HIGH-QUALITY SILUMIN ON PISTONS OF COMBUSTION ENGINES

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Abstract

In the paper the test results are presented for the AlSi12Cu5Ni5Mg0.5Cr0.05Mo0.05W0.05V0.05 newly worked out silumin close to eutectic piston-silumin with the elevated content of copper and nickel to approx. 5% with relation to generally applied the AlSi12 piston silumin. The novel silumin contains also Cr, Mo, In and V micro alloy additions in quantity approx. 0.05% for every element. Research of microstructure, HB hardness and coefficient of lineal thermal expansion α for the AlSi12Cu5Ni5Mg0.5Cr0.05Mo0.05W0.05V0.05 silumin in the cast state, after the separation strengthening and additional short duration high-temperature heat-treatment were performed. Research of the microstructure of the AlSi12Cu5Ni5Mg0.5Cr0.05Mo0.05W0.05V0.05 silumin showed the occurrence in it following constituent phases: α(Al), β(Si), Al2Cu and AlMoCrWVMgNiSiCuFe. The separation strengthening brought about the coagulation of silicon emissions. The short duration high-temperature heat-treatment caused additional coagulation of silicon emissions and also its coalescence. Measurement of the HB hardness showed high hardness investigated alloy in the rough state, approx. 30% higher from the AlSi12 piston silumin. Measurement of the α coefficient of thermal expansion showed beneficial effects of novel alloy connected with the value decreasing of this coefficient as well so called hysteresis. Further studies on novel alloy will concentrate on alloy-additional and processes of the heat treatment.

Keywords: *combustion engines, piston, composite alloys, heat-treatment, thermal expansion, hysteresis*

1. Introduction

The paper presents the results of investigations of microstructure and HB hardness and coefficient of linear thermal expansion α commonly used neareutectic piston silumin AlSi12 [1-4] and newly developed silumin of increased concentrations of Cu and Ni to about 5%, and with additives: Cr, Mo, W and V in the amount of 0.05% for each element (AlSi12Cu5Ni5Mg0.5Cr0.05Mo0.05W0.05V0.05) [4, 6].

The aim of this paper was to investigate the microstructure, HB hardness, and thermal expansion coefficient α of AlSi12Cu5Ni5Mg0.5Cr0.05Mo0.05W0.05V0.05 silumin alloy.

2. Research Methodology

The investigations were conducted on neareutectic silumin alloy having the following composition: 11.96% Si, 4.94% Cu, 4.84% Ni, 0.33% Mg 0.05% Cr, 0.06% Mo, 0.06% W, 0.05% V, 0.36% Fe, 0.30% Sr, 0.10% Ti and 0.02% B.

For melting compound silumin alloy, the AlSi11 base alloy was used. The composition of the base silumin was supplemented with technically pure metals: Cu, Ni, Si, Mg, Mo and W, and alloys AlCr15 and AlV10. Silumin alloy was melted in a laboratory induction furnace with graphite crucible. After thawing and overheating the alloy has been subjected to modification. Modification was applied by introducing to the molten metal, respectively, 0.30% Sr + 0.10% Ti + 0.02% B. Modifiers were introduced into silumin in the form of alloys: AlSr10 and AlTi5B. After modifications liquid metal was refined with nitrogen at the time of 15min.

Then gravity die casting rods of diameter d = 10mm were manufactured, from which specimens to the tests were made and the tests: metallographic, hardness and coefficient of linear thermal expansion α were performed. These studies were carried out on samples of both raw state and after heat treatment of various endeavours. Investigated silumin was separation strengthened. The solution heat treatment was carried out under the following conditions: 520°C, 8h, and cooling water, and aging: 160°C, 8h, and ambient air cooling. In addition, tested silumin has been given the short-term high-temperature heat treatment, consisting of placing the sample in a furnace heated to a temperature of 560°C, holding in furnace for 3 minutes and cooling in water. The examined silumin alloy hardness test was performed on Briviskop machine in Brinell scale for the conditions 62.5/2.5/30. Load factor K = 10. Metallographic examination was performed on the „Nikon" optical microscope with ×1000 magnification. The samples were etched with 2% HF.

These investigations became performed with use of a precise dilatometer. Equipment enables the registration of the changes of the dimensions of the sample in the function of temperature and time. The measurements are possible in straight and in differential system. The results of measurements are very precise, because they are compared with the reference material, which is platinum. The tests of investigated and reference materials take place in the same conditions, and investigations in differential system take place in the same equipment. Heating and cooling took place in the special equipment, which can realize temperature program, controlled with the usage of computer. The changes of dimensions were measured by the inductive transducer. The samples were placed in the quartz tube and the changes of their lengths were carried through the quartz rods. The temperature of a tested material was measured with the Pt-PtRh thermocouple. The advantage of the method used is the constant measurement of the elongation changes straight or relative in the function of time and temperatures, in function of the temperature depending on the application of straight or differential measurement method. Schema and the view of research set-up are submitted on Fig. 1.

3. Research results

Commonly used neareutectic piston silumin AlSi12 has the following composition: 11.5-13.0% Si, 0.8-1.5% Mg 0.8-1.5% Cu, 0.8-1.3% Ni, <0.2% Mn and Zn and <0.6% Fe and <0.1% Ti. Its microstructure consists of partial phase α (Al), β (Si), intermetallic phases Mg_2Si, Al_2Cu, Al_3Ni and complex intermetallic phase AlSiMgCuFe. These phases crystallize as components in double, triple and quadruple eutectic: α + β, α + β + Mg2Si, Al2Cu + α + β, α + Al3Ni + β, α + Al2Cu + AlSiMgCuFe + Mg2Si. In this silumin free α phase separations may occur forming leading phase eutectic α + β crystallization. The hardness of this silumin after separation strengthening is 90-100HB, while its coefficient of linear thermal expansion in the temperature range 50-300°C is $\alpha = 22.5 \times 10\text{-}6°C^{-1}$.

