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PROPERTIES OF NOVEL COMPOSITE ALLOYS USED FOR THE ENGINE PISTONS

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Abstract

The article presents the results of the investigations cover novel composite silumins with new alloying additives, such as chromium and molybdenum (not yet used in this type of silumin) and increased content of nickel and copper. The samples strength tests were performed at room temperature (20°C) and at elevated temperatures (up to 350°C), and were carried out using the strength machine, equipped with the special climate chamber. The dimensional stability of the new aluminum alloy was investigated using the precision dilatometer. This device allows one to register and record the sample dimensions as a function of temperature, during sample heating and cooling. During the DTA crystallization process investigations, derivative curves have been determined, that allows the analysis of the solidification process and the analysis of the heat transfer process in the sample structure and phase transformations. In the article shows the derivative curve and representative microstructures, and characteristic temperatures for the conventional AlSi12 alloy and novel composite alloy. All research results indicated that the newly developed composite aluminum alloy has far better parameters than aluminum alloys used previously for pistons of the internal combustion engines.

This article concludes with a summary of the advantages of the new composite alloys.

Keywords: *novel composite alloys, the engine pistons, thermal derivative analysis*

1. Introduction

Permanent increase in work parameters, related to increases in engine performance, requires the development of new materials that could perform in much more difficult conditions. This applies in particular to materials used in the production of internal combustion engines, in aviation and aerospace industries. Higher temperature values, higher pressures in which various components of engines and machines operate, become more and more challenging for researchers, working on new materials. Particularly interesting is the use of composite materials, which make it possible to meet often very diverse requirements, which are practically impossible to meet for conventional materials. Composite metal materials are obtained by introducing new elements or chemicals into the base material during the manufacturing process, which results in increased properties such as alloy strength, heat resistance, abrasion resistance and dimensional stability (2, 3).

Silicon aluminum alloys (silumins) are widely used in motor designs. Almost all internal combustion engine pistons are manufactured using silumins (1). The research works presented in this article deal with the silumins, used in the manufacturing of engine pistons and plain bearings. The requirements relate primarily to high strength values at operating temperatures, thermal shock resistance, high hardness, abrasion resistance and dimensional stability when operating under varying temperature conditions (2, 3). The results of the investigations presented in this article cover novel composite silumins with new alloying additives, such as chromium and molybdenum (not yet used in this type of silumin) and increased content of nickel and copper.

2. Experimental

Materials

The subject matter of the study was the new composite Al-Si alloy for of the internal combustion engines pistons, which parameters were compared to the conventional silumin alloy AlSi12. The chemical composition of both alloys is shown in Tab. 1.

Tab. 1 Chemical composition of tested alloys, %

	Si	Mg	Cu	Ni	Fe	Mo	Cr
Conventional	12.5	0.37	1.4	1.3	≤0.7	-	-
Composite alloy	12.5*	0.43	5.2	4.1	≤0.5	0.25	0.28

During the study, the content of the different alloying elements was varied to determine the effect of the content of the individual component on the strength of the alloy and its dimensional stability, which was the main objective of the researches.

Apparatus and procedures

The studies involved both casting process and post-cast material testing. The research included metallography (chemical composition, microstructure), material strength, abrasive wear, thermal expansion. Research of the alloy crystallization process during casting was carried out, using the differential thermal derivative analysis (DTA) method. Samples were cast in the ATD-10 chill, Fig. 1. The chill was equipped with a thermocouple and an instrument for recording course of metal solidification, and a heat flow analyser.

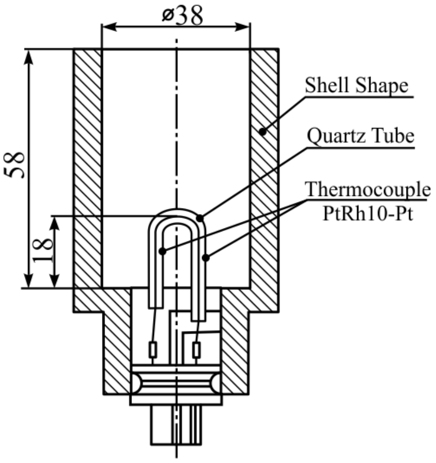

Fig. 1. Chill for casting process testing of aluminium alloy samples

The cast samples were used for metallographic studies. The samples strength tests were performed at room temperature (20°C) and at elevated temperatures (up to 350°C), and were carried out using the Instron 8802 strength machine, equipped with the Instron 3119-406-222 special climate chamber.

