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DILATOMETRIC RESEARCHES OF NOVEL ALLOY FOR COMBUSTION ENGINE PISTONS

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Abstract

The article presents dilatometric research results of composite alloy (in-situ) for combustion engines piston. Researches were performed with a precise dilatometer. Alloy's research test stand and test results including relative elongation, course of derivative of dimension increasing versus time with phase transition and course of coefficient of linear thermal expansion α for composite alloy versus temperature are presented in the article. Novel composite alloy allows getting a minimum difference of the coefficient of linear thermal expansion α during heating and cooling. In particular, the chemical composition of the novel composite silumin alloys; ATD of standard alloy – silumin Ak12 and novel composite alloy; schema of research stand and view of the measuring-head of the extension; course of the coefficient of linear thermal expansion α versus temperature during heating and cooling for the standard alloy and novel composite alloy; course of the relative piston elongation $\Delta L/L_o$ versus temperature during heating and cooling for the standard alloy and novel composite alloy; course of the derived function of the extension in relation to time dL/dt versus temperature for the standard alloy on pistons and novel composite alloy; course of the relative elongation in function of time during ageing of composite alloy at the temperature of 200°C with two-stage ageing process; course of the relative elongation in function of time during ageing of composite alloy at the temperature of 200°C for the first stage and second stage are presented in the article.

Keywords: *combustion engine piston, composite alloy, piston sample elongation, hysteresis, piston clearance*

1. Introduction

Novel alloys for the pistons of combustion engines are characterized with high mechanical properties within the range operating temperatures of the piston that is 100-300°C. These alloys contain enlarged quantities of nickel copper until 4.0% and alloy-additives of the chrome and molybdenum, in the quantity until 1.0%. Novel composite alloys, at the temperature of 250°C, have following mechanical properties: $R_{p0.2}$=120-190 MPa, R_m=160- 230 MPa, A_5=3.0-6.0% and HB=90-130. Applied at present piston-alloys have at this temperature considerably lower mechanical properties, namely: $R_{p0.2}$=90-130 MPa, R_m=110- 140 MPa, A_5=1.0-8.0% and

HB=60-90. The enlargement of the properties of alloys is caused by a creation of multiple phases of the type of AlSiCrMoNiFeCu of the large dispersion, decreasing of the quantity of the silicon in the eutectic and its very large fragmentation until size of 0.3-1.0 mm. The occurrence of given microstructure in of piston alloys causes that practically their elongation during heating to the temperature of 300°C and the next cooling to the ambient temperature is covered with the change of the contraction. The lack of the difference between the elongation and the contraction of the piston gives the constant clearance between it and cylinder liner. Consequently, this clearance gives the low level of the noise and the low level of emission of toxic exhaust combustion gases. Unmistakable advantage novel of composite alloys is the high wear resistance for adhesion. From novel alloys, the pistons for engines both with the spark-ignition, as and heavy duty of Diesel can be performed [1, 5].

The most loaded parts of internal combustion engines are pistons, which have to fulfil growing functional and durability demands [2]. Object of the article, is the working out of alloy with the high durability and functional properties principally basing on lowering of difference in thermal expansion during the piston heating and cooling [3, 6]. It increases the resistance of piston structure on fatigue damages and increases piston resistance on thermal shocks [7, 8]. Partial plastic deformation of the piston occurs, which results in gradual growth of difference between its expansion during the heating and contraction in the cooling processes that is so-called hysteresis [9, 11, 12]. Minimal difference of coefficient of linear thermal expansion α during the heating and cooling will allow increasing the piston resistance on fatigue damages and on thermal shocks but moreover, it will enable the application of engine designs with the smaller working clearances [4, 10].

2. Subject of research and research stand

Chemical composition of composite (in-situ) novel alloy is presented in Table 1.