To investigations presented in this paper the neareutectic silumin was developed with increased content of Cu and Ni to 4%, compared to the presented piston silumin type AK12. It also introduces microadditives Cr, Mo, W and V in an amount of about 0.05% of each element. Microstructure of the raw silumin is shown on Fig. 2.

It consists of phases: α, β, the complex intermetallic phase AlMoCrWVMgNiSiCuFe and the phase Al_2Cu. These phases crystallize in the form of triple eutectics: α + lMoCrWVMgNiSiCuFe + β and α + β + Al_2Cu.

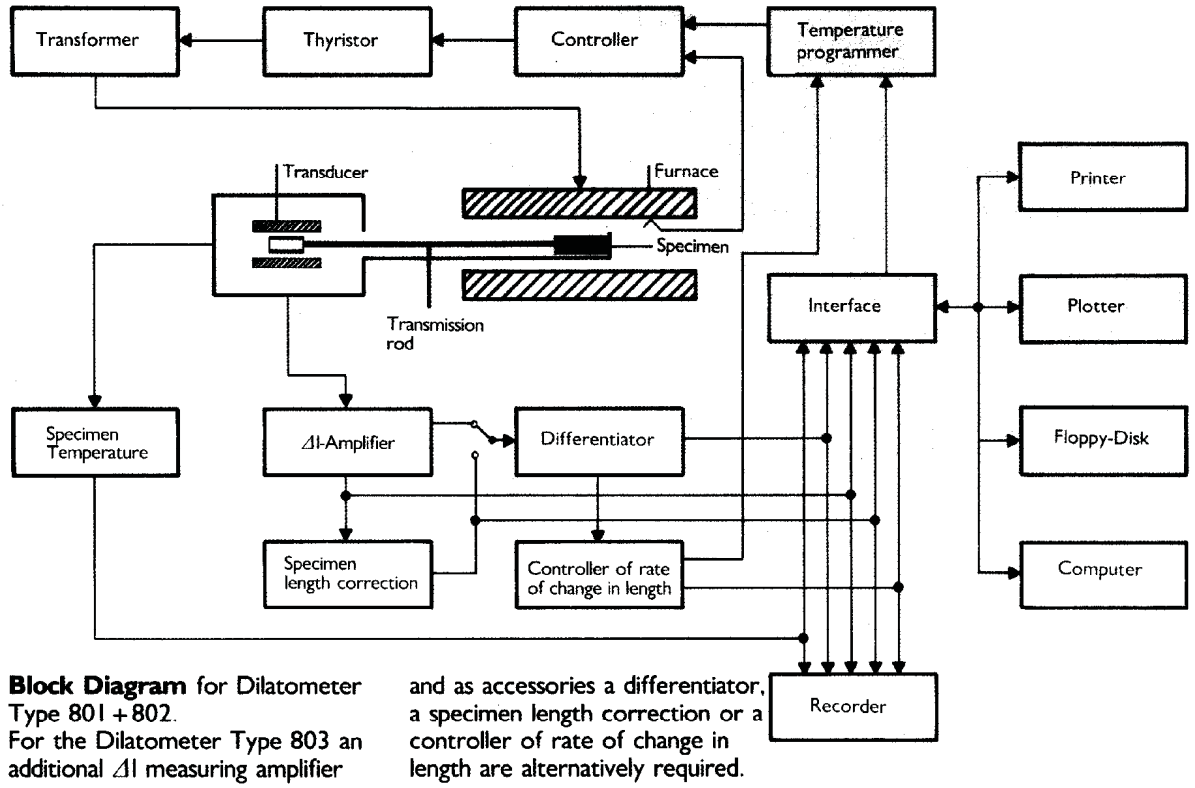

Fig. 1. The schema of the 801+802 research set-up

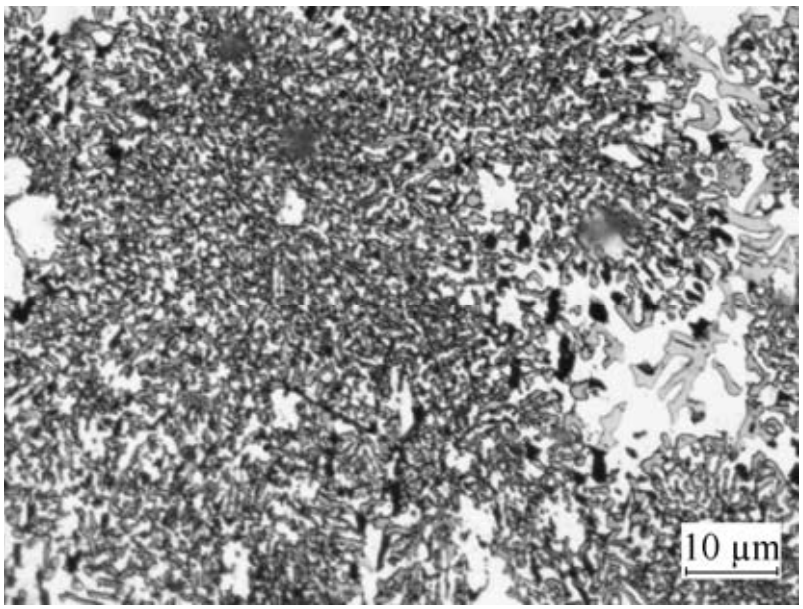

Fig. 2. Microstructure of raw silumin AlSi12Cu5Ni5Mg0.5Cr0.05Mo0.05W0.05V0.05. Phases: Eutectic α + β + AlMoCrWVMgNiSiCuFe, Al2Cu

Separations of silica have characteristic for strontium-modified silumins the very small fibrous morphology. Al_2Cu phase occurs as pale gray, and the complex AlMoCrWVMgNiSiCuFe phase as very dark small crystals.