Samples for strength testing were cast in metal chill in the form of rods of $\phi15/\phi11$ diameter and 185 mm length.

Abrasive wear testing was performed using samples of diameter d = 18.5 mm and length L = 40 mm. The countersample was a C45 steel disc with a hardness of 56 HRC: a diameter of D = 100 mm and a thickness of s = 10 mm. The disc rotational speed of n = 100 rpm. The specimen pressures on the disc are 4 MPa. The sample was lubricated with engine oil. The sample wear was determined hourly, and the abrasive wear test time for the one sample was 10 hours. The results of abrasive wear tests for the new aluminum alloy were compared with the results of abrasive wear tests of various types of cast iron specimens.

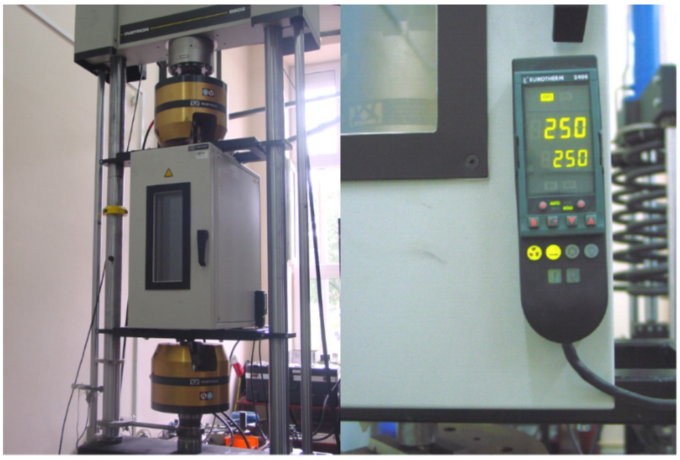

Fig. 2. Instron 8802 strength testing machine with climatic chamber Instron 3119-406-222

The dimensional stability of the new aluminum alloy was investigated using the BAHR 802/801 precision dilatometer. This device allows one to register and record the sample dimensions as a function of temperature, during sample heating and cooling. Measurements can be conducted in a comparative system (with pure aluminum or platinum samples) or by direct measurement. The results of measurements are very precise. The device operates according to a special temperature program which is a computer controlled.

3. Test results and discussion

During the DTA crystallization process investigations, derivative curves have been determined, that allows the analysis of the solidification process and the analysis of the heat transfer process in the sample structure and phase transformations. Fig. 3 shows the derivative curve for the conventional AlSi12 alloy and representative microstructures, and characteristic temperatures.

