The object of this study is carbon and alloy steels for parts with high surface hardness and increased wear resistance at low deformation. Carbon steels 40, 45, and similar steels with increased manganese content 40G, 45G, 50G are used to manufacture a wide variety of machine parts. Most often, these steels are used for articles that bear the greatest impact loads. Machine parts are exposed to vibration and impact, which results in the generation of intense noise. Noise has a negative impact on human health and reduces performance. One of the ways to solve this problem is to reduce noise by damping it at the source. The results of studies conducted in this area have made it possible to design damping alloys, subject to taking into account the operation of the parts, the percentage of alloying elements, carbon-containing additives, temperature, holding, and not allowing a decrease in the strength properties of the developed alloys.

Chromium, manganese, silicon, and nickel were selected as alloying elements for the designed alloys. The chemical composition of the studied carbon alloy steels, average values of sound levels, and sound pressure levels of the studied steels after forging, annealing, and normalization were analyzed.

The ADM-1 grade alloy has been proposed for the manufacture of the main transport units (crankshafts, connecting rods, gear rims, passenger car axle shafts, camshafts). Comparison of the acoustic properties (frequency spectrum in octave bands) of the designed steels and known steels with high surface hardness and increased wear resistance after various types of heat treatment has made it possible to identify a pattern. At frequencies of 8000 and 16000 Hz, the designed steels ADM-1, ADM-2, ADM-3 emit noise 6–13 dB lower than similar steels 40, 45, 40G, 45G, 50G

Keywords: noise pollution, high-damping steels, damping, amplitude of sound, level of sound pressure

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DESIGNING DAMPING ALLOYS FOR TRANSPORT EQUIPMENT

Dariya Akubayeva
Candidate of Technical Sciences
UNESCO Chair in Sustainable
Al-Farabi Kazakh National University
Al-Farabi ave., 71, Almaty,
Republic of Kazakhstan, 050040
Roza Zhumagulova
Corresponding author
Candidate of Technical Sciences, Professor,
Head of Department*
E-mail: roza_j@mail.ru
Gulzhanar Zharaspaeva
Candidate of Technical Sciences*
Galiya Azhiyeva
Candidate of Technical Sciences*
*Department of Technical and Natural Sciences
International Educational Corporation
Ryskulbekova str., 28, Almaty,
Republic of Kazakhstan, 050043

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1. Introduction

In modern cities there are hundreds of mobile and stationary sources of external noise – transport, industrial, construction, road vehicles and units, loading and unloading yards of stores, warehouses, public utilities, playgrounds, and sports grounds, etc.

Under conditions of strong urban noise, there is constant strain on the auditory analyzer. This causes an increase in the hearing threshold by 10–25 dB. Noise makes speech intelligibility difficult, especially at a level of over 70 dB.

Noise in large cities shortens human life expectancy. According to Austrian researchers, this reduction ranges from 8 to 12 years. Excessive noise can cause nervous exhaustion, mental depression, autonomic neurosis, peptic ulcer disease, endocrine and cardiovascular disorders. Noise interferes with people's work and rest, reduces labor productivity.

There is a relationship between the number of complaints and the nature of the work performed. The disturbing effect of noise affects people engaged in mental work more than people performing physical work (60 % and 55 %, respectively) [1–3].

According to the Department of Automobile Transport of Almaty, the Republic of Kazakhstan, the share of motor transport alone in the total emissions of pollutants into the atmosphere reaches 60 %, and the share of motor transport in the acoustic impact on the population of cities reaches 75–85 %. Rail transport, having a smaller specific contribution to the acoustic impact on the population, has high levels of impact, exceeding the noise of motor transport. The amount of annual environmental damage from motor transport alone reaches 2–3 % of the gross national product of Kazakhstan. The annual environmental damage from the operation of the transport complex in Kazakhstan is estimated at billion US dollars, with the main share of the damage associated with the impact of harmful emissions and acoustic impact [4].

One of the sources of noise is transport. Noise pollution from transport (motor, rail) is observed both on the roads and in production (mining transport vehicles, conveyors).

Analysis of the data in Table 1 reveals that the predominant harmful factor from the impact of motor transport on the environment is acoustic pollution [5–7].

Partially, mechanical noise of transport equipment is generated as a result of friction, impact of parts and units. One of the effective methods of noise control is its damping at the source of its occurrence (replacement of impact processes with non-impact ones, replacement of gear pairs with V-belt ones, use of non-metals, damping alloys).

Damping alloys for parts of transport equipment to reduce noise and vibration are extremely rarely used, although this is one of the modern and promising techniques for reducing noise of transport equipment.