Investigated silumin is characterized by high raw hardness of 134HB. Results of dilatrometric tests are posted on Figs. 3 – 12.

The graph of changes in the value of linear thermal expansion coefficient α as a function of temperature for the standard material is presented in Fig. 3.

For comparison of results of thermal properties, in every case the values of the α coefficient were determined for the temperature of 200°C for heating and cooling curve. The difference of the α coefficient for the heating and cooling curve is known as hysteresis. This difference for standard material is 2.62 1E-6 / K, which is 12.7%. For relative elongation the temperature of 50°C was adopted for a comparison of the various options of the investigated alloys.

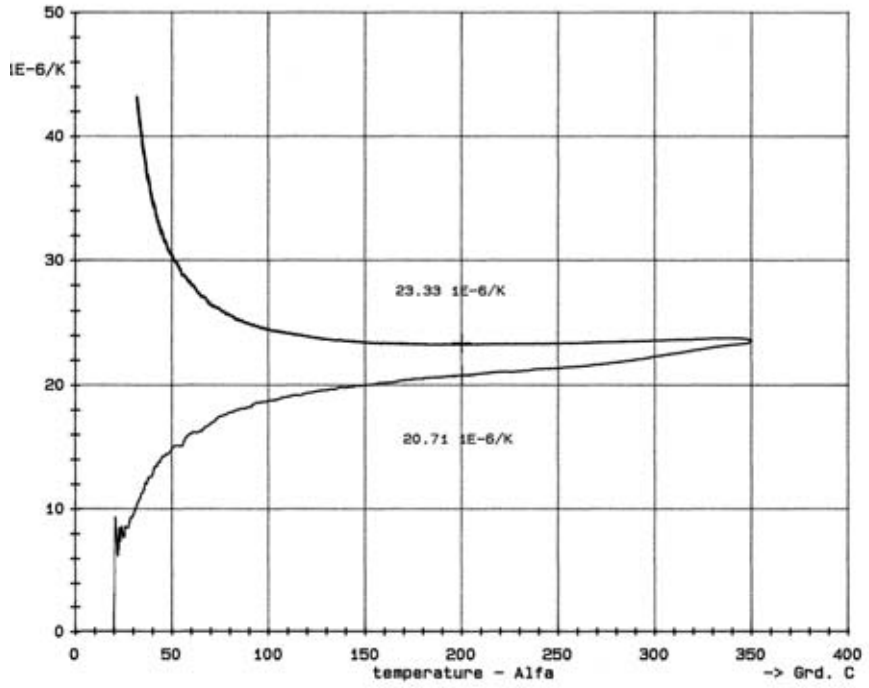

*Fig. 3. Coefficient of linear expansion α for the standard material (Δα = 2.62 * 1E-6 / K)*

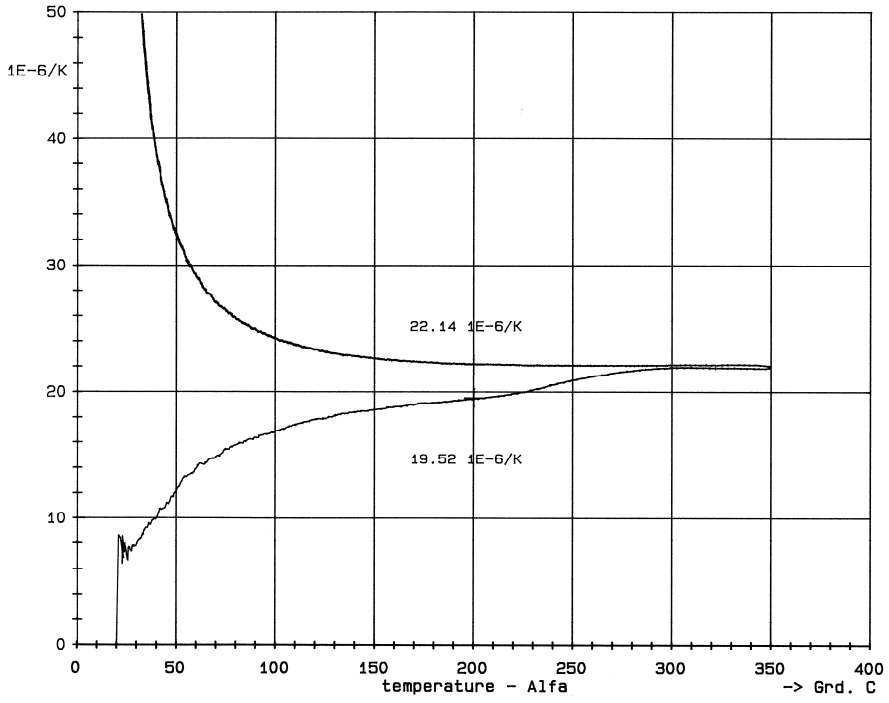

*Fig. 4. Coefficient of linear expansion α for the new composite material neareutectic alloy AlSi12 in a raw state (Δα = 2.62 * 1E-6 / K)*

