Mathematical Modeling of Changes in Wear Resistance Properties of Aluminum Alloys Under the Influence of Modifying Elements

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**Abstract.** Improving the properties of aluminum with the help of various modifying elements is one of the most common methods. This article analyzes the change in wear-resistant properties of aluminum alloys when adding different amounts of Ge and Si to the samples. The wear resistance of the cast samples was determined and a graph of its dependence on the amount of germanium in the composition was constructed. Based on the obtained results, an analysis of the change in wear resistance was carried out using mathematical modeling. The article shows that it is theoretically possible to determine the change in wear resistance without conducting additional experiments using mathematical modeling.

**Keywords:** Germanium, modifier, silicon, temperature, mathematical modeling, mechanical properties, aluminum

# INTRODUCTION

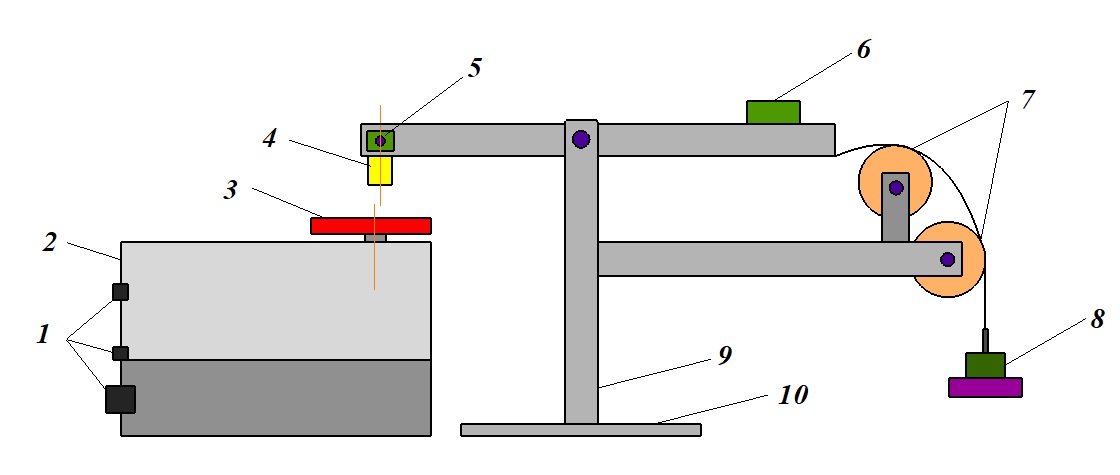
Nowadays, non-ferrous alloys are the most widely used alloys after ferrous alloys in the production of machine parts [1, 2, 3, 4]. One of the common technologies is to improve the properties of the alloy by introducing modifying elements into it [5, 6, 7, 8]. In this research paper, germanium and silicon were included as modifying elements in the composition of aluminum.

Wear resistance, unlike the modulus of elasticity or thermal conductivity, is not an intrinsic property of the metal, although these and other properties can significantly affect wear resistance. Wear resistance can only occur as a result of friction of one surface against another, which can be solid, liquid or gaseous, and can occur both under load and in motion. Wear resistance occurs depending on the specific friction pair and the environmental conditions present on the interacting surfaces. [9]. The most common type of wear resistance is abrasive wear resistance. This type of wear resistance is found in mining, agricultural, drilling equipment and tools, working bodies and chassis of road construction and transport equipment, crushing, mixing machines and equipment in the processing industry, etc. [10].

# MATERIALS AND METHODS

There are several methods for determining the wear resistance of metals, one of which is to determine the wear resistance of samples using a specific device. In this case, the samples are held in a device with a diamond disk under a certain force (5 or 10 N). The contact between the sample and the disk must be adjusted accordingly to ensure better friction with the surface. The wear rate (ω) of each sample volume was tested at a load of 10 N and calculated using the formula below.

(1)



**FIGURE 1.** Structure drawing with diamond disc measuring stability: 1-control buttons, 2 - electrodvigatel, 3 - diamond disc, 4-sample, 5 - sample holder, 6 - balancing load, 7 - rollers, 8 - loads (5 or 10 N), 9-10-supports.

