# Investigation of the effect of various silicon contents on the crystallization pattern and the composition of silumin phases



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**A I Cherepanov[1], V A Kukartsev[1], V S Tynchenko[1,2], L N Korpacheva[1] , I Yu Makarchuk[1,3] and R S Dremin[2]**

[1]Siberian Federal University, 79, Svobodny ave., Krasnoyarsk, 660041, Russia
[2]Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy ave., Krasnoyarsk, 660037, Russia
[3]Krasnoyarsk State Agrarian University, 90, Mira ave., 660049, Krasnoyarsk, Russia

E-mail: vadimond@mail.ru

**Abstract.** Silumin is an alloy composed of aluminum and silicon, that can contain up to 22% of silicon. It has a low cost, wear resistance and low relative weight. The main industries for using silumin are aircraft manufacturing and mechanical engineering. Given the relatively low cost of the alloy, silumin is used to produce cheap household appliances, which are often not inferior in reliability to expensive analogues. Recently, silumin has gained particular popularity in the arms industry, especially for the production of air rifles. The properties of these alloys primarily depend on the Si content, which leads to changes in its microstructure. The paper presents studies of the effect of silicon content on changes in the nature of crystallization and phase composition of silumins with Si content from 1 to 21%.

## 1. Introduction

Modern structural material should have good mechanical strength combined with low density and good corrosion resistance. This also applies to aluminum alloys [1]. First of all, this applies to silumins, which are widely used in almost all areas of production.

According to the double Al-Si diagram, silumins are usually classified into three groups: pre-eutectic (4-9% Si), eutectic (10-13% Si) and hypereutectic (14-22% Si). Pre-eutectic alloys are often conventionally divided into low-silicon (<6-7%) and high-silicon (> 7-8%). Silumin with a Si content of up to 13%, are characterized by ease of processing and excellent casting properties. The absence of various impurities makes this type of silumin neutral to the effects of an aggressive environment and various chemicals.

Alloys with a Si content of up to 22% belong to wear-resistant alloys. Such an amount of silicon gives silumin an increased strength significantly exceeding the strength of aluminum. But the processing of products from this alloy is more complex and requires great effort. Changes in the properties of silumins aimed at creating lighter alloys depend on changes in its microstructure and linear expansion coefficient at various operating temperatures of future parts [2]. The main element that has a significant impact on the properties of alloys of the Al – Si system is silicon.

An increase in the silicon content promotes the appearance of the silicon phase in the structure of the primary crystals, which are located in the places of dendrites accumulation of the α-solid solution and areas of weakly modified eutectics. This change leads to the elimination of porosity and, accordingly, to a change in the properties of the alloy itself [3].

## 2. Problem statement

Improving the quality and reliability of parts and structures is one of the most important challenges facing metallurgists and machine builders. The main way to improve the properties of shaped castings from aluminum alloys is to improve standard alloys and apply the optimal technology for their production [4].

In the molten condition, the main structural component of all silumins is the (Al) + (Si) eutectic. Its main parameter is the dispersion (the thickness of the branches of crystals (Si)). The leading phase during crystallization is A1. Depending on the chemical composition and cooling conditions, various phases can be present in the structure of silumins, which, depending on their nature, crystallize either as part of cooperative eutectics or as independent intermetallic compounds [5].

An increase in the silicon content to eutectic concentration leads to a decrease in the liquidus temperature and, accordingly, to a decrease in the crystallization interval, which has a beneficial effect on the casting properties. After the eutectic point, the liquidus line has a steeper ascension with an increase in the crystallization interval [6].

The creation of new alloys of the Al - Si system requires knowledge of the processes occurring in their structure, a change in the phase composition, which affect their new properties [7, 8].

## 3. Results

Alloys of the Al - Si system containing Si from 1 to 21% were investigated. For this, 6 heats were carried out in the Tamman furnace. In order to increase the purity of the experiment, no ligatures were used - alloying elements change the effect of silicon on the alloy microstructure. The chemical composition of the obtained alloys is presented in table 1.