Table 1

Impact of motor transport on the atmosphere [8]

Harmful factor	Standardized characteristic	Size of SPZ, m
Harmful chemicals	MPC, mg/m^3	30–60 (to 100)
Suspended substances	MPC, mg/m^3	20–30 (to 50)
Electromagnetic fields	MPL, A/m	10–20
Increased noise	MPL, dBs	600–1000
Infrasound	MPL, dB	40–70 (to 200)
Due to the wide range of MPC and MPL of various pollutants, specific values are not given		

Note: SPZ – sanitary protection zone; MPC – maximum permissible concentration; MPL – maximum permissible level.

Therefore, research into combating noise at the source of its occurrence and designing damping alloys is relevant.

2. Literature review and problem statement

Paper [9] reports the results of a study on magnesium alloy AZ61, which was subjected to heat treatment. As a result, it was proven that an increase in internal damping is achieved by the alloy after plastic deformation. However, questions about sound production of this alloy remained unresolved, which may be associated with additional costs.

Work [10] studies magnesium alloys: the mechanism of plastic deformation, strengthening, design of new materials and processing technologies, operational properties. The widespread use of magnesium alloys is limited by low corrosion resistance, depending on the microstructure and introduced alloying elements. However, magnesium is not considered as an additive to other alloys. This is due to the fact that magnesium is studied as the main component of the alloy.

Paper [11] investigates the effect of adding alloying elements Ag and Nb on alloys. It has been shown that in Cu-Al-Mn shape memory alloys (SMA) based on copper, the damping capacity and mechanical strength are improved by optimizing the chemical composition. However, the issues of reducing emitted sounds have not been studied. This may be due to increased material and energy costs.

In [12], the attenuation process of metallic materials is studied using aluminum alloy 6061 as an example. It has been shown that the damping properties of this alloy depend on many factors, including frequency, deformation amplitude or stress, temperature, corrosion fatigue, grain size, and porosity. It has been revealed that there is a functional relationship between attenuation, the number of cycles, and the applied stress. However, it has not been revealed how this alloy maintains its damping properties. This may be due to the need for additional thermal exposure.

Paper [13] examines transverse vibrations and mechanical properties of aluminum nanocomposites, Al7020 alloy (Al-Zn-Mg alloy) and aluminum-multi-walled carbon nanotube (Al-MWCNT) nanocomposites. It is shown that Al-MWCNT nanocomposites demonstrated the most stable structure when tested for transverse vibration at maximum applied load and higher frequencies. The mechanical properties of aluminum alloys and nanocomposites are considered, but the issues of studying their sound-absorbing characteristics remain unresolved, which may be due to the complexity of working with nanoparticles.

Pointing to the growing demand for lightweight, high-strength, and damping materials, work [14] studies magnesium alloys Mg-Zr, Mg-Cu-Mn, as well as composites with a magnesium matrix and porous magnesium. By investigating the progress in the field of damping magnesium alloys with integrated structures and functions, their development trends are predicted. The damping characteristics and mechanical properties are investigated, but there is still a lack of data on acoustic studies.

In [15], the sound-absorbing and damping properties of fiber-reinforced and nanoparticle-reinforced polymer matrix composites are considered. With the activation of the use of composite materials, they have revealed the influence of the parameters of thickness, porosity, viscoelasticity and density and the inclusion of nanoparticles in the polymer matrix on the acoustic characteristics of polymer matrix steels. These materials effectively absorb any types of vibrations: acoustic and mechanical but have low strength properties and are not used as structural materials for the purpose of damping.

In [16], transverse vibrations and mechanical properties of aluminum alloy and nanocomposites are investigated. It is shown that Al7020 alloy has the highest tensile strength, axial rigidity, etc. compared to other samples.

In [17], three groups of samples with different content of carbon, copper and phosphorus were prepared to study changes in the chemical composition. It is shown that a change in the chemical composition is one of the most important parameters affecting the microstructure and mechanical properties of powder metallurgy parts. But the issues of reducing sound vibrations in these samples have not been resolved. Powder metallurgy is associated with complex technological processes and additional research may be costly.

In [18], Mg97Zn1Y2 alloy and the effect of adding Al are studied. It was found that Mg97Zn1Y2-3 wt. %Al alloy has the best mechanical and damping characteristics. However, no results of studies of the acoustic characteristics of this alloy are given. This may be due to their structure and mechanical behavior, which may lead to a decrease in corrosion resistance.

Thus, there is a problem of assessing the damping and acoustic properties of alloys, in particular the sound level and sound pressure. This requires designing appropriate alloys, including high-damping steels.

3. The aim and objectives of the study

The aim of our study is to design damping alloys to reduce noise in transport equipment. The designed alloys with increased dissipative properties, alloyed with chromium, nickel, manganese, and silicon will improve working conditions by reducing noise during collisions.