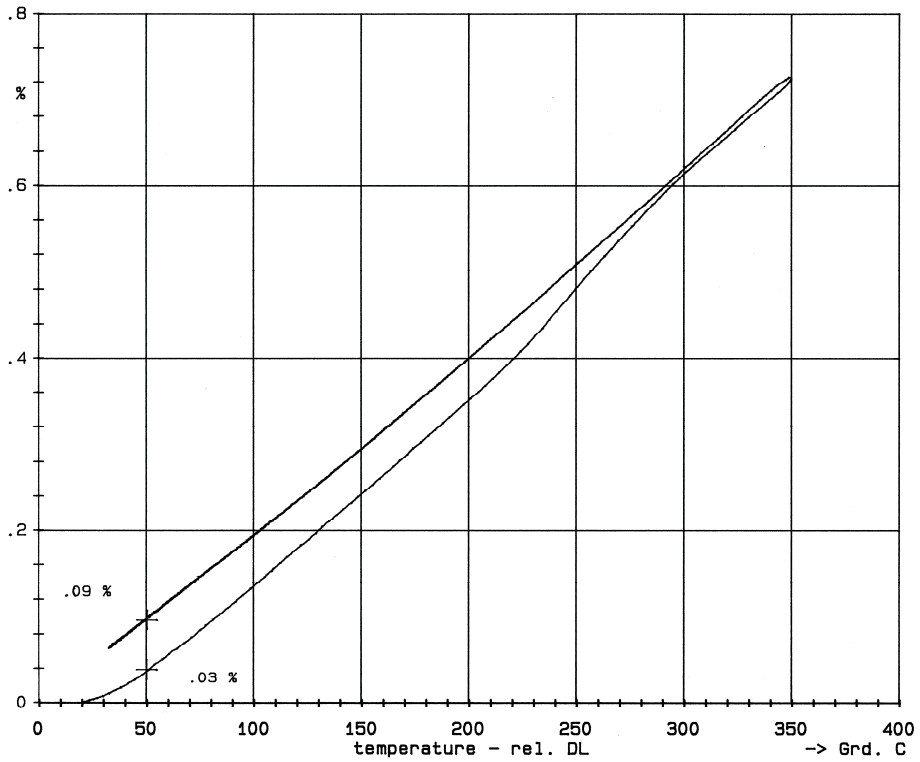

*Fig. 5. Relative elongation as a function of temperature for the new composite material neareutectic alloy AlSi12 in a raw state (Δα = 2.62 * 1E-6 / K)*

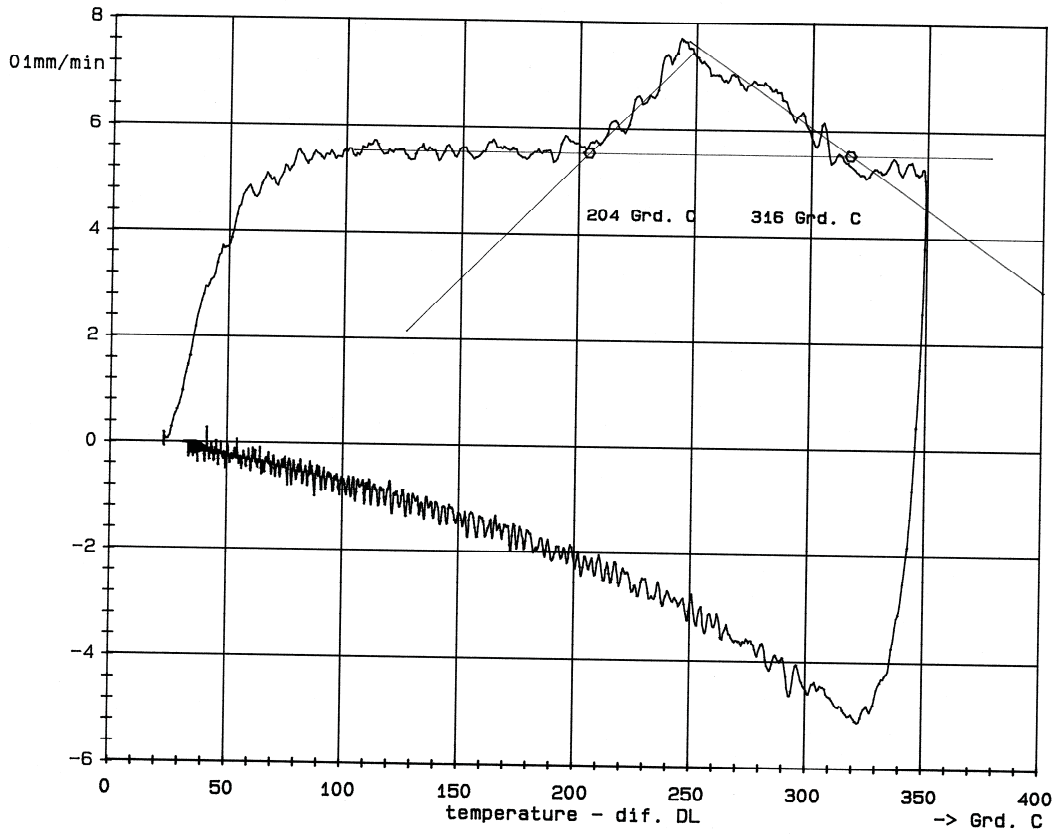

Fig. 6. The course of elongation derivative as a function of temperature for the new composite material neareutectic alloy AlSi12 in a raw state

