



## ORIGINAL ARTICLE

# Vibration-Acoustic Damping Properties of Modified Cast Al-Si Alloys

B.N. Odinaev <sup>1,\*</sup>, M.M. Haqdod <sup>2</sup>

<sup>1</sup> Branch of the National University of Science and Technology «MISIS» in Dushanbe, Republic of Tajikistan

<sup>2</sup> Institute of Water Problems, Hydropower and Ecology of the National Academy of Sciences of Tajikistan, Dushanbe, Republic of Tajikistan

\*Corresponding Author: B. N. Odinaev (Email: [Insert Email Address])

**Citation:** Odinaev, B.N., & Haqdod, M.M. (2026). Vibration-Acoustic Damping Properties of Modified Cast Al-Si Alloys. *Tajikistan Journal of Sciences & Technology*, Volume(Issue), PP.27-34. <https://doi.org/>

**Received:** 15.05.2026 | **Revised:** 30.06.2026 | **Accepted:** 08.07.2026

## ABSTRACT

This article presents the results of a study on the vibration-acoustic damping and mechanical properties of modified cast aluminum alloys of the Al-Si system (silumins), which are used as structural materials in the manufacture of machine parts and mechanisms for various purposes. Using an original setup developed by the authors, the vibroacoustic characteristics of the materials were determined, including frequency spectra, sound pressure levels, sound levels, and sound attenuation rates proportional to the loss coefficient of the material. Based on an analysis of the phase diagram of aluminum-silicon alloys and of the modification process, it was established that modifying cast Al-Si alloys (silumins) with antimony, barium, and strontium improves alloy quality and enhances their vibroacoustic characteristics. The results indicate that antimony-, barium-, and strontium-modified silumins are promising structural materials for reducing vibration-acoustic factors in machines and mechanisms operating under industrial noise and vibration-impact conditions.

**Keywords:** cast aluminum alloy; modification; antimony; barium; strontium; vibroacoustic damping properties; sound pressure level; sound attenuation rate; loss coefficient.

## 1 | INTRODUCTION

Vibration-acoustic damping capacity is one of the most important characteristics of structural materials used to manufacture equipment that operates under conditions of mechanical vibration and noise. Consequently, the development of materials combining high damping capacity with high strength has become a pressing research topic [1–4].

Among materials that meet these requirements, when properly processed, are casting alloys of the Al-Si system (silumins), which are characterized by good processability, relatively high physical and mechanical properties, corrosion resistance, and vibration-acoustic damping properties, and which find application across a wide range of

industries. This combination of properties makes silumins promising structural materials for reducing vibration-acoustic factors in the mechanisms and machines used in various branches of industry.

In this study, these materials were selected to determine their vibration-acoustic damping properties for protection against industrial vibration-acoustic factors. Such factors arise from vibration-impact processes occurring during the collision of machine parts and mechanisms in the course of various manufacturing operations, including ore processing, the mechanical working of metals and alloys, metal forming, and the transportation of raw materials and blanks at various stages of processing. These operations are encountered in almost all industries that generate vibration and sound emissions exceeding permissible limits. The underlying premise of this work is that vibroacoustic factors in manufacturing processes originate as vibrations of components and mechanisms (primary sound emission), which subsequently transform into noise emissions that propagate through the surrounding environment.

## 2 | MATERIALS AND RESEARCH METHODS

The choice of cast Al-Si aluminum alloys (silumins) for this study was motivated by their use as structural vibration-acoustic damping materials for reducing vibration-acoustic factors in industrial workplaces.

The main characteristics of the alloys studied are presented in Table 1.