To achieve these goals, the following tasks were set:

– to smelt alloys with increased damping properties;

– to evaluate the damping, acoustic, characteristics of the designed and standard steel grades;

– to investigate the designed high-damping alloys.

4. The study materials and methods

Carbon and alloy steels for parts with high surface hardness and increased wear resistance at low deformation were chosen as the object of our study. Carbon steels 40, 45, and similar steels with increased manganese content 40G, 45G, 50G are used to manufacture a wide variety of machine parts.

Manganese steels (40G, 45G, 50G) have high hardenability, but manganese increases the tendency to grain growth. Therefore, they are sensitive to overheating and can have reduced impact toughness, especially at sub-zero temperatures. Most often, these steels are used for articles that bear the greatest impact loads.

The above parts are subject to vibration and impact effects, which results in intense noise.

The hypothesis of the study assumed that alloying with silicon, manganese, chromium, nickel in combination with rational heat treatment modes could make it possible to obtain steel with increased damping properties, without compromising the strength characteristics.

It was assumed that the results of the study of the obtained alloys for their acoustic and damping characteristics, in the case of confirmation of the effectiveness of the proposed solutions for the composition and technological modes of production, would make it possible to recommend these alloys for practical use. The smelted alloys were labeled as ADM-1, ADM-2, ADM-3, ADM-4; the technology for their production involved alloying with silicon, manganese, chromium, nickel, as well as heat treatment.

5. Results of investigating the acoustic properties of alloys used for parts of transport equipment

5. 1. Technological modes for obtaining steel with increased damping properties

Table 2 gives the chemical compositions of the steels used and designed.

Table 2

Chemical composition and mechanical properties of the studied carbon alloy steels (data from [8] were used)

Steel grade	Chemical composition, % weight					
	C	Si	Mn	Cr	Ni	Other elements
40	0.37–0.45	0.17–0.37	0.50–0.80	0.25	≤0.3	S≤0.035; P≤0.035 Cu≤0.30
45	0.42–0.50		0.50–0.80	0.25	≤0.3	
40G	0.37–0.45		0.70–1.00	0.30	≤0.3	
45G	0.42–0.50		0.60–1.00		≤0.3	
50G	0.48–0.56		0.70–1.00		≤0.3	
ADM–1	0.40	1.9	0.7	0.9	0.4	S=0.035; P=0.035; Cu=0.35; Al=0.02; Bi=0.01; Ti=0.03
ADM–2	0.42	0.20	0.8	0.8	0.5	
ADM–3	0.41	0.30	0.7	0.8	0.6	
ADM–4	0.48	0.32	0.9	0.8	0.8	–

The content of alloying elements in steel was determined based on the study of the Fe-C, Fe-Cr, Fe-Mn, Fe-Si, Fe-Ni diagrams. Chromium, silicon, manganese, and nickel are among the most commonly used special alloying elements. The addition of alloying elements varied within the following limits: chromium 0.8–0.9 %, manganese from 0.7 % to 0.9 %, silicon from 0.2 % to 1.9 %, nickel from 0.4 to 0.8 %.

The choice of chromium, manganese, silicon, and nickel as alloying elements is explained by the following. Chromium contributes to obtaining high and uniform hardness of steels. Steels alloyed with chromium have higher hardenability. It, dissolving in ferrite and cementite, has a beneficial effect on the mechanical properties of steel, which predetermined its wide application in structural steels. Manganese increases the strength of steel in hot-rolled articles and reduces the red brittleness of steel. Manganese is often used as a substitute for nickel, it significantly increases the yield strength of steel. Manganese additives of 2–4 % affect the damping properties of alloys.

Silicon is a chemical element that is constantly present in steels, and it has a significant effect on the composition and nature of non-metallic inclusions. Silicon is the most effective graphitizer in steel, and the presence of graphite increases the tendency of steel to irreversible dissipation of vibration energy. It greatly increases the yield strength, reduces viscosity, and increases the cold brittleness threshold when the content is over 1 %. Manganese and silicon are usually introduced into steel for deoxidation.

The choice of nickel as an alloying element is explained by the fact that this element is also widely used in high-damping alloys. Additions of nickel to other metals significantly change their properties and create opportunities for obtaining a wide range of various very valuable materials. Strongly strengthening ferrite, nickel does not reduce its viscosity and lowers the cold brittleness threshold, while other elements, if they do not reduce viscosity (Cr), then weakly strengthen ferrite, or intensively strengthen ferrite and sharply reduce its viscosity (Mn, Si). Also added in a small percentage content are such alloying elements as titanium, aluminium, and bismuth. The additives of alloying elements varied within the following limits: titanium 0.03 %, aluminium 0.02 %, titanium 0.01 %.