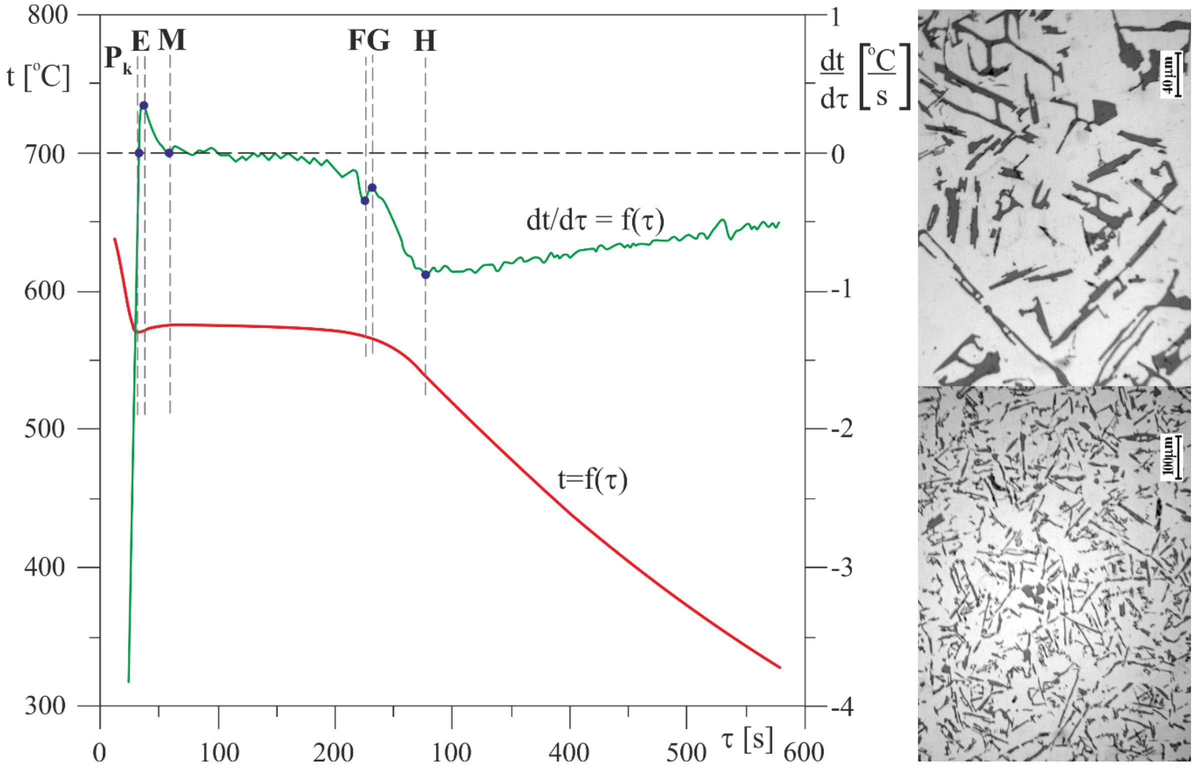

Fig. 3. The DTA curves and representative microstructures of conventional AlSi12 alloy

Figure 4 shows the derivative curve for the new composite aluminum alloy and the representative microstructures and characteristic temperatures.

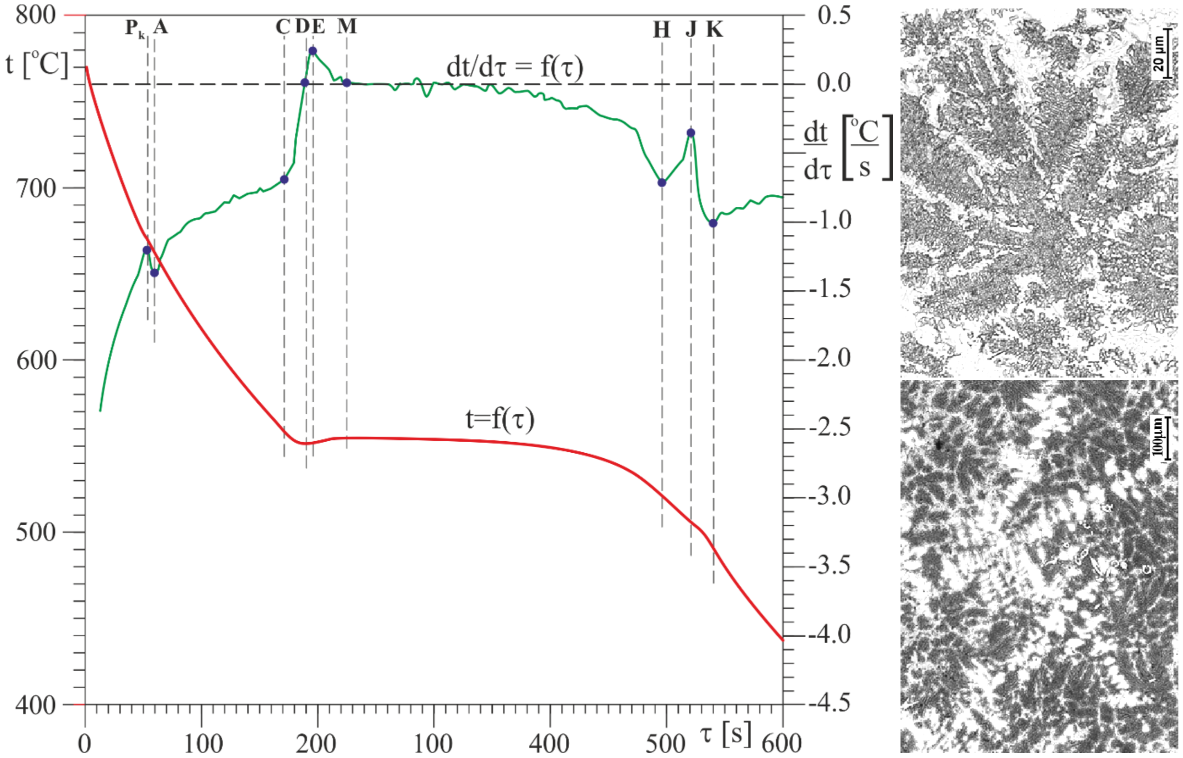

Fig. 4. The DTA curves and representative microstructures of the novel composite alloy