**Table 1. Chemical composition and mechanical properties of the studied alloys**

| Si     | Mg        | Sb, Ba, Sr      | Al       | $\sigma_u$ , MPa | $\delta$ , % | HB      |
|--------|-----------|-----------------|----------|------------------|--------------|---------|
| 6 / 9  | 0.1 / 0.3 | 0.005Sb / 0.1Sb | Bal. / – | 218 / 216        | 7.0 / 5.6    | 79 / 77 |
| 6 / 9  | 0.1 / 0.3 | 0.005Ba / 0.1Ba | – / –    | 196 / 202        | 7.4 / 8.0    | 74 / 75 |
| 6 / 9  | 0.1 / 0.3 | 0.005Sr / 0.1Sr | – / –    | 206 / 212        | 13.0 / 12.0  | 56 / 58 |
| 9 / 12 | 0.25      | – / –           | – / –    | 160 / 170        | 3.2 / 2.4    | 56 / 49 |

Samples for studying the vibration-acoustic damping and mechanical properties of the alloys were prepared after each alloy composition had been obtained separately in corundum crucibles at 720–740°C. The aluminum-strontium and aluminum-barium master alloys, together with metallic antimony, were introduced into the melt after it had settled for 10–20 minutes and the slag had been removed from the surface of the oxide film.

The macrocomponent content of the samples was monitored using atomic absorption, neutron activation, chemical spectral, and mass spectrometric analysis.

To homogenize the structure, the alloys were annealed at temperatures of 400–450°C for 200–250 hours; microscopic and X-ray diffraction analysis were used to examine the alloy structure.

The mechanical properties of the alloys were determined by standard methods on an Instron universal testing machine.

The vibration-acoustic damping properties of the Al-Si alloys were studied using the TTU-2 setup developed by the authors [5]. This method characterizes the vibration-acoustic damping properties of the alloys by exciting sound vibrations in the samples through impact of a ball on a plate, since the vibrations and sound generated by a single pulse are attenuated as a result of internal and external energy losses in the sample material [6]. This procedure makes it possible to determine not only the sound emission of the metals and alloys, characterized by sound pressure levels and sound levels, but also the sound attenuation rate and the loss coefficient describing the dissipation of sound-vibration energy in the material.

### 3 | RESULTS OF THE STUDY AND DISCUSSION

The vibration-acoustic damping and mechanical properties of the studied alloys in the initial state are presented in Table 2.

**Table 2. Vibroacoustic damping and mechanical properties of the studied alloys**

| Alloy No. | Si | Mg   | Sb, Ba, Sr | Al   | Sound level, dBA | Sound attenuation rate $d_s$ , dB/ms | $\sigma_u$ , MPa | $\delta$ , % | HB |
|-----------|----|------|------------|------|------------------|--------------------------------------|------------------|--------------|----|
| 1         | 6  | 0.1  | 0.005Sb    | Bal. | 84               | 3.85                                 | 218              | 7.0          | 79 |
| 2         | 9  | 0.3  | 0.1Sb      | —    | 87               | 3.46                                 | 226              | 5.6          | 77 |
| 3         | 6  | 0.1  | 0.005Ba    | —    | 81               | 3.88                                 | 196              | 7.4          | 74 |
| 4         | 9  | 0.3  | 0.1Ba      | —    | 80               | 4.21                                 | 202              | 8.0          | 75 |
| 5         | 6  | 0.1  | 0.005Sr    | —    | 84               | 3.76                                 | 206              | 13.0         | 56 |
| 6         | 9  | 0.3  | 0.1Sr      | —    | 82               | 4.18                                 | 212              | 12.0         | 58 |
| 7         | 9  | 0.25 | —          | —    | 95               | 2.18                                 | 160              | 3.2          | 56 |
| 8         | 12 | 0.25 | —          | —    | 93               | 2.42                                 | 170              | 2.4          | 49 |

The results presented in Table 2 for the vibration-acoustic damping and mechanical properties of the multicomponent cast aluminum alloys of the Al-Si-(Sb, Ba, Sr) system show that these alloys are superior in these parameters to the well-known AK9 and AK12 alloys.

To analyze the results obtained, consider the phase diagram of the aluminum-silicon alloys shown in Fig. 1 [7, 8].