The experimental alloys were smelted in a high-frequency induction furnace LPZ-1-67 with a capacity of 15 kg with a basic lining. The furnace capacity was 70 kW. After casting and cooling, the ingots were forged at a temperature of 1100–1150 °C.

Powdered iron served as the starting material. Alloying was performed with 99.5 % metallic manganese, 99.98 % metallic nickel, 98.0 % powdered titanium, 99.97 % granulated aluminium, 93.0 % metallic bismuth. Synthetic cast iron with a carbon content of 3.9 % served as a carbon-containing additive. The steel was cast in a metal mold measuring 210×115×115 mm.

Samples for studying acoustic and physical-mechanical characteristics were cut from forged strips. Surface purity after mechanical treatment corresponded to class 5. Forged samples were subjected to milling, planing, cutting, grinding. Deviations in the specified dimensions (50×50×5 mm) did not exceed 0.2 mm. Acoustic (sound level, sound pressure levels) and vibration (vibration acceleration level and vibration velocity level) properties were determined after forging, then the same samples were annealed and normalized. Annealing mode – heating to As3 (830 °C + 50 °C), holding for 0.5 hours, cooling with a furnace. Normalization was carried out according to the following regime: heating to Ac3 (830 °C+50 °C, holding for 0.5 hours, cooling with the furnace.

Annealing is carried out at a temperature of Ac3+50 °C, then slow cooling with the furnace (Table 3).

After aging (usually 1 hour), the steel is cooled in a furnace (slowly) to obtain an equilibrium structure (ferrite+pearlite).

Table 3

Annealing (soft annealing to relieve stress and improve machinability)

Steel grade	Ac3 (°C)	Annealing temperature (°C)
40, 40G	810–830	860–880
45, 45G	800–820	850–870
50G	780–800	830–850

Normalization is carried out at a temperature of Ac3 +50 °C, but cooling occurs in air, which gives a finer structure (pearlite, sorbite). Heating and aging during normalization and annealing were carried out in quartz ampoules in a vacuum with a vacuum of 10^{-3} atm (Table 4) [19, 20].

Table 4

Normalization (improving structure, eliminating large grains)

Steel grade	Ac3 (°C)	Annealing temperature (°C)
40, 40G	810–830	860–880
45, 45G	800–820	850–870
50G	780–800	830–850

Air cooling results in a pearlite or sorbite structure, which improves mechanical properties.

The forging temperature is higher than Ac3, but it is important to avoid overburning (destruction of the structure) (Table 5).

Table 5

Forging (plastic deformation)

Steel grade	Ac3 (°C)	Annealing temperature (°C)
40, 40G	1,250–1,280	800–850
45, 45G	1,220–1,260	800–850
50G	1,200–1,240	800–850

After forging, it is necessary to cool slowly (this is done in a furnace or under a layer of insulation) to avoid hardening stresses.

Annealing is to soften the metal, it relieves stresses (cooling in a furnace).

Normalization improves mechanical properties, reduces grain (cooling in air).

Forging is carried out at high temperatures, but it is important to avoid overburning (sudden overheating).

Since the objective of this work is to study the acoustic and vibration characteristics of the studied alloys, a method for studying the sound radiation of steels and alloys by impact excitation and measuring the sound pressure level using a Bruel&Kjær pulse noise meter was proposed, to design materials with high damping properties.

During the measurements, steel (ShKh15) striker balls of the following diameters were used: 9.5 mm; 12.7 mm; 15.2 mm; 15.8 mm; and 18.3 mm (the mass of the striking balls is, respectively, 2.5 g; 5 g; 9 g; and 25 g).

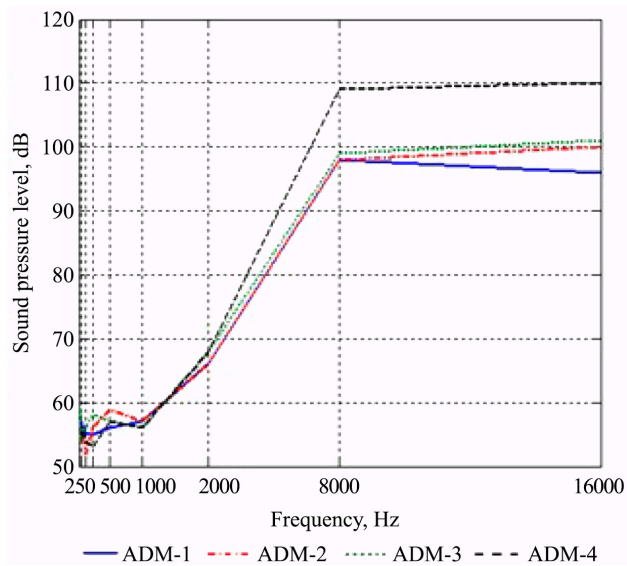
The width and length of the sample plate must be at least 5 times its thickness. The test plate with dimensions of 50×50×5 mm meets these requirements.