Where m1 and m2 are the masses of the samples before and after determining the wear resistance, ρ is the density of the main element (Al) in each sample, F (N) is the standard load force, S (m) is the wear path [11]. Figure 1 shows the design of the device used for the tests.

# EXPERIMENTS AND RESULTS

## Experiments

The samples were melted in foundry furnaces and poured into sand-clay molds at a temperature of 750 °C . The samples cast in sand-clay molds were cut and prepared on a lathe to determine wear resistance. The wear value of the prepared samples was determined using the device shown in Figure 2. The wear value was determined based on the mass of the original sample and the samples after testing. The sample testing process took 10 minutes. Each sample was kept on a diamond wheel in the device for 10 minutes. The results obtained during the tests are presented in Tables 1 and 2.

By putting the results obtained in Formula 1, the rate of wear resistance of the sample volume (ω) was determined. In this, the density of the aluminum element ρ= 2.71 gr/cm3 was equal, F=10 N was taken, and the edible path S = 54 m was taken. Based on the above results, the rate of wear resistance (ω) of the sample volume was calculated.



**FIGURE 2.** Wear resistance determining device

**TABLE 1.** Alloy results in aluminum-copper system

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| № | The amount of Ge added to the sample (%) | The amount of Si added to the sample (%) | The initial mass of the sample is m1 (mg) | Sample mass after test m2 (mg) | Sample mass difference  (mg) | The wear rate of the sample volume (ω) N·m |
| 1 | 0 | 0 | 50.96 | 49.50 | 1.46 | 0.99 |
| 2 | 1 | 0 | 50.57 | 48.28 | 2.29 | 1.56 |
| 3 | 2 | 0 | 49.45 | 46.78 | 2.67 | 1.82 |
| 4 | 3 | 0 | 47.26 | 44.38 | 2.88 | 1.96 |
| 5 | 1 | 5 | 46.80 | 45.56 | 1.24 | 0.84 |
| 6 | 2 | 5 | 50.27 | 49.11 | 1.16 | 0.79 |
| 7 | 3 | 5 | 49.38 | 48.06 | 1.32 | 0.90 |

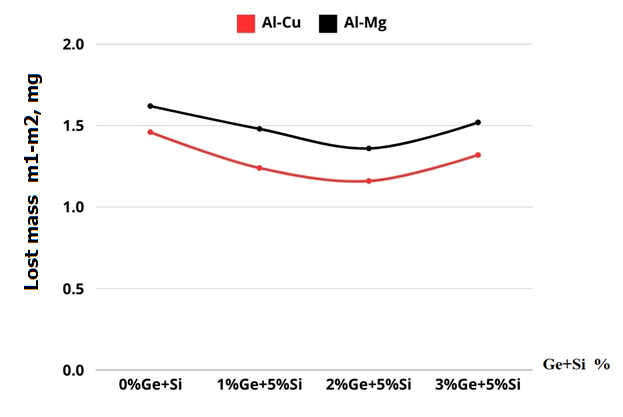
**TABLE 2.** Alloy results in the aluminum-magnesium system.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| № | The amount of Ge added to the sample (%) | The amount of Si added to the sample (%) | The initial mass of the sample is m1 (mg) | Sample mass after test m2 (mg) | Sample mass difference  (mg) | The wear rate of the sample volume (ω) N·m |
| 1 | 0 | 0 | 50.88 | 49.26 | 1.62 | 1.10 |
| 2 | 1 | 0 | 49.68 | 47.11 | 2.57 | 1.75 |
| 3 | 2 | 0 | 50.30 | 46.12 | 4.18 | 2.85 |
| 4 | 3 | 0 | 49.16 | 42.17 | 6.99 | 4.77 |
| 5 | 1 | 5 | 51.55 | 50.07 | 1.48 | 1.01 |
| 6 | 2 | 5 | 48.79 | 48.03 | 1.36 | 0.92 |
| 7 | 3 | 5 | 49.86 | 48.34 | 1.52 | 1.03 |

Based on the obtained results, a graph of the dependence of the mechanical properties on the amount of modifying elements was developed. Figures 3 and 4 show the results of the samples with GeO itself in the charges, and Figures 5 and 6 show the dependence of the samples with the inclusion of germanium and silicon in the composition of aluminum alloys.