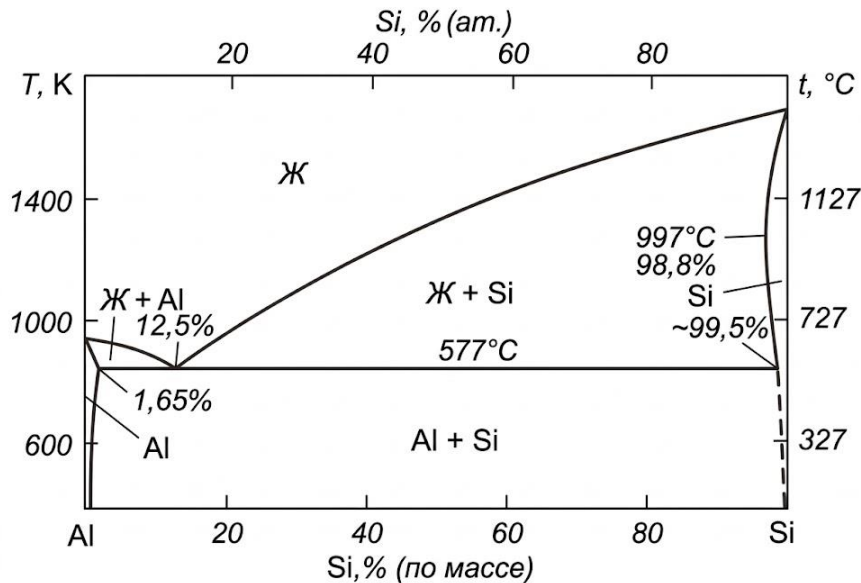


**Fig. 1. Phase diagram of aluminum-silicon alloys [7]**

As follows from Fig. 1, a characteristic feature of aluminum-silicon alloys is the variable solubility of silicon in aluminum near the eutectic temperature. A change in this solubility produces a supersaturated solid solution of silicon in aluminum, which upon subsequent cooling decomposes with the release of dispersed silicon particles; this renders these alloys thermally non-hardenable and results in low strength properties [7].

To increase the strength, ductility, and vibration-acoustic damping characteristics of Al-Si alloys, it is necessary to refine the eutectic silicon crystals. This can be achieved by increasing the cooling rate during melt crystallization and by introducing small additions (hundredths of a percent) of alkali and alkaline-earth metals — sodium, lithium, barium, and strontium — which also contribute to an increase in the vibration-acoustic damping properties of

these alloys [8]. In addition, various methods of physical action on the melt, such as vibration and ultrasound, are used in practice for these purposes [9–11].

In practice, modification with small additions of sodium, barium, and strontium is widely used to improve the structure of Al-Si alloys [12, 13].

For example, when 0.01% Na is added to Al-Si alloys as a  $2/3 \text{ NaF} + 1/3 \text{ NaCl}$  salt mixture, the eutectic silicon crystals are refined and the eutectic point shifts toward higher silicon concentrations, resulting in the formation of the chemical compound  $\text{AlSiNa}$  and of the ternary eutectic  $\alpha\text{-Al} + \text{Si} + \text{AlSiNa}$  in the alloy structure.

Modification with strontium exerts an approximately similar effect on the structure and properties of aluminum-silicon alloys, as noted by the authors of [12]. Compared with sodium, strontium is considered an environmentally cleaner modifier, since it is introduced into the melt as an Al-Sr master alloy (ligature), whereas sodium is introduced via its fluoride or chloride salts, which release toxic gases (F, Cl) that are harmful to the environment.

Antimony and barium are also used as modifiers for aluminum-silicon alloys [12–16]. Antimony is introduced for refining and modifying the eutectic silicon in cast aluminum alloys at 0.05–0.2 wt.%, given that the solubility of antimony in solid aluminum is very low ( $<0.01\%$ ); at higher antimony contents in hypereutectic cast aluminum-silicon alloys, antimony prevents the formation of primary silicon precipitates.

The modifying effect of strontium and antimony can be examined via the aluminum corner of the ternary Al-Si-Sr phase diagram shown in Fig. 2 [12].