Sound pressure levels were studied in octave frequency bands in the range of 1,000–31,500 Hz, vibration acceleration levels in the range of 31.5–31,500 Hz. Sound level – on the “A” scale, general vibration acceleration level – on the “Lin” characteristic.

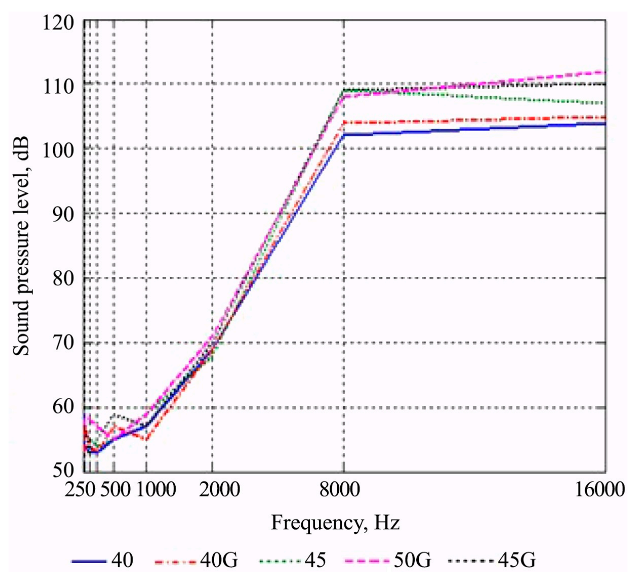
The ZG-10 sound generator was used to calibrate the measurements of the sound signal. Correction for changes in the sound signal from atmospheric pressure was carried out using a PF-101 piston phone. Air temperature and humidity in the laboratory were maintained constant. Acoustic measurements were found as the average value of five measurements.

5. 2. Evaluation of damping and acoustic characteristics of the proposed steels

The average values of sound levels (L_A) and sound pressure levels (SPLs) of the studied steels and designed alloys after forging are shown in Fig. 1, *a*, *b*.



a

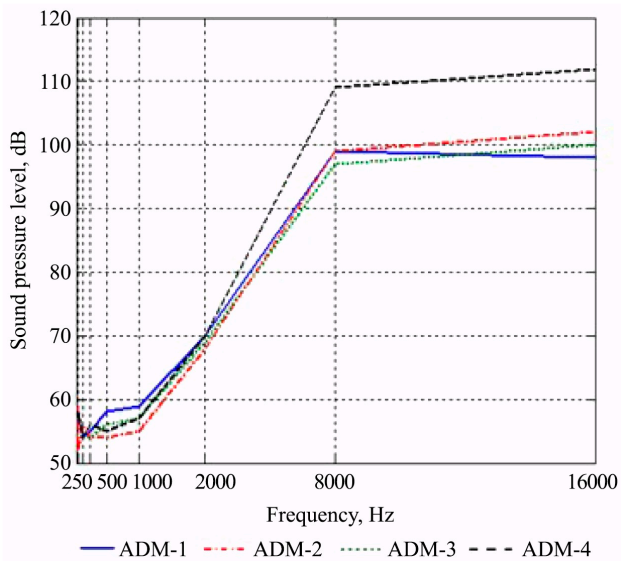


b

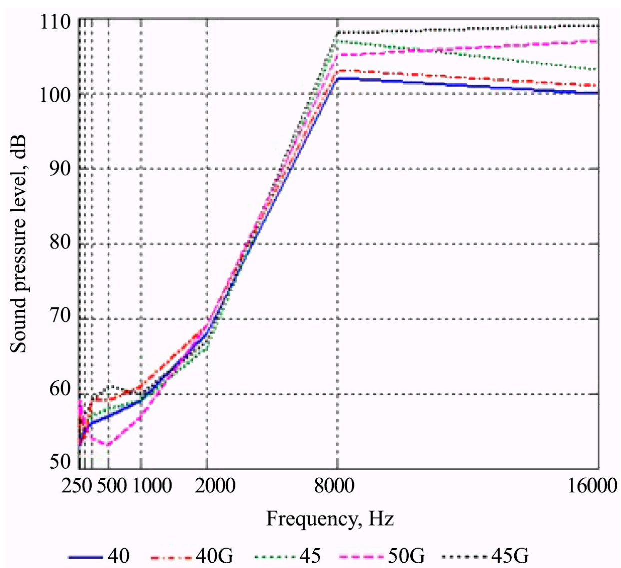
Fig. 1. Sound levels and sound pressure levels after forging: *a* — designed alloys; *b* — standard steels

Among the designed alloys, low sound emission is typical for alloys ADM-1 (91 dBA); ADM-3 (92 dBA); ADM-2 (94 dBA). The alloy ADM-4 is characterized by an increased sound level (103 dBA). Among standard steels, low sound emission is typical for steels 40 (97 dBA) and 40G (99 dBA). High L_A is typical for steels 45 and 45G (104 dBA); 50G (103 dBA).