**Table 1**. The chemical composition of the experimental meltings.

| No. | Al | Mg | Si | Mn | Cu | Ti | Fe |
|---|---|---|---|---|---|---|---|
| 1 | 98.55 | 0.01 | 0.15 | 0.0005 | 0.003 | 0.003 | 0.16 |
| 2 | 98.45 | 0.001 | 1.5 | 0.0004 | 0.004 | 0.003 | 0.12 |
| 3 | 94.2 | 0.0001 | 5.0 | 0.0005 | 0.0001 | 0.004 | 0.11 |
| 4 | 91.55 | 0.002 | 8.5 | 0.001 | 0.002 | 0.002 | 0.10 |
| 5 | 87.9 | 0.002 | 12.0 | 0.002 | 0.001 | 0.002 | 0.11 |
| 6 | 78.2 | 0.001 | 21.0 | 0.0006 | 0.002 | 0.001 | 0.12 |

From each melting, a sample was poured into a metal chill mold, the inner surface of which was covered with refractory paint (figure 1).

**Figure 1.** Disassembled chilled mold.

As a non-stick coating, a solution of hydrated lime was used, which was applied with a brush to a work surface previously heated to a temperature of 200-250 °C, followed by heating under pouring to 300 °C. Before painting, the chill mold was heated to 150-180. Then samples were cut to study the microstructure of each heat.

Sample preparation was carried out using a Saphir 520 grinding machine and a Saphir 520 polishing machine. The laboratory complex for sample preparation is shown in figure 2.

**Figure 2.** A set of equipment for sample preparation.

The prepared samples were examined using a Carl Zeiss AxioObserver A1m microscope. Figure 3 shows the microstructure of an alloy containing 0.15% Si.

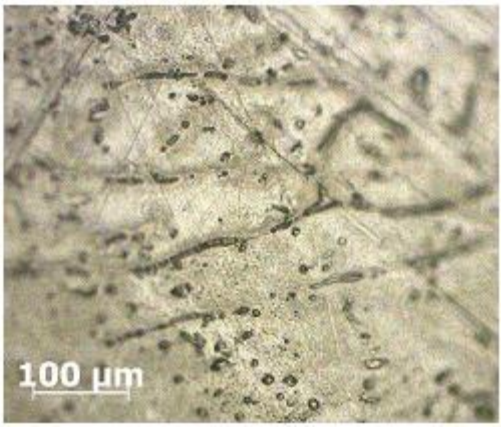


**Figure 3.** The microstructure of alloy 1 of the sample containing 0.15% Si.

In pre-eutectic silumins, in addition to eutectic, the main structural component, there is a solid solution of silicon in aluminum, which is primarily crystallized from a liquid, - (αAl). Its volume fraction is usually 30-70%. Dendritic cells (αAl) in pre-eutectic silumins are surrounded by eutectic colonies (Al + Si) or weakly branched crystals of the silicon phase. The leading phase during crystallization is Al. With an increase in the silicon content (1.5%; 5.5%; 8.5%), this is observed in Figures 4, 5, 6.

The cast alloy structure is characterized by α-Al dendrites and eutectic (Al + Si). Due to the increased iron content in the eutectic, a significant number of plate crystals of β-FeSiAl5 are contained, therefore, the eutectic component of the alloy can be qualified as a triple eutectic (Al + Si + β-FeSiAl5). The main phases in the molten state are: α-Al, Si, β-FeSiAl5. Iron-containing phases do not change their morphology when heated, maintaining the shape of extended plates. This causes a low level of ductility.

The microstructure of alloy 5, with a content of 12.0% silicon, in addition to a-solid solution and eutectic, includes a coarse-grained silicon phase formed during primary crystallization, as well as a fine crystalline one formed during secondary crystallization (figure 7). A feature of Al-Si system alloys is that a purely eutectic structure, as a rule, is not realized in castings. The leading phase is Si.

Figure 8 shows the microstructure of a hypereutectic silumin composition 6 containing 21% silicon. Here you can see the primary crystallized silicon, eutectic (a - solid solution of aluminum + silicon), and small crystals of secondary crystallization (a - solid solution of aluminum + silicon).