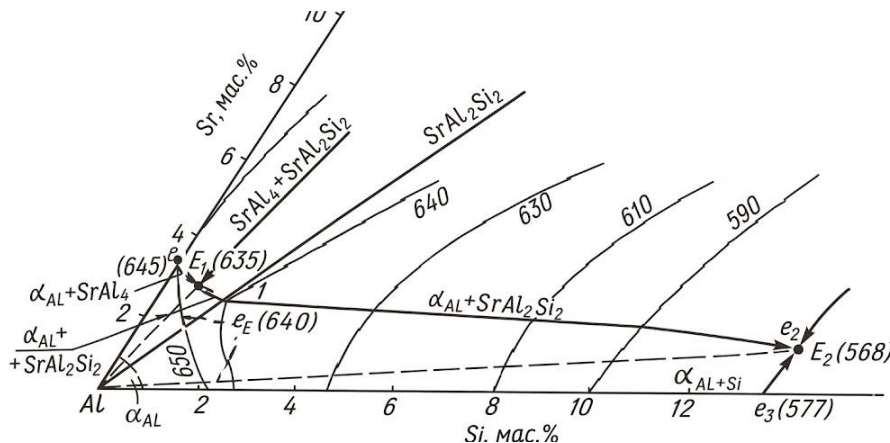


Fig. 2. Aluminum corner of the Al-Si-Sr ternary alloy system [12]

As can be seen from Fig. 2, in the aluminum corner two eutectic equilibrium lines form at  $t_m = 568^\circ\text{C}$ :  $E1\text{-}\alpha\text{-Al} + \text{SrAl}_4 + \text{SrAl}_2\text{Si}_2$  and  $E2\text{-}\alpha\text{-Al} + \text{Si} + \text{SrAl}_2\text{Si}_2$ . The line connecting the eutectic point  $E2$  with aluminum (the  $E2\text{-Al}$  line) is considered the “normal modification” line. Al-Si-Sr ternary alloys located above the  $E2\text{-Al}$  line are considered over-modified, and those below this line are considered under-modified.

The influence of strontium and barium on the structure and properties of aluminum-silicon alloys, owing to the similarity of their physical and chemical properties, has been examined in [13, 14–16].

In the present study, antimony was also used as a modifier for aluminum-silicon alloys, since it significantly refines the grains of the  $\alpha\text{-Al} + \text{Si}$  binary eutectic compared with barium and strontium. Crystallization of Al-Si-Sb alloys, corresponding to grain refinement of the aluminum-based eutectic angle, is facilitated by supercooling of the melt. Following the introduction of antimony, the ternary eutectic  $E2 = \alpha\text{-Al} + \text{Sb} + \text{AlSnSb}_4$  — i.e., a soft phase — forms in Al-Si (Sb, Ba, Sr) alloys located on the Al- $E2$  line (Fig. 2). This apparently enhances the vibration-acoustic damping properties of the studied alloys.

The acoustic characteristics of the studied alloys are presented in Fig. 3.

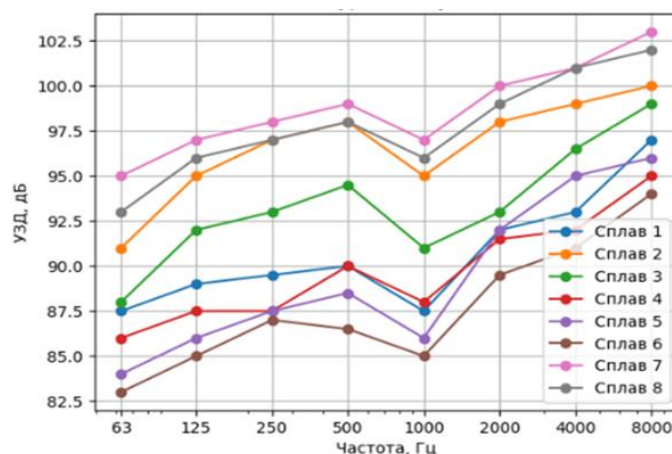


Fig. 3. Sound emission of the studied alloys

As shown in Fig. 3, all alloys modified with antimony, barium, and strontium exhibit lower sound emission than the unmodified alloys, with the lowest sound emission observed at a frequency of 1000 Hz. The modified alloys also demonstrated relatively high mechanical properties (Table 3). As Table 3 shows, both the vibration-acoustic damping properties (sound attenuation rate and loss coefficient) and the mechanical properties of the modified alloys are significantly higher than those of the unmodified alloys.