Fig. 2, *a*, *b* shows the average values of sound levels (L_A) and sound pressure levels (SPLs) of the studied steels and designed alloys after annealing.



a



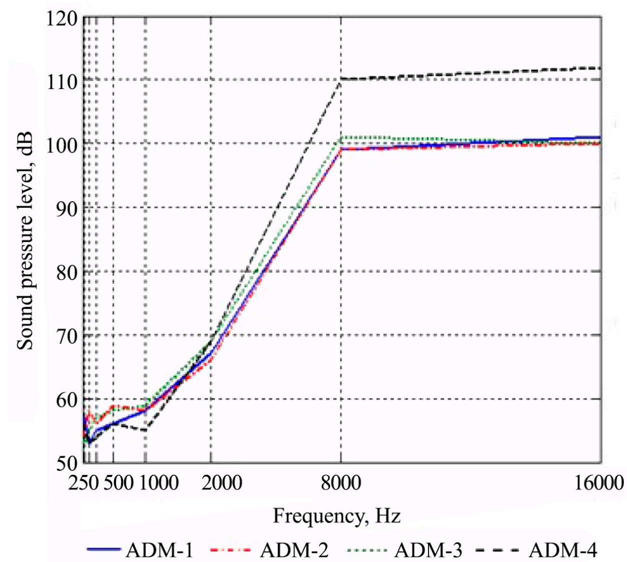
b

Fig. 2. Sound levels and sound pressure levels after annealing: *a* – designed alloys; *b* – standard steels

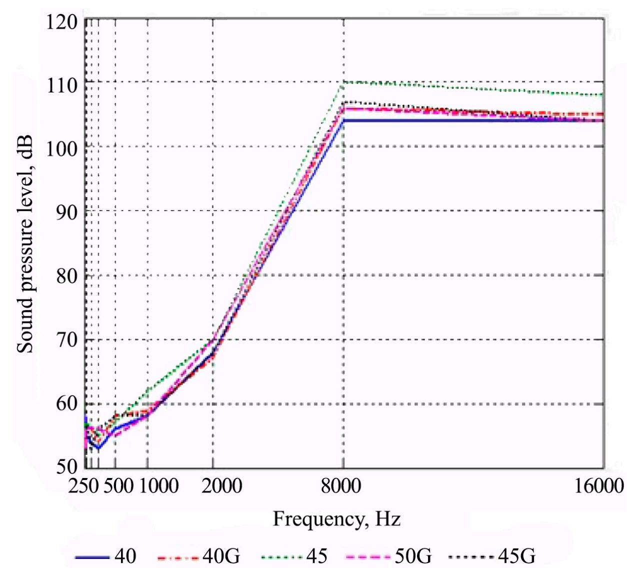
Of the designed alloys, low sound emission is typical for alloys ADM-1 and ADM-2 (92 dBA); ADM-3 (94 dBA). The alloy ADM-4 is characterized by a sound level of 105 dBA. Among standard steels, low sound emission is typical for steels 40 and 40G (97 dBA) after annealing. High L_A is typical for steels 45, 45G (102 dBA); 50G (100 dBA).

The average values of sound levels (L_A) and sound pressure levels (SPLs) of the studied steels and designed alloys after normalization are shown in Fig. 3, *a*, *b*.

Of the designed alloys, after normalization, reduced sound emission is typical for alloys ADM-1 (92 dBA); ADM-2 (93 dBA); ADM-3 (94 dBA). The alloy ADM-4 is characterized by an increased sound level of 105 dBA. Of the standard steels, steel 40 is characterized by reduced sound emission after normalization (98 dBA). Steels 45 and 50G (102 dBA); 40G and 45G (100 dBA) are characterized by increased L_A.



a



b

Fig. 3. Sound levels and sound pressure levels after normalization: *a* – designed alloys; *b* – standard steels

5. 3. Investigating the obtained steels

The average values of sound levels (L_A) and sound pressure levels (SPLs) of the studied steels and designed alloys after forging are given in Table 6.

