріктігін арттыруға бағытталған жаңа материалдар мен қорғаныс элементтерін әзірлеу кезінде пайдаланылуы мүмкін.

Негізгі сөздер: *соққы шуы, демпферлік қасиеттер, акустикалық өнімділік, ванадиймен легірлеу, төмен легірленген болаттар, дыбыс шығаруды бәсеңдету.*

Исследование акустических свойств новых выплавленных сталей, легированных хромом ванадием марганцем

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Аннотация. В статье представлены результаты комплексного исследования акустических, демпфирующих и вибрационных свойств новых выплавленных сталей, легированных ванадием, хромом и марганцем. Актуальность работы обусловлена возрастающей потребностью промышленности в снижении уровня ударного шума и вибраций, возникающих при эксплуатации машиностроительного, горнорудного и металлургического оборудования. Повышенные акустические нагрузки приводят к ускоренному износу деталей, снижению надёжности агрегатов и неблагоприятному воздействию на работников, что делает поиск новых материалов особенно востребованным. В ходе исследования проведён анализ литературных данных по существующим методам шумоподавления и продемонстрированы преимущества использования сплавов с повышенным внутренним демпфированием по сравнению с традиционными конструкционными материалами. Экспериментальная часть выполнялась на основе моделирования ударных процессов с применением специализированного измерительного оборудования, позволяющего фиксировать уровень звукового давления, частотный спектр и скорость затухания колебаний. Особое внимание уделено влиянию химического состава, фазовой структуры и морфологии зерна на акустические характеристики сталей. Установлено, что оптимальное сочетание легирующих элементов способствует формированию структуры, обеспечивающей более эффективное гашение колебаний. Полученные результаты могут быть использованы при разработке новых материалов и защитных элементов, направленных на снижение производственного шума и повышение долговечности оборудования.

Ключевые слова: *ударный шум, демпфирующие свойства, акустические характеристики, легирование ванадием, низколегированные стали, снижение звукоизлучения.*

Publisher's note