The results of the analysis indicate that the microstructure of the new composite alloy is more finely grained and that many intermetallic compounds can be observed at the grain boundaries. When is analysing the effect of nickel and copper in increased quantity and new additional additives chromium and molybdenum so they can be beneficial not only for the microstructure fragmentation but also for neutralizing the harmful effects of iron in aluminum alloys. As a result of the increased amount of Ni and Cu and the presence of previously unused chromium and molybdenum, intermetallic compounds such as: $(CrFe)_4Si_4Al_{13}$, $Al_2(CrSiFe)$, Al(SiMoFe), $Al_{12}(SiWFe)$, AlSiFeCo, Al_9Co_2, Al(SiMgCuNiFeCo) were created. In silumin and other aluminum alloys, containing small amounts of alloying elements and large amounts of iron, an intercrystalline Al_9Fe_2Si compound is formed, which occurs in the form of long, sharp-pointed crystals. This has a detrimental effect on the strength of the materials, particularly on the ultimate tensile strength, the relative elongation, the yield strength and the fatigue strength. This has also adversely affects on other alloy properties.

Tests of the samples strength allowed determining the influence of different alloying elements on strength at ambient temperature and at elevated operating temperatures. The increased nickel additive is particularly beneficial.

Figure 5 shows the influence of nickel on alloy strength at various temperatures, with 2% and 4% nickel content in the alloy. The tensile strength of the alloy containing 4% nickel at 20°C was 43% greater than the alloy containing 2% nickel, but at 350°C, tensile strength was greater by as much as 87%. Comparative results of the tensile strength of the new composite alloy and the conventional AK12 alloy are shown in Tab. 2.

The results of the abrasive wear test of the new aluminum composite alloy were compared with the samples of different types of pearlite − martensitic microstructure with carbides, ductile cast iron EN-GJS-800-2 and grey cast iron EN-GJL-250. Diagrams of the wear course over time are presented in Fig. 6.

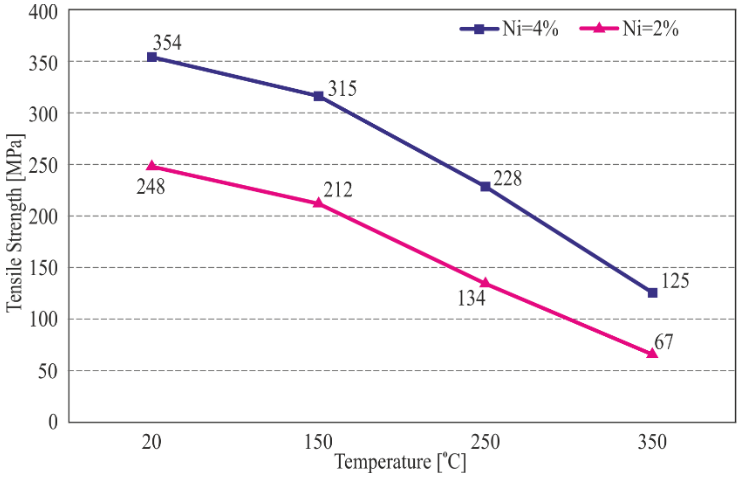

Fig. 5. Dependence of the tensile strength versus temperature for the samples of the novel alloy with various nickel content: 2% and 4%

Tab. 2. Comparison of the tensile strength for the novel alloy and conventional alloy at ambient and 250°C temperatures

Material	Rm [MPa]	$R_{p0.2}$ [MPa]	As [%]
AlSi12	371.0	320.8	3.7
AlSi12, 250°C	250.2	215.7	11.4
Composite alloy	451.0	385.0	3.7
Composite alloy, 250°C	364.0	299.0	6.7