Analysis of the acoustic properties of steels revealed that the SPL of the studied materials changes in the range of 52–112 dB in the frequency range of 63–16000 Hz. The SPL peaks occur at frequencies of 8,000 and 16,000 Hz. The sound levels of steels change in the range of 91–104 dBA. In terms of frequencies, the maxima were recorded at frequencies of 63 Hz – for ADM-2 alloys and steel 40 (59 dB); 125 Hz – for steel 50G (58 dB); 250 Hz – 50G (58 dB); 500 Hz – ADM-2 (58 dB); 1,000 Hz – 45G and ADM-3 (59 dB); 2,000 Hz – 45 and

50G (59 dB); 4,000 Hz – 50G (71 dB); 8,000 Hz – 45, 45G and ADM-4 (109 dB); 16,000 Hz – 50G (112 dB).

Table 6

Average values of sound levels and sound pressure levels of the studied steels after forging

Steel grade	Sound pressure levels, dB, in octave bands with geometric mean frequencies, Hz									L_A, dBs
	63	125	250	500	1,000	2,000	4,000	8,000	16,000	
40	59	54	53	53	55	57	69	102	104	97
45	55	56	55	54	55	59	68	109	107	104
40G	53	57	54	53	57	55	69	104	105	99
45G	57	57	53	55	59	57	70	109	110	104
50G	57	58	58	57	55	59	71	108	112	103
ADM-1	56	57	55	55	56	57	66	98	96	91
ADM-2	59	54	56	58	57	56	68	99	101	94
ADM-3	55	56	52	56	59	57	66	98	100	92
ADM-4	55	56	54	53	58	56	68	109	110	103

Table 7 gives average values of the sound levels (L_A) and sound pressure levels (SPLs) of the studied steels and designed alloys after annealing.

Table 7

Average values of sound levels and sound pressure levels of the studied steels after annealing

Steel grade	Sound pressure levels, dB, in octave bands with geometric mean frequencies, Hz									L_A, dBs
	63	125	250	500	1,000	2,000	4,000	8,000	16,000	
40	55	53	55	56	57	59	68	102	100	97
45	57	54	56	57	58	59	66	107	103	102
40G	53	58	54	59	59	61	69	103	101	97
45G	54	56	57	59	61	60	67	108	109	102
50G	57	59	56	54	53	57	69	105	107	100
ADM-1	55	58	54	55	58	59	70	99	98	92
ADM-2	56	57	54	54	56	57	69	97	100	92
ADM-3	59	52	56	54	54	55	68	99	102	94
ADM-4	57	58	54	56	55	57	70	109	112	105

The results of studying the acoustic properties of steels after annealing showed that the SPL of the studied materials changes in the range of 52–112 dB at frequencies of 63–16,000 Hz. The SPL peaks occur at frequencies of 8000 and 16000 Hz. The sound levels of steels change in the range of 92–105 dBA. In terms of frequencies, the SPL maxima were recorded at a frequency of 63 Hz for the ADM-3 alloy (59 dB); 125 Hz for 50G steels (59 dB); 250 Hz – 45G (57 dB); 500 Hz – 40G and 45G (59 dB); 1,000 Hz – 45G (61 dB); 2,000 Hz – 40G (61 dB); 4,000 Hz – ADM-1 and ADM-4 (70 dB); 8,000 Hz – ADM-4 (109); 16,000 Hz – ADM-4 (112 dB).

Average values of sound levels (L_A) and sound pressure levels (SPLs) of the studied steels and designed alloys after normalization are given in Table 8.

Analysis of the acoustic properties of steels after normalization revealed that the SPLs of the studied materials change in the range of 52–112 dB at frequencies of 63–16,000 Hz. The SPL peaks occur at frequencies of 8,000 and 16,000 Hz. The sound levels of steels change in the range of 92–105 dBA. In terms of frequencies, the maxima are recorded at frequencies of 63 Hz – for steels 40 (58 dB); 125 Hz – for steels 45, 45G, ADM-1 (57 dB); 250 Hz – ADM-3 (58 dB); 500 Hz – ADM-2 (57 dB); 1,000 Hz – ADM-3 (59 dB); 2,000 Hz – 45 (62 dB); 4,000 Hz – 45 and 50G (70 dB); 8,000 Hz – 45 and ADM-4 (110 dB); 16,000 Hz – ADM-4 (112 dB).

Table 8

Average values of sound levels and sound pressure levels of the studied steels after normalization

Steel grade	Sound pressure levels, Db, in octave bands with geometric mean frequencies, Hz									L_A, dBs
	63	125	250	500	1,000	2,000	4,000	8,000	16,000	
40	58	55	54	53	56	58	68	104	104	98
45	55	57	56	55	57	62	70	110	108	102
40G	54	56	56	54	58	59	67	106	105	100
45G	52	57	53	56	58	58	68	107	104	100
50G	53	56	56	56	55	58	70	106	104	102
ADM-1	54	57	53	55	56	58	67	99	101	92
ADM-2	56	53	55	57	58	59	69	101	100	93
ADM-3	54	55	58	56	59	58	66	99	100	94
ADM-4	56	55	53	54	56	55	69	110	112	105