Tab. 1. The chemical composition of the tested composite silumin alloys

The chemical composition % Wt.									
Si	Cu	Mg	Ni	Fe	Mn	Cr	Mo	W	V
11.5-12.5	3.0-4.0	0.3-0.6	4.0-5.0	≤ 0.50	0.20-0.35	0.05-0.8	0.05-0.8	0.05-0.8	0.05-0.8

Fig. 1 shows microstructure of standard alloy – silumin Ak12. Fig. 2 shows microstructure of novel composite alloy. The aim of research works was the elaboration of the novel composite alloy, based on the standard silumin, with better properties than at present applied alloy on the pistons of combustion engines. Novel composite alloy on the pistons should have increased mechanical properties in the ambient temperature: $R_m \geq 400$ MPa; $R_{p0.2} \geq 330$ MPa; $A_5 \geq 3.5\%$; HB ≥ 130, and at the higher temperature of 250°C: $R_m \geq 320$ MPa; $R_{p0.2} \geq 240$ MPa; $A_5 \geq 5\%$; HB ≥ 90. Earlier researches showed that high alloy properties can be achieved by the introduction of copper and nickel in greater quantities and not used yet elements in piston silumins, such as chrome, vanadium, molybdenum and wolfram. These chemical elements create high-melting fine disperse intermetallic phases which should assure high useful properties. Formed multiple fine disperse intermetallic phases give to piston-silumins the features of composite alloy, from here the name of composite alloy was accepted. The ATD of standard alloy – silumin Ak12 of the standard alloy is shown on Fig. 1, and the composite alloy – on Fig. 2.

Researches were performed with a dilatometer. They were performed with use of a precise dilatometer, which allows on the registration of the changes in specimen dimensions in the function of temperature and time. Tests of novel and reference materials take place in the same conditions, and measurements in differential coordinate system are performed in the same equipment.

The dilatometer records changes of dimensions of the sample in the function of the temperature. Measurements are possible in the simple and differential arrangement. Results of measurements are very exact because they are obtained based on comparison of examined material with reference material. Platinum is reference material. Tests of examined materials and reference one take place in such same conditions. The heating and the cooling takes place in the special device which can realize the programme temperature, controlled by means of the computer.