Table 3. Vibroacoustic damping and mechanical properties of the studied alloys

| Alloy No. | $\sigma_u$ , MPa | $\delta$ , % | HB | Sound attenuation rate $d_s$ , dB/ms | Loss coefficient, $\delta$ |
|-----------|------------------|--------------|----|--------------------------------------|----------------------------|
| 1         | 218              | 14.0         | 62 | 3.06                                 | 0.30                       |
| 2         | 234              | 7.0          | 79 | 3.84                                 | 0.44                       |
| 3         | 215              | 7.2          | 59 | 2.36                                 | 0.24                       |
| 4         | 196              | 6.5          | 54 | 2.85                                 | 0.31                       |
| 5         | 202              | 8.0          | 75 | 4.22                                 | 0.52                       |
| 6         | 206              | 13.0         | 56 | 3.78                                 | 0.48                       |
| 7         | 212              | 12.0         | 58 | 2.19                                 | 0.24                       |
| 8         | 192              | 5.2          | 48 | 2.17                                 | 0.16                       |

Analysis of the data presented in Fig. 3 and Table 3 shows that the sound emission of the studied Al-Si alloys modified with strontium, barium, and antimony differs markedly from that of the unmodified alloys. A characteristic feature of the studied alloys is that they exhibit an identical minimum sound emission at a frequency of 1000 Hz.

It should be noted that various theories and hypotheses exist to explain the mechanism by which modification of aluminum-silicon alloys affects the refinement of the alloy structure [19–22], and thereby the influence of modification with antimony, barium, and strontium on the vibroacoustic damping properties of the studied alloys. It therefore appears that it is specifically the refinement of the aluminum-silicon alloy structure through modification with antimony, strontium, and barium that governs the vibroacoustic characteristics of the alloys.

Accordingly, when studying the vibration-acoustic damping properties of modified cast Al-Si aluminum alloys, it is necessary to take into account the full range of these theoretical considerations together with the structural changes that affect the vibroacoustic characteristics of silumins.

## 4 | CONCLUSION

Analysis of the phase diagram of the Al-Si system and of the characteristic changes in the properties of the studied alloys — that is, the improvement of the alloy structure through the introduction of small additions of modifying elements and their effect on the vibration-acoustic damping and mechanical properties of the alloys — shows that a more in-depth analysis is required of how variations in the content of modifying additives and different processing methods affect the vibroacoustic characteristics of alloys used in equipment operating under vibration-impact conditions.

## ACKNOWLEDGMENTS

The authors thank the staff of the Branch of the National University of Science and Technology «MISIS» in Dushanbe and the Institute of Water Problems, Hydropower and Ecology of the National Academy of Sciences of Tajikistan for their support in carrying out this study.

## AUTHOR CONTRIBUTION

Conceptualization, B.N.O.; Methodology, B.N.O. and M.M.H.; Software, B.N.O.; Validation, B.N.O., M.M.H.; Formal Analysis, B.N.O.; Investigation, B.N.O., M.M.H.; Resources, M.M.H.; Data Curation, B.N.O.; Writing – Original Draft Preparation, B.N.O.; Writing – Review & Editing, M.M.H.; Visualization, B.N.O.; Supervision, M.M.H.; Project Administration, M.M.H. All authors have read and agreed to the published version of the manuscript.

## FUNDING

This research received no external funding.

## DATA AVAILABILITY

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

### Creative Commons Licensing & Open Access

This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0). Under this license, users are free to share (copy and redistribute the material in any medium or format) and adapt (remix, transform, and build upon the material for any purpose, even commercially), provided appropriate credit is given to the original author(s) and source, a link to the Creative Commons license is provided, and any changes made are indicated.