6. Discussion of the research results and analysis of the damping and acoustic characteristics of the designed alloys and standard steels

For the obtained ADM-1, ADM-2, ADM-3, ADM-4 alloys, the damping and acoustic properties (frequency spectrum in octave bands) of the designed alloys and known steels were studied. Steels and alloys with high surface hardness and increased wear resistance were subjected to various types of heat treatment (Fig. 1–3, Tables 3–5). That has made it possible to reveal that at frequencies of 8,000 and 16,000 Hz, the designed alloys ADM-1, ADM-2, ADM-3, ADM-4 emit noise 6–13 dB lower than similar steels 40, 45, 40G, 45G, 50G. In contrast to papers [10–12], which discuss issues of improving the physical and mechanical properties of various alloys and steels, our studies revealed that at frequencies of 8,000 and 16,000 Hz, ADM-1,2,3 alloys emit noise 6–13 dB lower than steels 40, 45, 40G, 45G, 50G. The high attenuation found in metals with ferromagnetism served as the basis for creating a number of alloys on their basis with a different set of properties, but distinguished by high damping capacity, which allows these alloys to be distinguished as a special group of structural materials.

Chemical, physical properties, microstructure of alloys and nanocomposites for transport equipment are considered [9, 13, 14], and the obtained data on heat treatment such as forging, annealing, normalization for the purpose of studying sound levels and ultrasound of steels and alloys made it possible to identify damping alloys for parts of transport equipment. The alloy of grade ADM-1 has been proposed for the manufacture of the main units of transport.

Unlike standard steel grades, the designed alloys can increase resistance to impacts, improve sound absorption characteristics, and provide more effective detection of non-metallic inclusions on a ferrite basis, which effectively ensures noise damping [10–12, 15–17].

Unlike standard steel grades, the designed alloys can increase resistance to impacts, improve sound absorption characteristics and provide more effective detection of non-metallic inclusions on a ferrite basis, which effectively ensures noise damping.

By reducing transport noise, the living conditions of people improve, the level of acoustic pollution decreases, and the working capacity of workers with impaired hearing decreases.

The limitation of our study is the need to conduct experiments to clarify the results (such as tensile strength, impact strength) and expand the scope of their application. To reproduce the acoustic properties, it is necessary to strictly observe the proportions of alloying elements and the technology of alloy smelting.

The development of this study involves studying the effect of various concentrations of alloying elements on the damping properties and mechanical characteristics of materials.

7. Conclusions

1. We have smelted the designed alloys doped with silicon, manganese, chromium, and nickel. Their composition and structure affect their acoustic properties, making it possible to achieve high damping properties. This opens up new prospects for their application in the transport industry.

2. The sound levels and ultrasound pressure of the designed steels and alloys were studied after forging, normalizing, and annealing, which has made it possible to identify damping alloys for parts of transport equipment: alloys after forging ADM-1 (91 dBA); ADM-2 (94 dBA); ADM-3 (92 dBA); steel 40 (97 dB). After normalization: alloys ADM-1 (92 dBA); ADM-2 (93 dBA); ADM-3 (94 dBA); steel 40 (98 dBA). After annealing: alloy ADM-1 (92 dBA); ADM-2 (92 dBA); ADM-3 (94 dBA); 40 (97 dBA). The alloy of grade ADM-1 has been proposed for the production of the main transport units (crankshafts, connecting rods, toothed rims, axle shafts of passenger cars, camshafts).

3. The effect of heat treatment on the damping and acoustic properties of alloys and steels was studied. The following patterns have been identified:

– annealing, which ensures the formation of new equiaxed metal grains instead of the oriented fibrous structure of the deformed metal after forging, helps increase the damping properties (steel 40, 45, 50G, ADM-1), while damping occurs due to the braking of the sound wave by new grains, larger than the original ones;

– forging, which occurs at 1200 °C of alloys, enables the occurrence of a preferential orientation of crystallographic planes and stresses in grains, while the density of dislocations, vacancies, interstitial atoms increases, and this significantly improves the damping properties of metallic materials (alloys ADM-4, ADM-1; steels 40, 45, 40G, 45G, 50G);

– normalization, which involves heating alloys to a temperature of Ac3+50 °C, holding and cooling in air, causes complete phase recrystallization of steel and eliminates the coarse-grained structure obtained during casting and forging; the damping properties after normalization can be increased (steels 45, 50G), average (steels 40, 45G, alloys ADM-2, ADM-3), and decreased (steel 40, alloys ADM-1, ADM-4). In this case, the reason for the different degree of damping is the density of dislocations, vacancies, interstitial atoms – the higher the density of dislocations, the higher the damping.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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