The European Journal of Technical and Natural Sciences 2025, No 2
ISSN 2414-2352

PREMIER Publishing
ppublishing.org

Section 2. Materials science

DOI:10.29013/EJTNS-25-2-19-23

THE EFFECT OF GERMANIUM ON THE MICROSTRUCTURE OF ALUMINUM ALLOY

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Cite: *Tursunbaev S., Turakhujaeva A., Turaev A., Mardonakulov Sh., Murodqosimov R., Murodov S. and Rakhmonova M. (2025). The Effect of Germanium on The Microstructure of Aluminum Alloy. European Journal of Technical and Natural Sciences 2025, No 1.* https://doi.org/10.29013/EJTNS-25-2-19-23

Abstract

This article investigates the changes in the structure of the D16 (Al-Cu) alloy, which belongs to the aluminum-copper system, under the influence of the germanium element using experiments. A resistance furnace was used for casting the samples. The samples were cast into sand-clay molds at a temperature of 750 °C. The microstructure of the cast samples was analyzed using an optical microscope, and the authors' conclusions are presented in the article.

Keywords: *furnace, germanium, microstructure, alloying, aluminum, copper, temperature, sand-clay mold*

Introduction

A number of scientific studies of aluminum alloys are aimed at obtaining high-quality foundry products with enhanced casting and mechanical properties. The world's leading countries in this field are Canada, the USA, Japan, China, Sweden, Germany, Russia, Ukraine and others. In the above-mentioned countries and in Uzbekistan, in subsequent years, due to the increase in the number of non-ferrous alloys in the production of foundry products in the foundry industry, great attention has been paid to creating a technology for producing high-quality, durable foundry products based on an effective method that ensures resource conservation (Robson, J. D., 2004; Lin, R., Liu, B., Zhang, J., & Zhang, S., 2022; Gao, L., Xue, S., Zhang, L., Sheng, Z., Ji, F., Dai, W., ... & Zeng, G., 2010; Tursunbaev, S., Turakhodjaev, N., Zhang, L., Wang, Z., Mardonov, U., & Saidova, M., 2024; Habazaki, H., Shimizu, K., Skeldon, P., Thompson, G. E., Wood, G. C., & Zhou, X., 1997; Tursunbaev, S., Turakhodjaev, N., Odilov, F., Mardanokulov, S., & Zokirov, R., 2023; Davis, R. M., & Koch, C. C., 1987). The scientists from Al-Baha University and King Khalid University (Saudi Arabia) investigated the changes in Sn-

Ag-Cu alloy properties when Ge (0.0, 0.05 and 0.5wt%) is added. The finding reveals that the addition of germanium in the amount of 0.05 and 0.5wt% can potentially promise a noticeable improvement in mechanical properties, namely tensile strength, elongation, etc., and in the microstructure of the alloys. Experiment shows that the addition of Ge (0.5wt%) can increase the values of elongation, ultimate and yield tensile strength from 45.6%, 47.5MPa, 40.6 MPa to 58.3%, 56.3MPa and 49.4MPa respectively. Not only were the characteristics improved, but the addition of Ge (0.5wt%) to the alloy caused the development of tiny germanium particles, whereas adding 0.05wt% germanium reduced the shape of β-Sn grains. The authors concluded that the best percentage of germanium for improved performance was 0.5% (El-Taher, A.M., Ali, H. E., & Algarni, H., 2024).

Comparatively, in the study Muna Khethier Abbass et al. (Iraq) and Vesna Maksimovic et al. (USA), the researchers analyzed the performance of Al alloys while adding microalloying element (Ge). Vesna Maksimovic et al. found that alloying Aluminum alloys with Ge accelerates aging kinetics, while increasing the hardness level three times more quickly (Abbass, M.K., Radhi, M.M., & Adnan, R.S.A., 2017). Experts Muna Khethier Abbass et al. from University of Technology (Iraq) approved that the mechanical properties and microstructure can be enhanced by adding germanium to the alloy, however, as the amount of germanium increases, the hardness of the alloy decreases slightly. Three samples were analyzed (0.3% by weight, 1% by weight, 3% by weight) to study changes in the microstructure and mechanical properties of the alloy. As a result of the study, it was noticed that the Young's modulus increased with an increase in the amount of germanium, while the addition of this metal led to a decrease in hardness. The best performance was recorded with a Ge content of 3% by weight (Maksimović, V., Zec, S., Radmilović, V., & Jovanović, M.T., 2003). Based on experiments, the article analyzes the change in the structure of a D16 alloy under the influence of germanium, which is one of the alloys in the aluminum-copper system.