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**FIGURE 3.** Graph of the influence of the element Ge on the wear resistance of aluminum alloys [by weight loss (mg)]

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**FIGURE 4.** Graph of the influence of the element Ge and Si on the wear resistance of aluminum alloys [by weight loss (mg)]

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## FIGURE 5. Graph of the influence of the element Ge on the wear properties of aluminum alloys [wear rate of the sample volume (ω)]

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## FIGURE 6. Graph of the influence of Ge and Si elements on the wear properties of aluminum alloys [wear rate of the sample volume (ω)]

## MATHEMATICAL MODELING

For the mathematical modeling of the effect on the wear resistance, the graphs in figures 3,4,5,6 above were taken as a basis. These graphs are based on the dependence of indicators such as the lost mass of the sample and the rate at which the volume of the sample is eaten (ω) on the amount of germanium and germanium-silicon in the sample. Mathematical modeling was developed using the PTC MathCad Prime 10.0.1.0 program.

As a result of experiments, the initial form of the cubic polynomial function for 4 points has the following form:

*P*(*x*)= (2)

here, - Lagrange basic polynomials, - the y-coordinates of points.

A mathematical expression is developed in the following order:

1. At the initial stage of calculation, we can calculate the Lk(x).

2. In the next step, we write down *P*(*x*), which we express as follows: P(x)=y0⋅L0(x)+y1⋅L1(x)+y2⋅L2(x)+y3⋅L3(x)

3. Then, we simplify the resulting expression.

4. Using the results obtained through mathematical modeling, the dependence function of the wear resistance of the alloy under study on the percentage of germanium and germanium-silicon added to its composition was derived as follows:

Dependence functions found on lost mass

For Al-Cu alloy (Ge): P1(x)= 0.0467x3 - 0.365x2 + 1.1483x+1.46;

For Al-Mg alloy (Ge): P2(x)=0.09x3 +0.06x2+ 0.8x+1.62;

For Al-Cu alloy (Ge+Si): P3(x) = 0.0167x3+ 0.02x2- 0.2567x +1.46;

For Al-Mg alloy (Ge+Si): P4(x)= 0.0433x3 -0.12x2- 0.0633x+1.62;

Dependence functions for volumetric wear rate were found

For Al-Cu alloy (Ge): P1(x)= 0.0317x3-0.25x2+0.7883x+0.99;

For Al-Mg alloy (Ge): P2(x)= 0.0617x3+0.04x2+0.5483x +1.1;

For Al-Cu alloy (Ge+Si): P3(x) = 0.01x3+0.02x2+0.18x+0.99;

For Al-Mg alloy (Ge+Si): P4(x)= 0.0333x3 -0.1x2- 0.0233x+1.1;

# CONCLUSION

1. As can be seen from the results presented in the graphs and tables, the inclusion of germanium alone reduced the wear properties of the aluminum alloys, but with a combination of germanium and silicon, the wear resistance increased. At the same time, the wear properties of the aluminum alloys in a combination of germanium and silicon increased by an average of 9% - 16%.

2. Polygonal functions obtained using mathematical modeling make it possible to obtain changes in wear resistance without conducting practical experiments.

3. When comparing the results of the research based on the modifying elements(Ge and Si)included in the alloy to improve the wear properties of aluminum alloys, it was found that the difference between the results of the comparative graph developed through mathematical modeling and the results was 5-6%.

Based on the above conclusions, it is recommended to add germanium to aluminum alloys in an amount of 1% to 2% of the alloy mass, and silicon - up to 5%. It is recommended to study the properties of aluminum alloys in further research taking these factors into account.

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