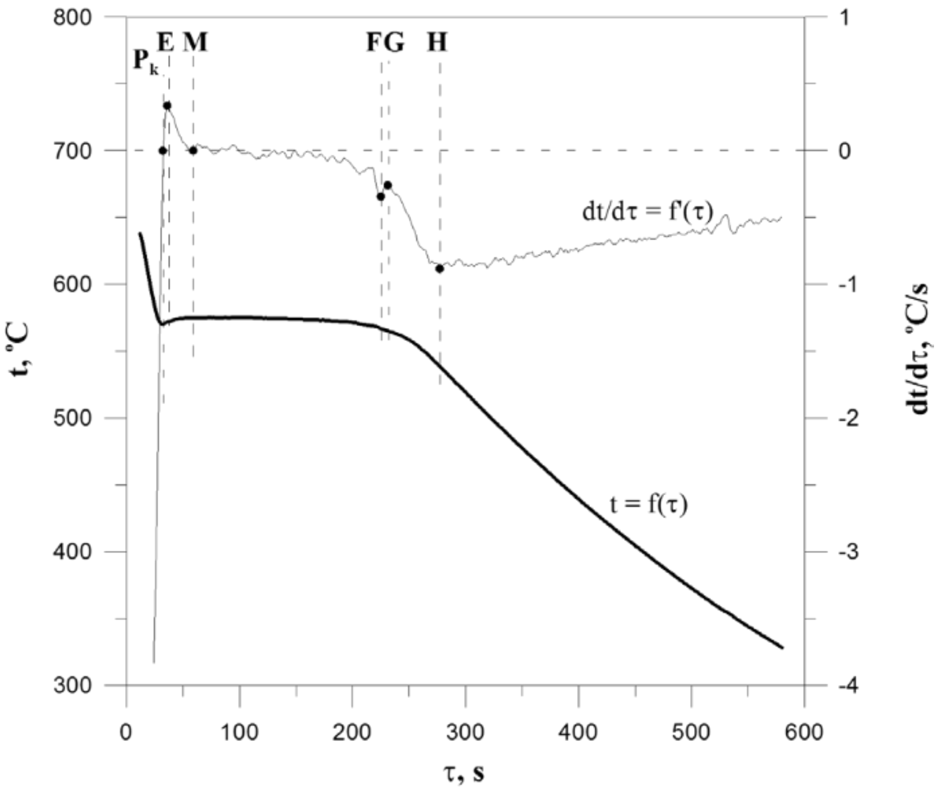

Fig. 1. ATD of standard alloy – silumin Ak12

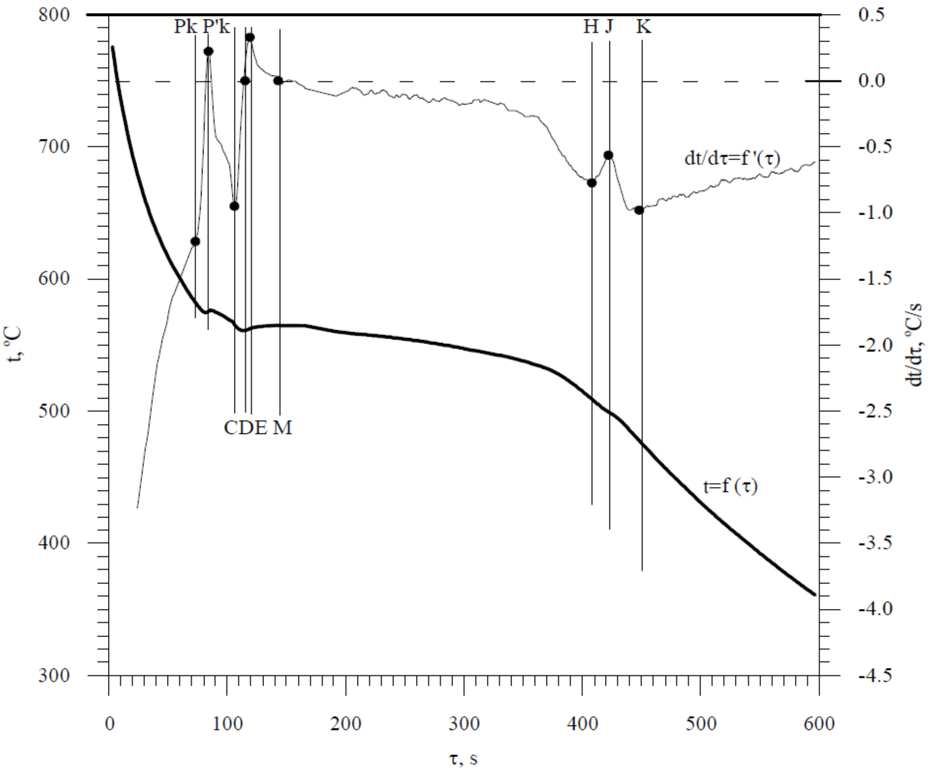

Fig. 2. ATD of novel composite alloy

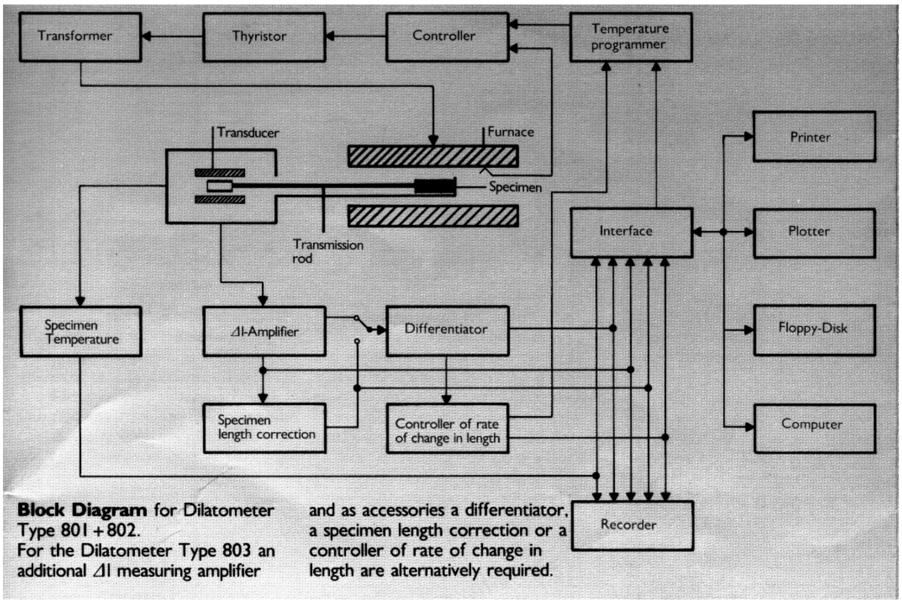

Fig. 3. Schema of research stand

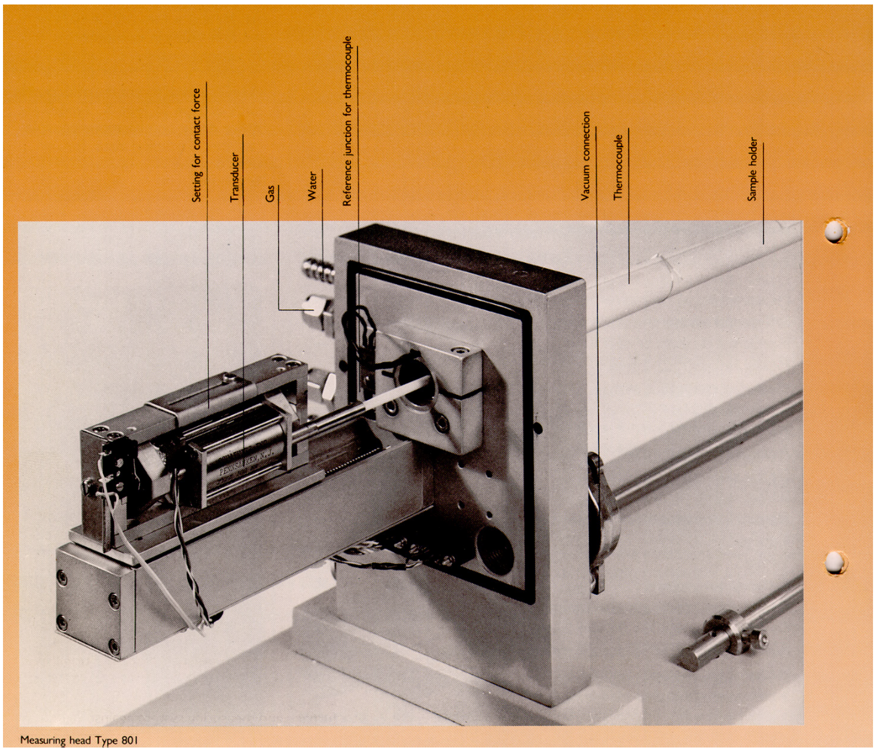

Fig. 4. View of the measuring-head of the extension

Changes of dimensions were measured with an inductive sensor. Material samples are placed in the quartz-pipe, and changes of their length were transferred by quartz-rods. The temperature of tested material was measured by means of the Pt-PtRh thermocouple. The dilatometer makes possible measurement and the recording of following parameters: changes of the length in the function of the temperature, relative changes of the length of two samples in the function of the temperature, the real temperature in the function of the programmed temperature, first derivative of changes of the length as the function of time and the temperature, the coefficient of linear thermal expansion α in the function of the temperature. Fig. 3 presents a schema of research stand and Fig. 4 presents the view of the measuring-head of the extension.

3. Test results

Fig. 5 shows a course of the coefficient of linear thermal expansion α versus temperature during heating and cooling for the standard alloy on pistons being characterized by increasing of the coefficient of linear thermal expansion α during cooling with the 2.63·1E-6/K difference of the coefficient α at the temperature of 200°C:

$$a(T) = \frac{\Delta L(T-20)}{L_0}, \tag{1}$$

where:
α – coefficient of linear thermal expansion,
T – sample temperature,
L_o – sample length at 20°C,
L – sample length at T temperature,
$\Delta L = L - L_o$.

Fig. 6 shows t h e course of coefficient of linear thermal expansion α versus temperature during heating and cooling, with the 0.12•1E-6/K difference of the coefficient α at the temperature of 200°C, for composite alloy.