Materials and methods

The research investigated the effect of germanium oxide on the microstructure of the D16 alloy in the aluminum-copper system. The chemical composition of the D16 alloy is shown in Table 1. This aluminum alloy contains 94.7% aluminum (Mueller, A., Wang, G., Rapp, R.A., Courtright, E.L., & Kircher, T.A., 1992). On the other hand, copper, the main alloying element, accounts for 4.9%. A resistance furnace was used to dilute the samples. The furnace used is mainly intended for the manufacture of small parts, up to 3 kg of metal can be liquefied in the crucible. The furnace crucible is made of graphite material, which helps to cast liquid metal without sticking to the base of the crucible. Germanium oxide from 0.1% to 0.3% was introduced into the composition of the aluminum alloy, and the samples were poured into sand-clay molds.

Table 1. Chemical composition of D16 alloy

Fe	Si	Mn	Cr	Ti	Al	Cu	Mg	Zn	Mixtures	–
up to 0.5	up to 0.5	0.3–0.9	up to 0.1	up to 0.15	90.9–94.7	3.8–4.9	1.2–1.8	Up to 0.25	all 0.15	Ti+Zr < 0.2

Results

The cast samples were ground and micro sections were made. The structural analysis of the prepared samples was carried out using an optical metrological microscope. The microstructures of the samples are shown in Figure 2 and Figure 3. Figure 2 shows the microstructure of the added sample, calculated so that in "a" there remains an alloy of aluminum and copper without the addition of Germanium oxide, and in "b" – germanium in the alloy in an amount of 1%. Figure 3 shows the microstructure of the added sample, calculated so that 2% of germanium in "a" remains in the alloy, and 3% in "b", calculated so that germanium remains in the alloy.

Figure 1. *Resistance furnace*

Figure 2. *Microstructure of the samples: a – D16; b – D16+ 1% Ge*

a) *b)*

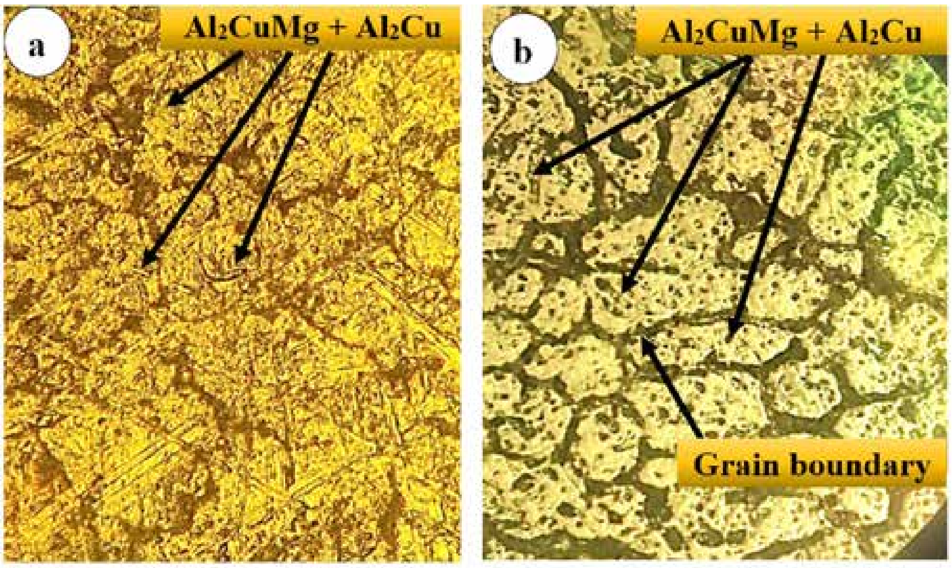
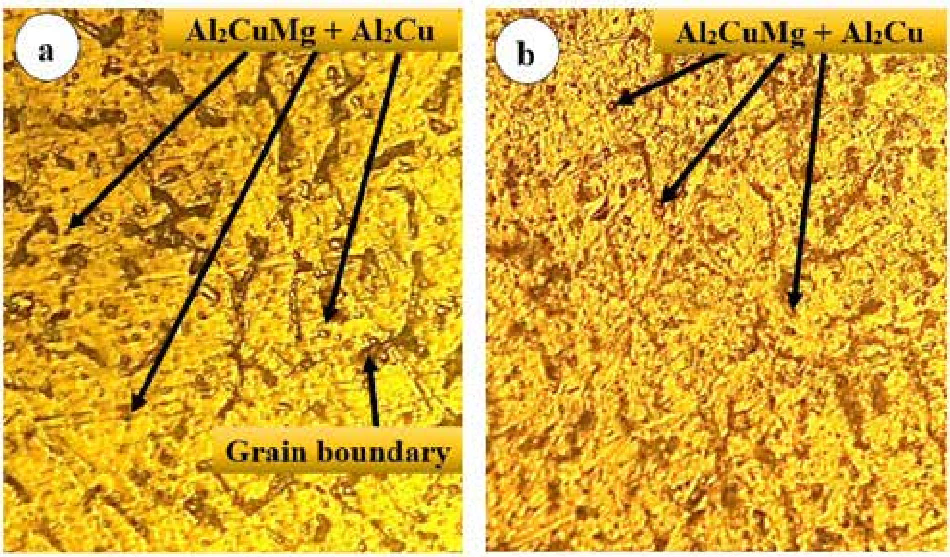