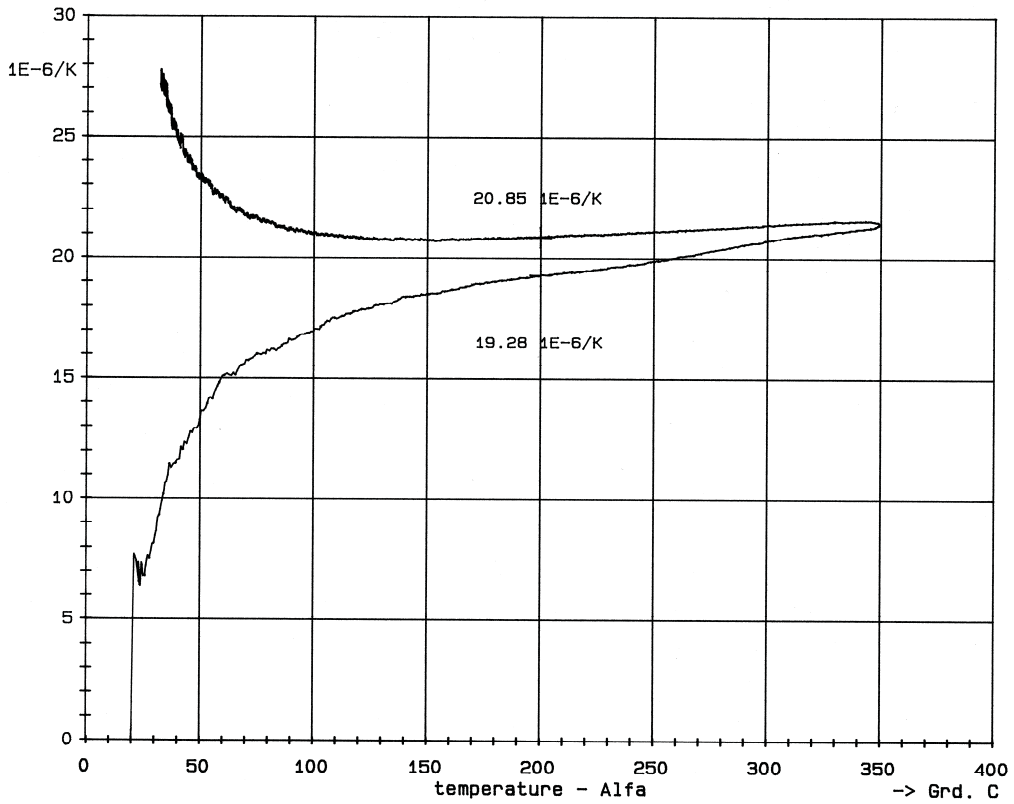

*Fig. 7. Coefficient of linear expansion α for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment (Δα = 1.57 * 1E-6 / K)*

Figure 4 shows changes in the value of coefficient of linear thermal expansion, α as a function of temperature for the material with new neareutectic alloy AlSi12 in raw state. For this material in the raw state the difference of coefficient α is 2.62 1E-6 / K, which is 13.4%. On Fig. 5 the relative elongation as a function of temperature is presented.

The difference of the elongation for temperature of 50°C is 0.06%. Significant increase in size occurs at temperatures above 250°C. On Fig. 6 is presented the course of elongation derivative in a function of temperature for the new composite material neareutectic alloy AlSi12 in a raw state. The data of this chart confirms the findings from the charts shown in Figs. 4 and 5.

On Fig. 7 is presented the linear expansion coefficient α for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment. For this material after solution heat treatment and aging heat treatment the difference of coefficient α at the time of heating and cooling is 1.57 1E-6 / K, what is 8.1%. Difference of the coefficient α is smaller than this difference for the standard material for the value of 1.05 1E-6 / K and the coefficient α alone is smaller than this coefficient for the standard material for the value of 1.43 1E-6 / K, it is equal to about 6.9%.

On Fig. 8 is presented the relative elongation as a function of temperature for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment. The elongation difference amounts to 0.03%.

On Fig. 9 is presented the course of elongation derivative in a function of temperature for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment.

Proper course can be observed to a temperature of 250°C. The introduction of additional short-term high-temperature treatment improves the course. On Fig. 10 the linear expansion coefficient α is shown for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment, and additional short-term high-temperature treatment.

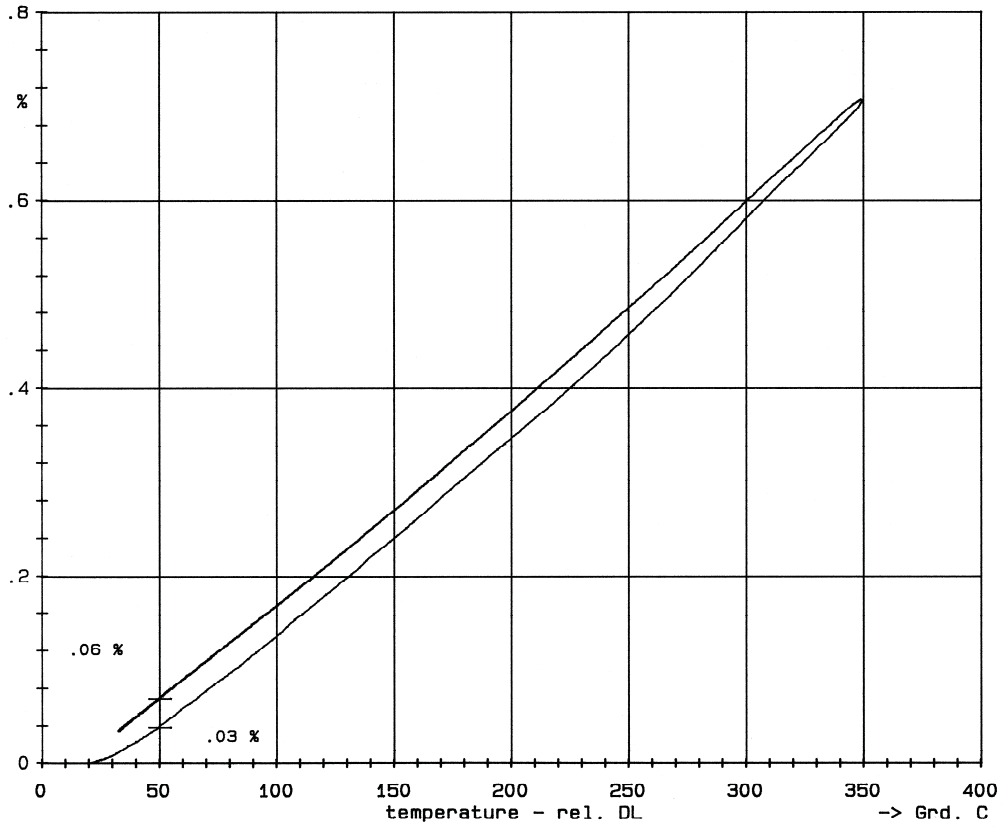

Fig. 8. Relative elongation in function of temperature for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment