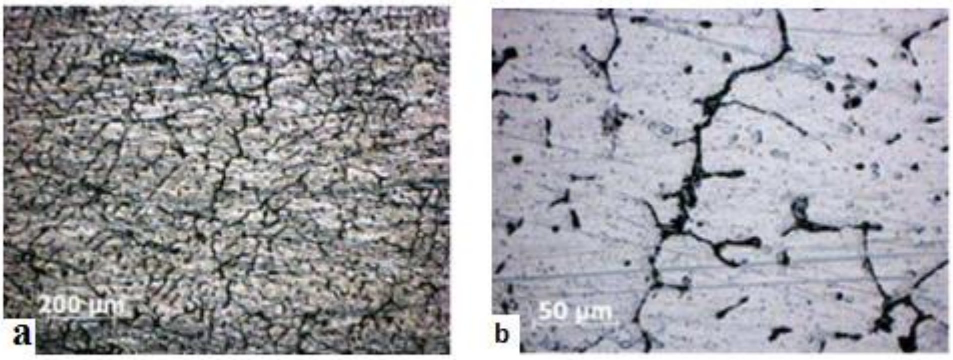


**Figure 4.** Microstructure #2 of an alloy containing 1.5% Si.

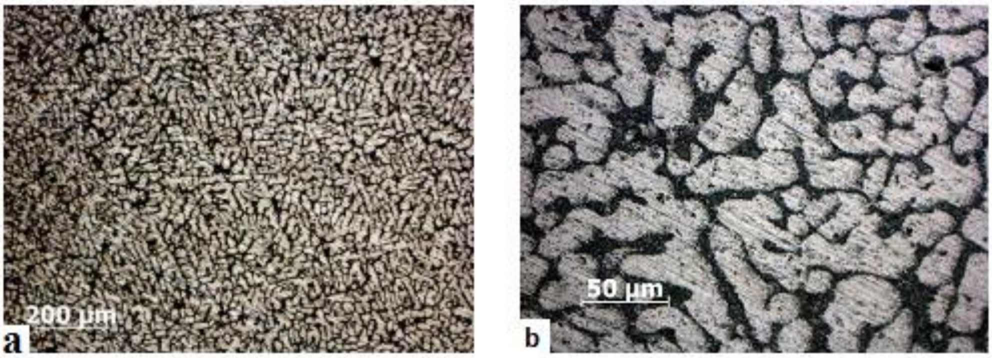


**Figure 5.** Microstructure #3, alloys containing 5.5 % Si.

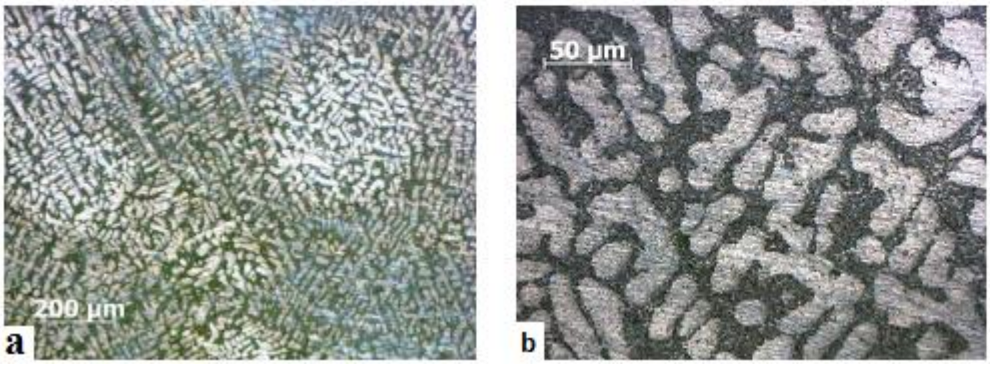


**Figure 6.** Microstructure #4, alloys containing 8.5% Si.

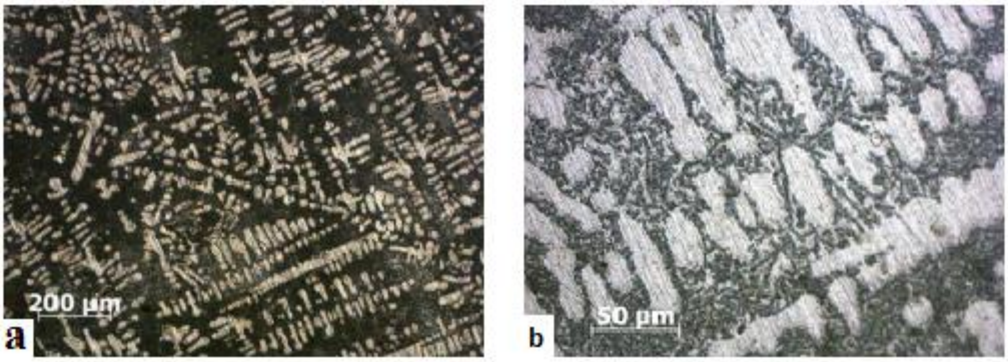


**Figure 7.** Microstructure #5 samples containing 12% Si.

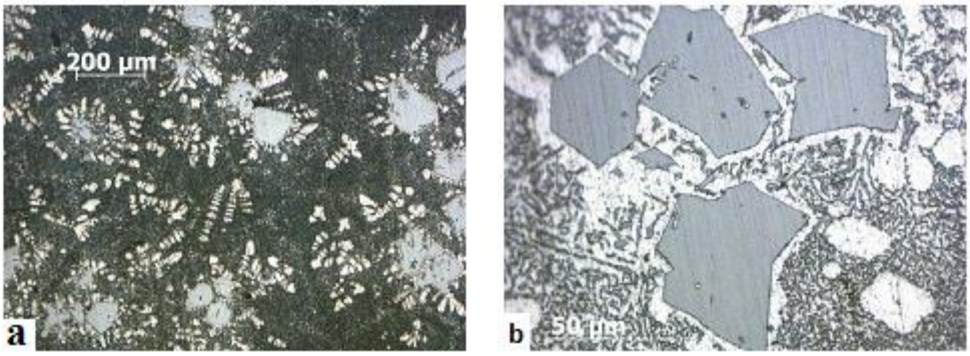


**Figure 8.** Microstructure containing 21% Si.

## 4. Conclusion

With an increase in silicon content to 8.5%, the leading phase during crystallization is Al.

In an alloy containing 12.0% silicon, in addition to a-solid solution and eutectic, during the primary crystallization, a rough needle-shaped silicon phase is formed, and in the secondary crystallization it is finely crystalline.

In the structure of the alloy, with 21% silicon, primary crystallized silicon, eutectic (a-solid solution of aluminum + silicon), and small crystals of secondary crystallization (a-solid solution of aluminum + silicon) are observed.

Thus, it was determined that, with an increase in the silicon content, the character of crystallization and the composition of the phases change. An increase in the composition of the silicon alloy leads from primary crystallization of alpha-solid solution + eutectic to primary crystallization of silicon + eutectic with fragments of secondary crystallization.