Figure 3. *Microstructure of the samples: a – D16+2% Ge; b – D16+ 3% Ge*

a) *b)*



The microstructure of the samples in Figures 2 and 3 above was analyzed based

on the standard grain sizes of Table 3 (GOST 5939–82).

Figures 2 and 3 show that the microstructure of the aluminum-copper alloy is the base metal aluminum and copper, in addition, the main component contains a solid solution of copper and magnesium in aluminum and the intermetallic phases Al2CuMg and Al2Cu. Melting foci located near accumulations of intermetallic compounds and periodic eutectic precipitation are not visually detectable.

Table 3. *Standard grain sizes (GOST 5939–82)*

Number grains (*G*)	Average area grain cross sections *a*, mm^2	Number of grains per area 1 mm^2, *m*			Average number of grains in 1 mm^3 (*Nv*)	Average grain diameter (*dm*), mm	Average conditional grain diameter (*dL*), mm
		minimum	medium	maximum			
1.	0.0625	12	16	24	64	0.250	0.222
2.	0.0312	24	32	48	181	0.177	0.157
3.	0.0156	48	64	96	512	0.125	0.111
4.	0.00781	96	128	192	1448	0.088	0.0783
5.	0.00390	192	256	384	4096	0.062	0.0553
6.	0.00195	384	512	768	11585	0.044	0.0391
7.	0.00098	768	1024	1536	32768	0.031	0.0267
8.	0.00049	1536	2048	3072	92682	0.022	0.0196

Figure 2 (a) The grain dispersion size of the sample corresponds to size No. 7–8 according to GOST 5639–82. The grains of intermetallides are columnar, elongated 9–10 × × 3 microns. Figure 2 (b) The grain dispersion size of the sample corresponds to size No. 6 according to GOST 5639–82. In the sample with the addition of 1% Germanium, the grains of intermetallides were reduced to a maximum of 5–6 microns.

Figure 3 (a) The grain dispersion dimensions of the sample according to GOST 5639–82 correspond to the dimensions of sample No. 6–7 according to GOST 5639–82. Germanium intermetallic grain grinders up to 3–4 microns when the sample contained 2% Germanium. Figure 3 (b) the presence of 3% Germanium in the composition, crushing of intermetallic grains to 2–3 microns.

Conclusion

According to the research results, it was found that germanium contained in germanium oxide remains in the aluminum alloy during liquefaction, destroying the microstructure of the alloy. In this case, the Germanium contained in it combines with other metals to form intermetallides. "Germanium can form a solid solution with aluminum, which restricts the movement of dislocations and increases the hardness of the alloy. In particular, Al-Ge alloys are used in applications requiring high mechanical strength."

An increase in the germanium content led to a decrease in the grains of the microstructure of the samples. When 3% is added, especially with respect to the germanium charge, the alloy granules are crushed to 2– –3 microns. From this it can be concluded that the germanium element improves the microstructure of aluminum alloys. However, an increase in the Germanium content in the aluminum alloy was accompanied by a decrease in its absorption in the alloy and its release into the slag during melting. Therefore, it is recommended to introduce the German element in an amount of 2–3% compared to the charge.

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submitted 21.01.2025;
accepted for publication 05.02.2025;
published 26.12.2024

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