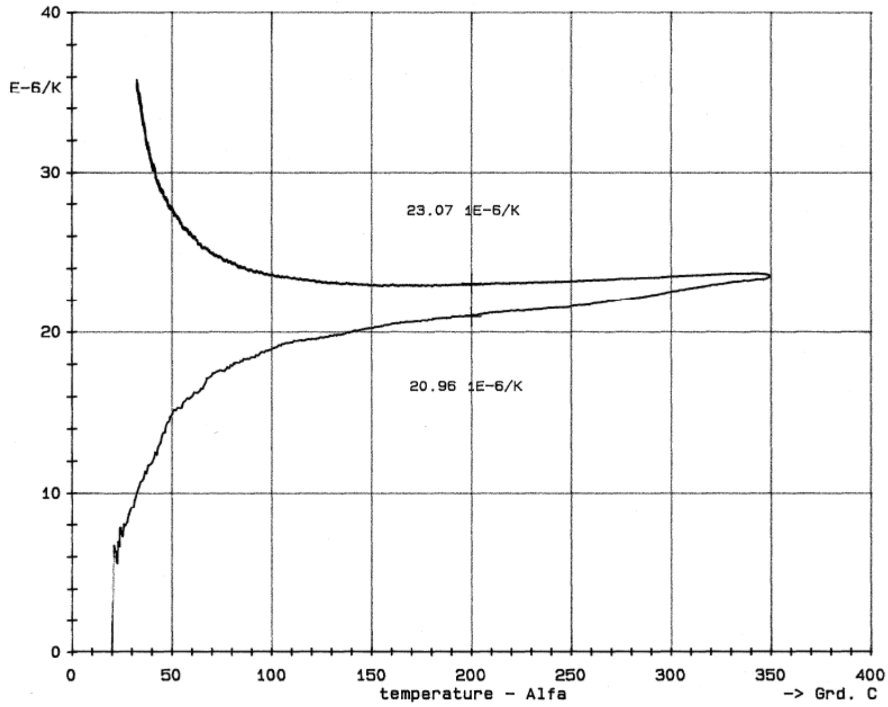

Fig. 5. Course of the coefficient of linear thermal expansion α versus temperature during heating and cooling for the standard alloy

The coefficient of linear thermal expansion α for the standard alloy is greater than the coefficient of linear thermal expansion α for the composite alloy from 0.6 to 3.1•E-6/K that is – from 3 to 15%.

Fig. 7 shows a course of the relative piston elongation $\Delta L/L_o$ versus temperature during heating and cooling for the standard alloy on pistons being characterized by increasing of the relative elongation during cooling with the 0.05% difference of the relative elongation at the temperature of 50°C.

Fig. 8 shows a course of the relative piston elongation $\Delta L/L_o$ versus temperature during heating and cooling for the composite alloy with the small difference of the relative elongation.