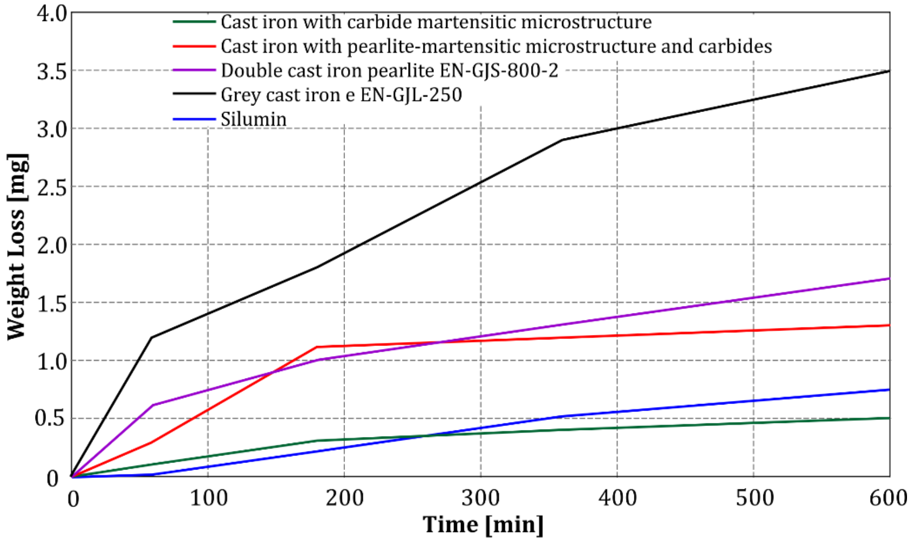

Fig. 6. Comparison of abrasive wear of samples, made of novel aluminium alloy and different cast iron

The abrasive wear of the investigated new aluminum composite alloy, as seen in the figure, was comparable to that of martensitic cast iron with carbide, but it was less than all other cast irons, even several times less wear.

In the dilatometric researches, a great deal of experience has been gained, regarding the composition of the alloy and its heat treatment. On selected courses of linear expansion and linear expansion coefficients, the quality and operability of a given element at elevated temperatures can be ascertained, especially if the possible thermal deformation of the element can be strictly defined.

Figure 7 shows the course of changes in thermal expansion coefficient as a function of the temperature for conventional silumin, without heat treatment. There are large differences in the coefficient values during heating and cooling, which is reflected in the deformation increase.

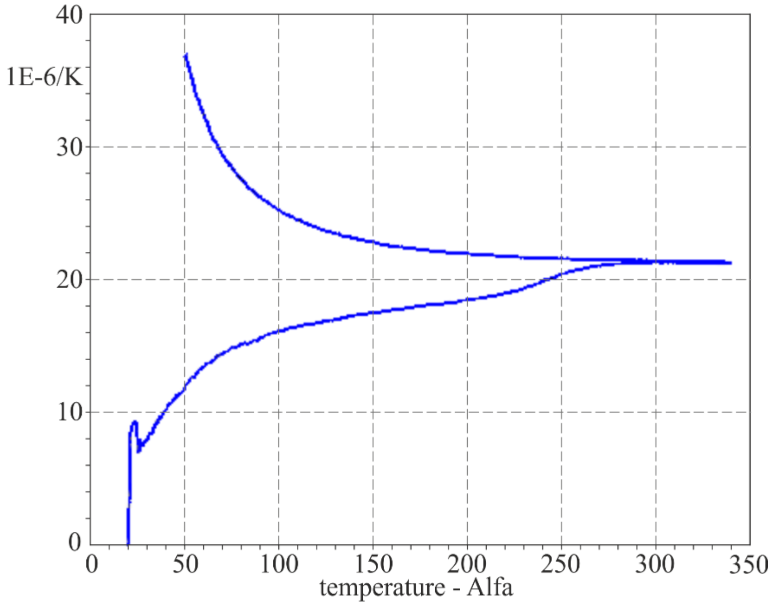

Fig. 7. Course of the linear expansion coefficient versus temperature during heating and cooling for the conventional AlSi12 alloy, with incorrect heat treatment

Figure 8 shows the course of the thermal expansion coefficient as a function of the sample temperature for the new composite alloy, which exhibited a lower expansion coefficient during sample cooling than for sample heating.