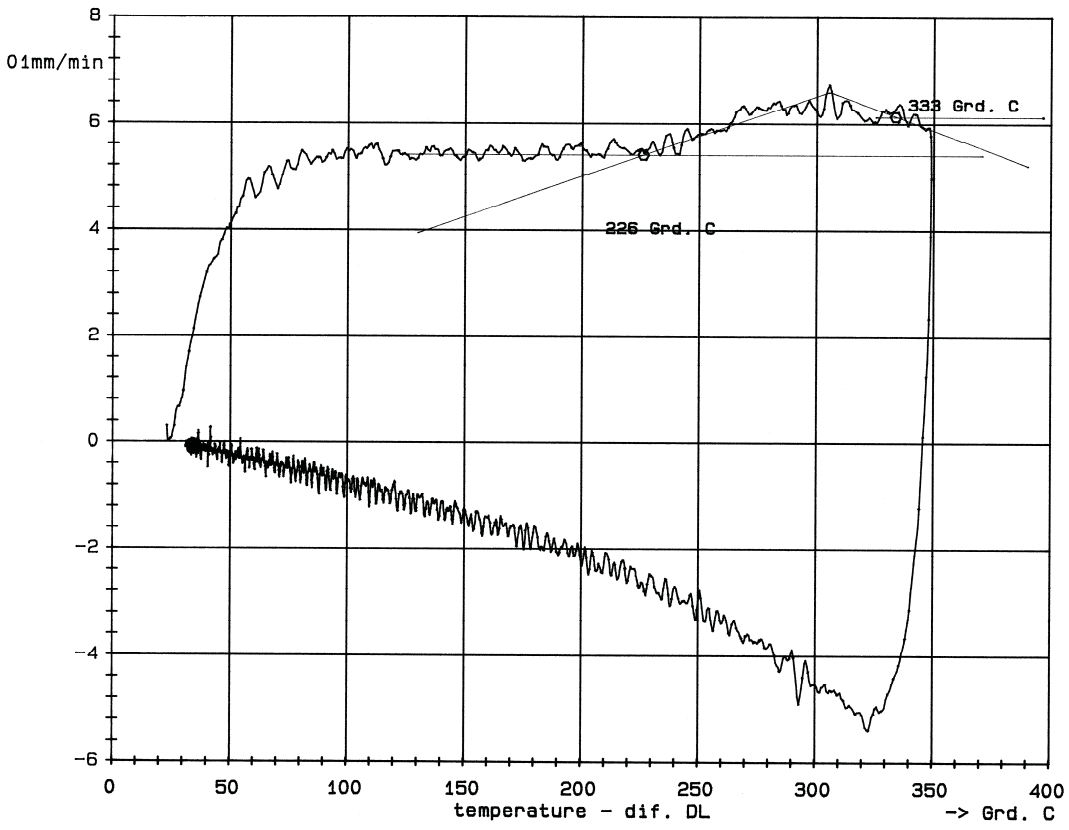

Fig. 9. The course of elongation derivative in a function of temperature for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment

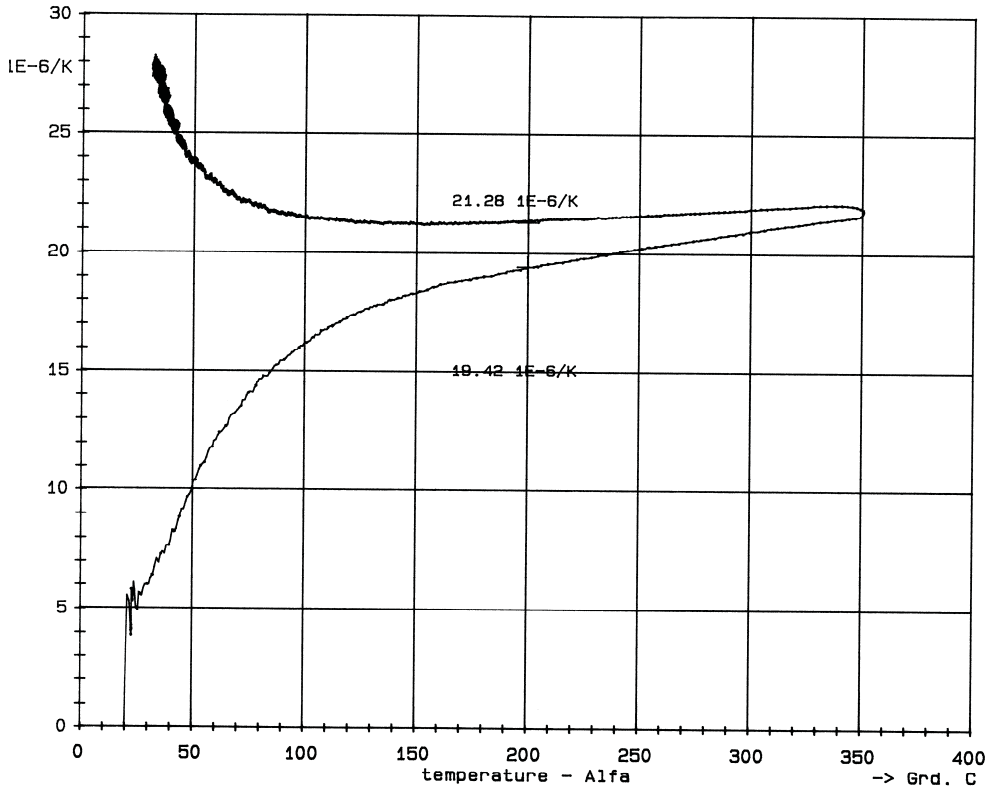

Fig. 10. The linear expansion coefficient α is shown for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment, and additional short-term high-temperature treatment