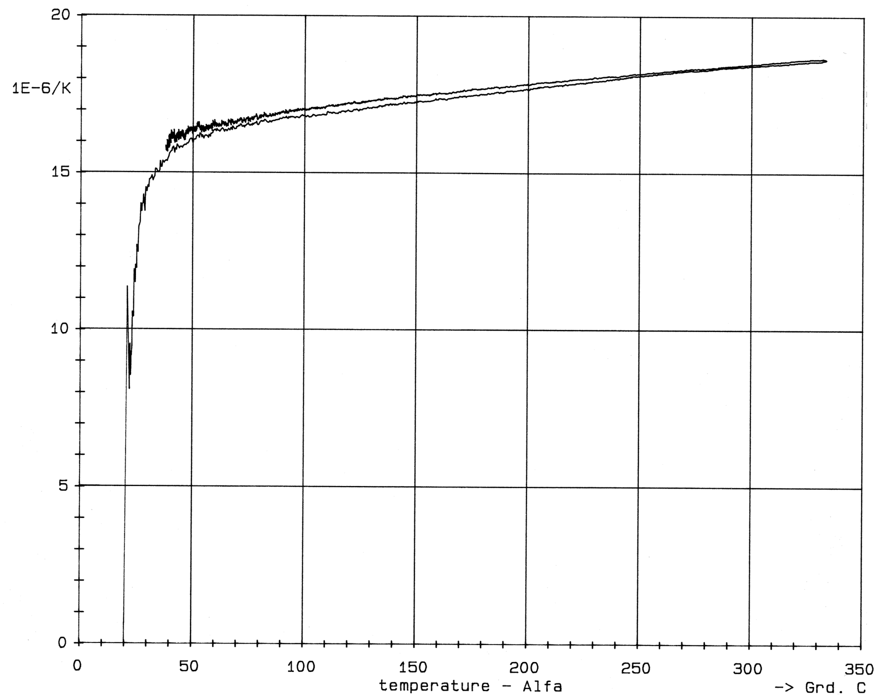

Fig. 6. Course of coefficient of linear thermal expansion α versus temperature during heating and cooling for composite alloy

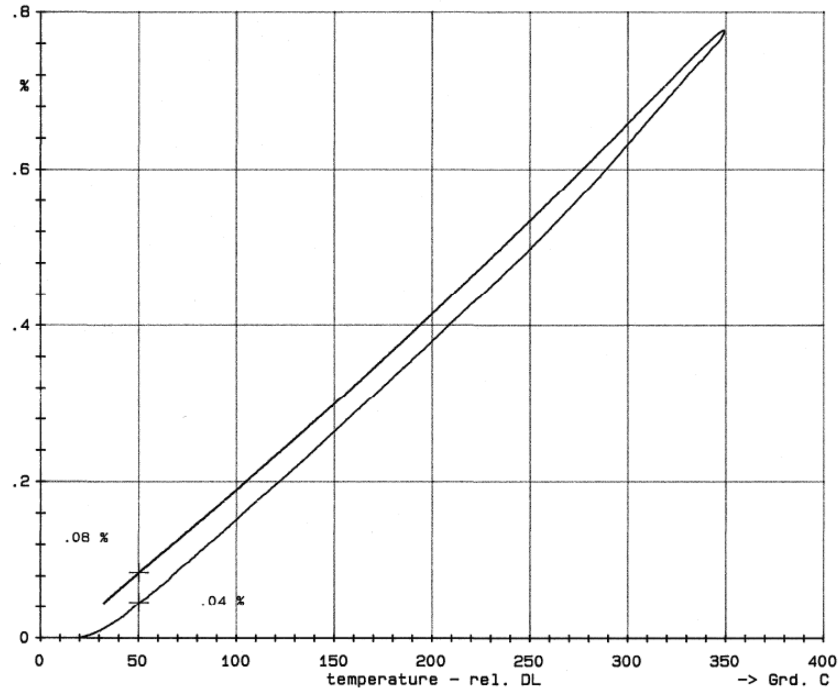

Fig. 7. Course of the relative piston elongation $\Delta L/L_o$ versus temperature during heating and cooling for the standard alloy

Fig. 9 shows a course of the derived function of the extension in relation to time dL/dt versus temperature during heating and cooling for the standard alloy on pistons. Derived function of the extension in relation to time increases when the temperature exceeds 237ºC.

Fig. 10 shows a course of the derived function of the extension in relation to time dL/dt versus temperature during heating and cooling for the composite alloy on pistons. Derived function of the extension in relation to time lies on the constant level during heating according to computer programme.