## REFERENCES

1. Favstov, Yu.K., Shulga, Yu.N., & Rakhshadt, A.G. (1980). Metallurgy of high-damping alloys. Moscow: Metallurgiya. (in Russian)
2. Drits, M.E., & Rokhlin, L.L. (1983). Magnesium alloys with special acoustic properties. Moscow: Metallurgiya. (in Russian)
3. Pisarenko, G.S., Matveyev, V.V., & Yakovlev, A.P. (1971). Vibration-absorbing properties of structural materials: A handbook. Kyiv: Naukova Dumka. (in Russian)

4. Utepov, E.B., Khokhlov, P.P., et al. (1998). Development of low-noise alloys. Almaty. (in Russian)
5. Odinzoda, B.N., & Haqdod, M.M. (2024). A device for studying the acoustic-damping properties of metallic materials (Patent of the Republic of Tajikistan No. TJ 1553, IPC G01H1/00, Application No. 2301874, filed 18.08.2023, published in Bulletin No. 213). (in Russian)
6. Haqdod, M.M., & Odinzoda, B.N. (2023). Modeling the noise generation process during collisions of machine parts and a methodology for studying the acoustic-damping properties of materials. Polytechnic Bulletin. Series: Metallurgy and Materials Science, (2/62), 95–99. Dushanbe: Tajik Technical University named after academician M.S. Osimi. (in Russian)
7. Prigunov, A.G., Belov, I.A., Taran, Yu.N., et al. (1996). Silumins – Atlas of microstructures and fractograms of industrial alloys: Reference publication. Moscow: MISiS. (in Russian)
8. Dzhuraev, T.D., Gazizova, E.R., Khakdodov, M.M., et al. (2013). Innovative technologies for the production and application of acoustic-damping aluminum alloys. Metallurgy of Mechanical Engineering, (5), 15–17. (in Russian)
9. Production of semi-finished products from aluminum alloys: Reference publication (Rev. ed.). (1985). Moscow: Metallurgiya. (in Russian)
10. Nikitin, V.I. (1991). Main patterns of structural heredity in the “charge – melt – casting” system. Foundry Production, (4), 4–5. (in Russian)
11. Khakdodov, M.M., Makhmadulloev, H.A., & Odinaev, B.N. (2011). Influence of vibration treatment of the melt on the acoustic-damping properties of modified silumins (pp. 192–196). Dushanbe: Tajik Technical University named after academician M.S. Osimi. (in Russian)
12. Ganiev, I.N., Parkhutik, P.A., Vakhobov, A.V., et al. (1985). Modification of silumins with strontium. Minsk: Nauka i Tekhnika. (in Russian)
13. Vakhobov, A.V., & Ganiev, I.N. (1992). Phase diagrams of binary and ternary systems involving barium and strontium. Dushanbe: Donish. (in Russian)
14. Ganiev, I.N., Vakhobov, A.V., & Dzhuraev, T.D. (1978). Phase diagram of the Ba-Al-Si system. Izvestiya AN SSSR, Metally, 247–250. (in Russian)
15. Kargapolova, T.B., Makhmadulloev, Kh.A., Ganiev, I.N., & Khakdodov, M.M. (2001). Barium – a new modifier of silumins. Foundry Production, (9), 62–64. (in Russian)
16. Ganiev, I.N., Vakhobov, A.V., & Khakdodov, M.M. (2001). New casting aluminum alloys that do not require modification. In Proceedings of the 5th Congress of Russian Foundrymen (pp. 215–217). Moscow: Radunitsa. (in Russian)
17. Jeffries, Z. (1922). Chemical and Metallurgical Engineering, 26, 750–752.
18. Gokhshteyn, M.B., & Vasilyeva, L.S. (1970). On the mechanism of silumin modification. Metallovedenie i Termicheskaya Obrabotka Metallov, (7), 42. (in Russian)
19. Chadwick, G.A. (1963). Eutectic alloy solidification. Progress in Materials Science, 12(2), 159–169.
20. Edwards, J.D., & Acher, R.C. (1924). The new aluminum-silicon alloys. Chemical and Metallurgical Engineering, 31, 504–505.
21. Mal'tsev, M.V. (1964). Modification of the structure of metals and alloys. Moscow: Metallurgiya. (in Russian)
22. Bochvar, A.A. (1956). Physical metallurgy. Moscow: Metallurgiya Publishing House. (in Russian)