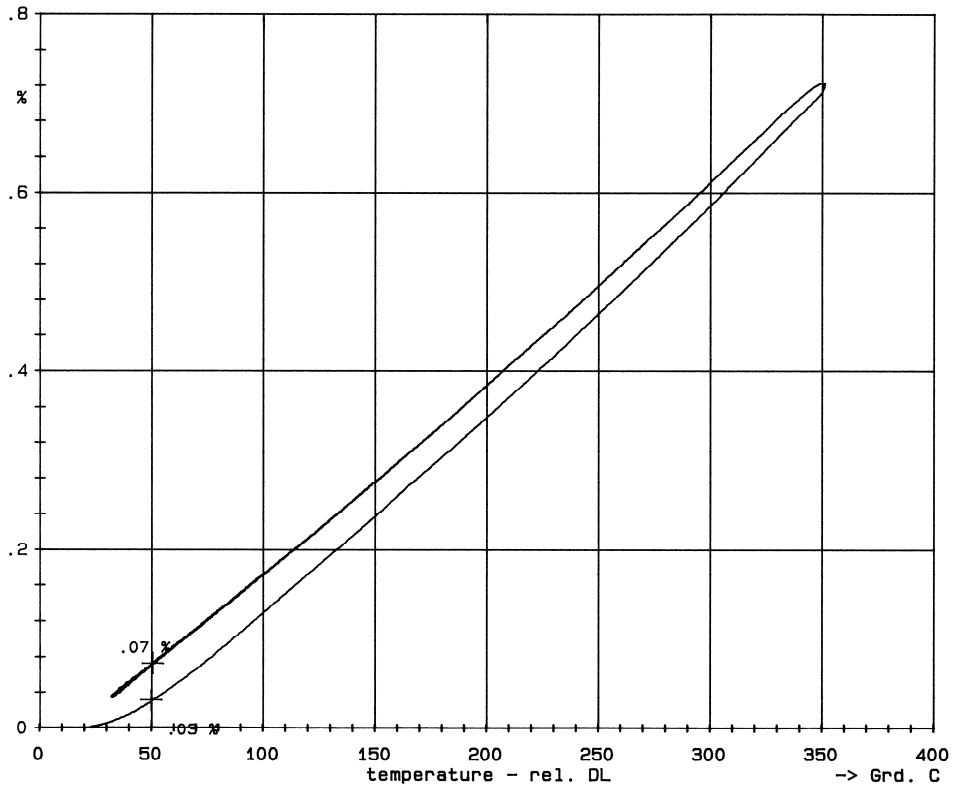

Fig. 11. The relative elongation as a function of temperature is shown for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment, and additional short-term high-temperature treatment

On Fig. 11 the relative elongation as a function of temperature is shown for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment, and additional short-term high-temperature treatment.

On Fig. 12 is presented the course of elongation derivative in a function of temperature for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment, and additional short-term high-temperature treatment.

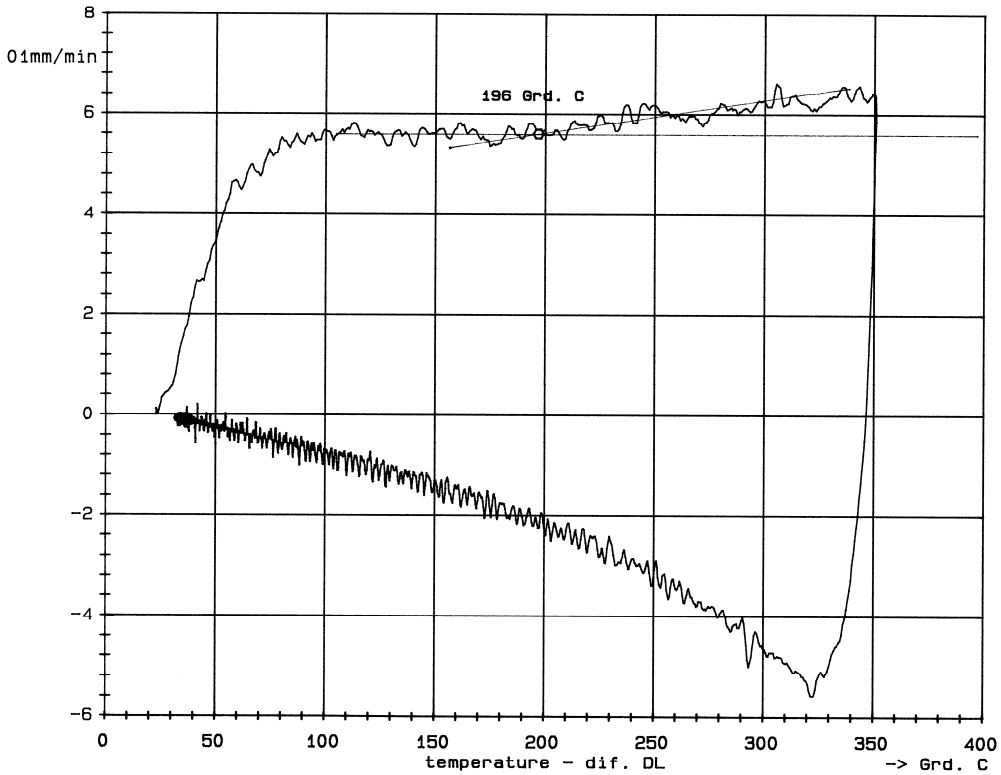

Fig. 12. The course of elongation derivative in a function of temperature for the new composite material neareutectic alloy AlSi12 in the state after solution heat treatment and aging heat treatment, and additional short-term high-temperature treatment