Understanding the occurring phenomena during the crystallization of silumins allows the development of preparations to obtain the required microstructure and properties of silumins developed for workpieces of various functional purposes.

## References

[1] Goncharenko E S and Kornysheva I S 2012 Prospects for the use of castings from aluminum alloys *Foundry* **1** 21-3

[2] Kablov E N 2012 Strategic directions for the development of materials and technologies for their processing for the period up to 2030 *J. of Aviation materials and technologies* (Moscow: VIAM) 7-17

[3] Zolotorevsky V S 1981 *The Structure and Strength of Cast Aluminum Alloys* (Moscow: Metallurgy) p 315

[4] Goncharenko E S, Trapeznikov A V and Ogorodov D V 2014 Foundry aluminum alloys (on the occasion of the 100th birthday of M B Altman) *Proceedings of VIAM* **4(2)**
[5] Belov N A, Savchenko S V and Khvan A V 2008 *Phase Composition and Structure of Silumins* (Moscow: MISIS) p 282
[6] Zolotorevsky V S and Belov N A 2005 *Metallurgy of Foundry Aluminum Alloys* (Moscow: MISIS) p 376
[7] Afanasyev V K, Gorshenin A V and Starostina M A 2010 Features of the effect of small additions of silicon on the linear expansion of aluminum *Izvestiya of Universities. Ferrous Metallurgy* **6** 88-9
[8] Mondolfo L F 1979 *The Structure and Properties of Aluminum Alloys* (Moscow: Metallurgy) p 640