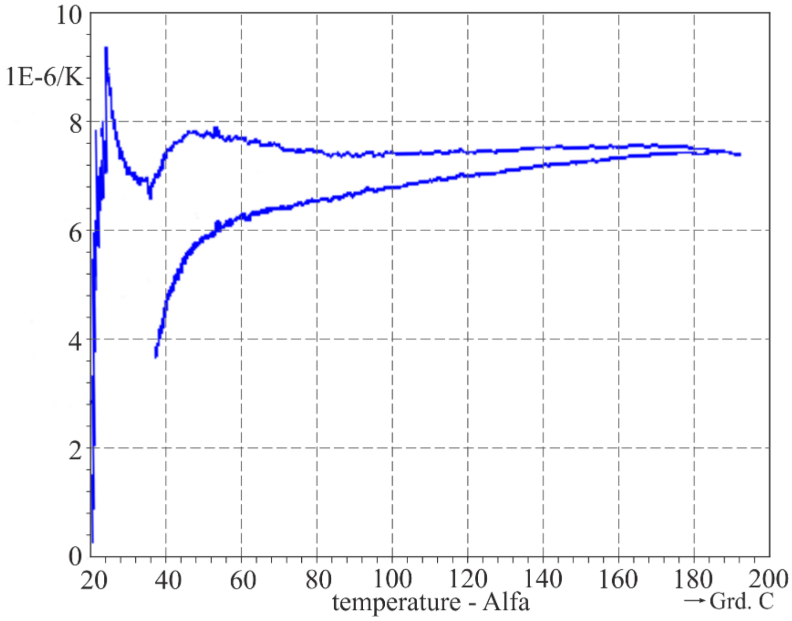

Fig. 8. Course of the linear expansion coefficient versus temperature during sample heating and cooling for one of tested silumin alloy, which expansion coefficient during sample cooling is smaller than during sample heating

Figure 9 shows the course of the thermal expansion coefficient as a function of the sample temperature, made of the new composite material during heating and cooling, after properly performed heat treatment.

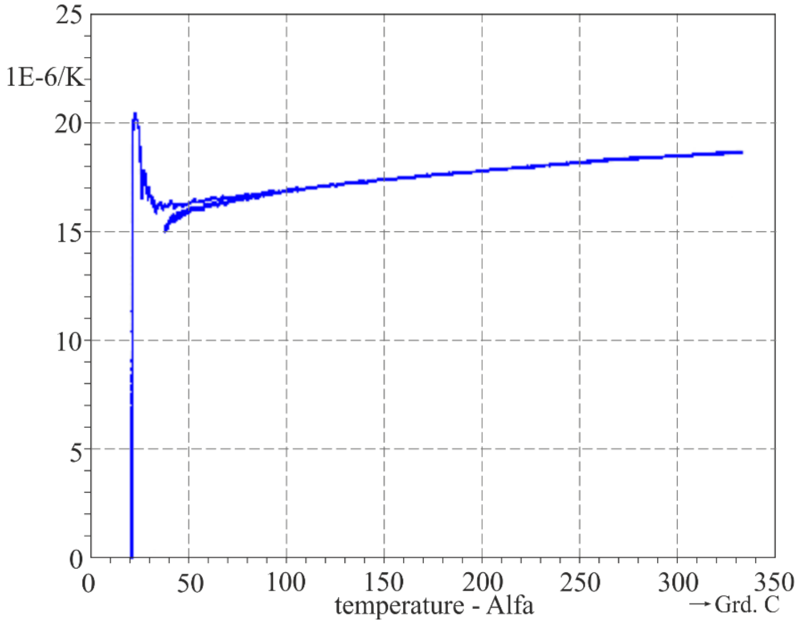

Fig. 9. Course of the linear expansion coefficient versus temperature, during heating and cooling for the novel composite silumin alloy, after correct heat treatment

All research results indicate that the newly developed composite aluminum alloy has far better parameters than aluminum alloys used previously for pistons of the internal combustion engines.

4. Conclusions

1. Using the DTA method, one can control the type and order of crystallization in silumin castings.
2. The introduction of new silumin alloy additives: Cr, Mo, W, Co and amount of growth Ni and Cu causes the alloy strength increase, abrasive wear reduce and dimensional stability increase.
3. Introduced alloy additives, composed of hard-to-melt elements, caused crystallization of the alloy phases before $\alpha + \beta$ eutectic, which were reflected in the reduction of silicon in the eutectic and significant silicon fragmentation.
4. New alloying elements have a beneficial effect on neutralizing the harmful effects of iron in aluminum alloys, as they contribute to the formation of crystals of intermetallic compounds, which shape is more favourable than the shape of the compounds formed in the absence of these elements.
5. Thanks to the introduction of new elements into the silumin, multi-phase microstructures with very high fineness are produced, which has beneficial effect on the increasing of the material strength and reducing the abrasive-wear.

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