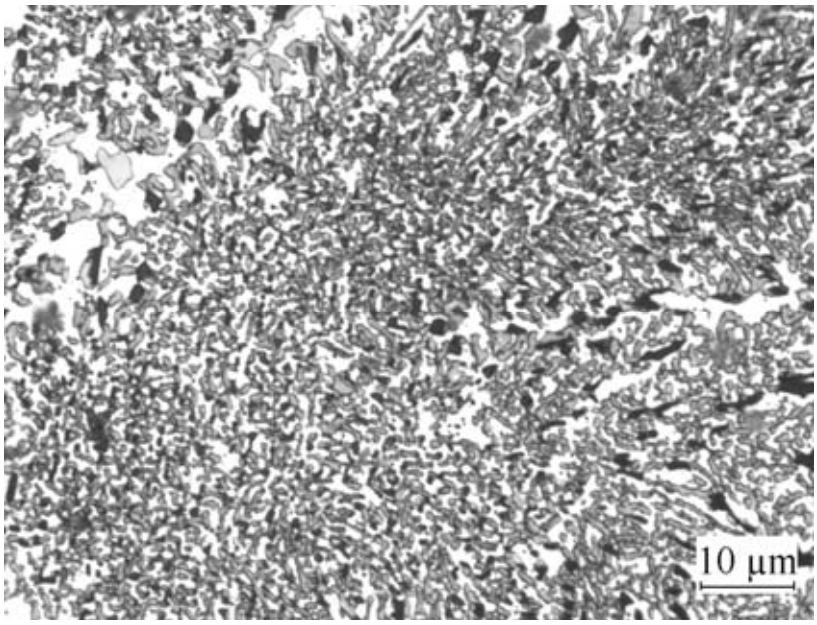

Fig. 13. Microstructure of silumin AlSi12Cu5Ni5Mg0.5Cr0.05Mo0.05W0.05V0.05 after separation strengthening Phases: Eutectic α + β + AlMoCrWVMgNiSiCuFe, Al2Cu

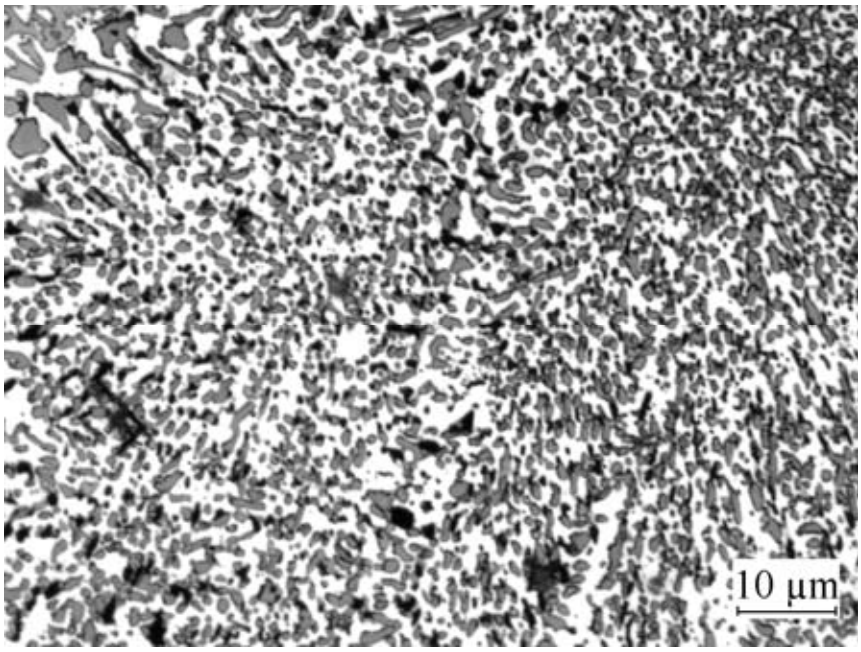

Fig. 14. Microstructure of silumin AlSi12Cu5Ni5Mg0.5Cr0.05Mo0.05W0.05V0.05 after separation strengthening and high-temperature heat treatment, Phases: Eutectic α + β + AlMoCrWVMgNiSiCuFe, Al_2Cu

On Fig. 13 is shown the microstructure of the tested silumin after separation strengthening. After separation strengthening in the microstructure of the tested silumin are existing phases similar as in the raw silumin. In the course of applied heat treatment the microstructure morphology changes occurred as a result of partial coagulation of silicon separations. The tested silumin after separation strengthening has a hardness of 109HB. In relation to the raw state also changed the value of linear coefficient of thermal expansion, α. The graph of changes in the value of linear thermal expansion coefficient α as a function of temperature is shown on Fig. 7. After an additional short-term high-temperature heat treatment the tested piston silumin microstructure was obtained as illustrated on Fig. 14.

From the presented data it shows that following an additional high-temperature heat treatment further coagulation and partial coalescence of silicon separations has been occurred. This change in the morphology of silicon caused a further slight decrease in silumin hardness to value of 106HB. Test results of linear thermal expansion coefficient are shown on Fig. 10.

4. Conclusions

The investigation results described in the paper make it possible to present the following conclusions:

- Increase in Cu and Ni and the presence of Cr, Mo, W and V in neareutectic piston silumin causes a change in their phase structure, crystallizes AlMoCrWVMgNiSiCuFe phase.
- AlMoCrWVMgNiSiCuFe phase increases HB hardness in the cast state of tested piston silumin by about 30% compared to the silumin commonly used.
- Silumin separation strengthening causes coagulation of eutectic silicon and a reduction of hardness in comparison to the raw state.
- Silumin short-term high-temperature heat treatment causes further coagulation and partial coalescence of silicon separations and reduces its HB hardness.
- The measurements of thermal expansion coefficient α have shown the beneficial effects of new material related to a reduction in the value of this coefficient and so called hysteresis.
- Further work on the new material will focus on the alloying additives and heat treatment processes.

- Difference in α coefficient for the new material is smaller than this difference for the standard material for the value of 1.05 1E-6 / K.
- The coefficient α for the new material is smaller than this coefficient for the standard material for the value of 1.43 1E-6 / K, this is about 6.9%.

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