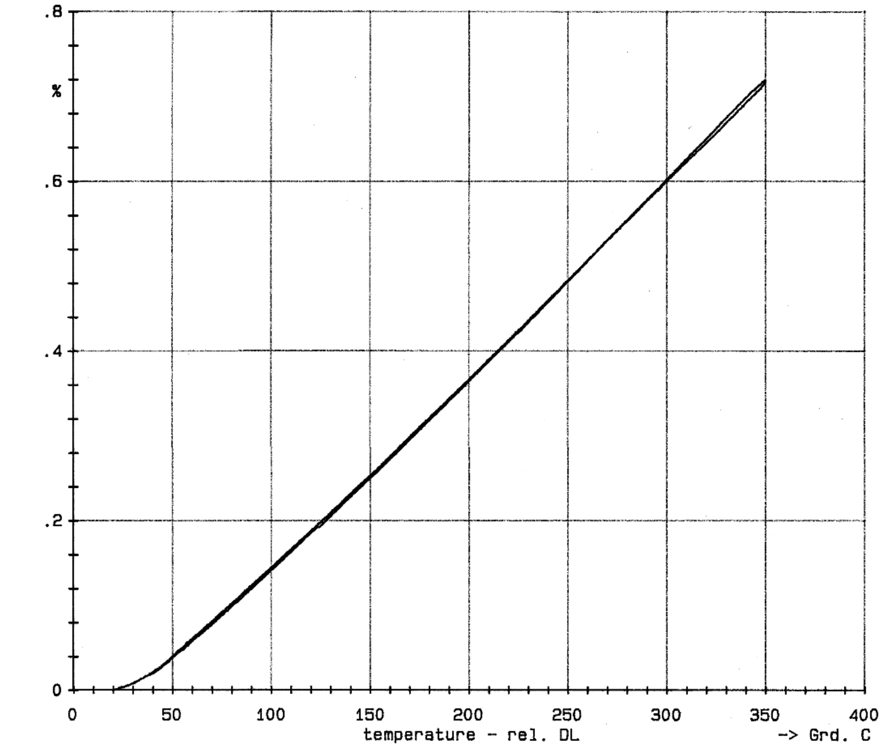

Fig. 8. Course of the relative piston elongation ΔL/Lₒ versus temperature during heating and cooling for the composite alloy

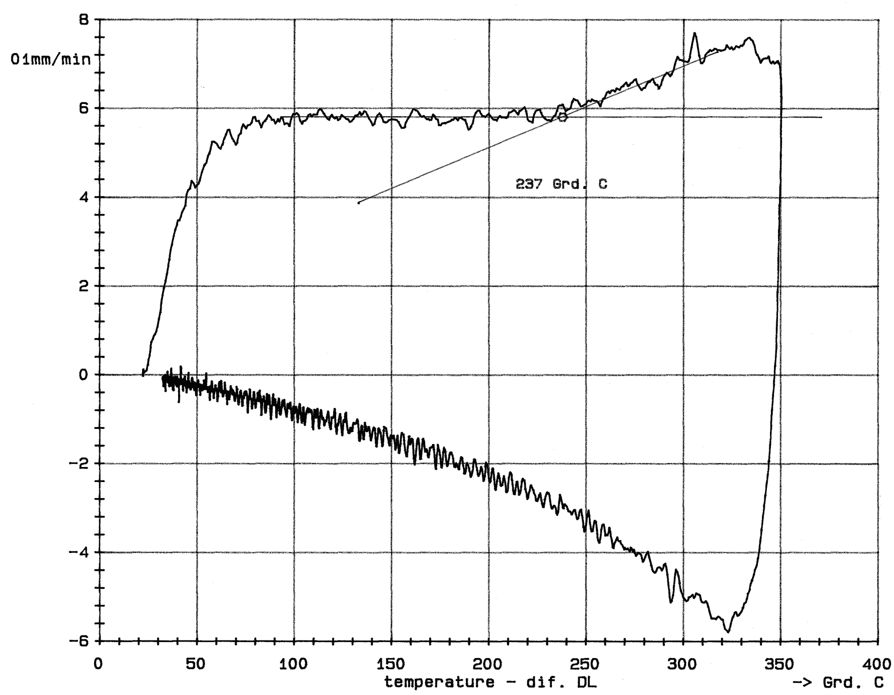

Fig. 9. Course of the derived function of the extension in relation to time dL/dt versus temperature for the standard alloy on pistons

Fig. 11 shows a course of the relative elongation in function of time during ageing of composite alloy at the temperature of 200°C with two-stage ageing process.

During the first stage of ageing, the relative elongation increases from 0.38% to 0.411% that means that the difference of the relative elongation is 0.031% in period of 480 minutes (8 hours). During the second stage of ageing, the relative elongation increases from 0.411% to 0.419% that means that the difference of the relative elongation is 0.08% in period of 450 minutes (7.5 hours) and the difference of the relative elongation is 4 times higher for the first stage of the ageing. In reference to the second stage of ageing, the relative elongation lies on the constant level (0.419%) after 7.5 hour

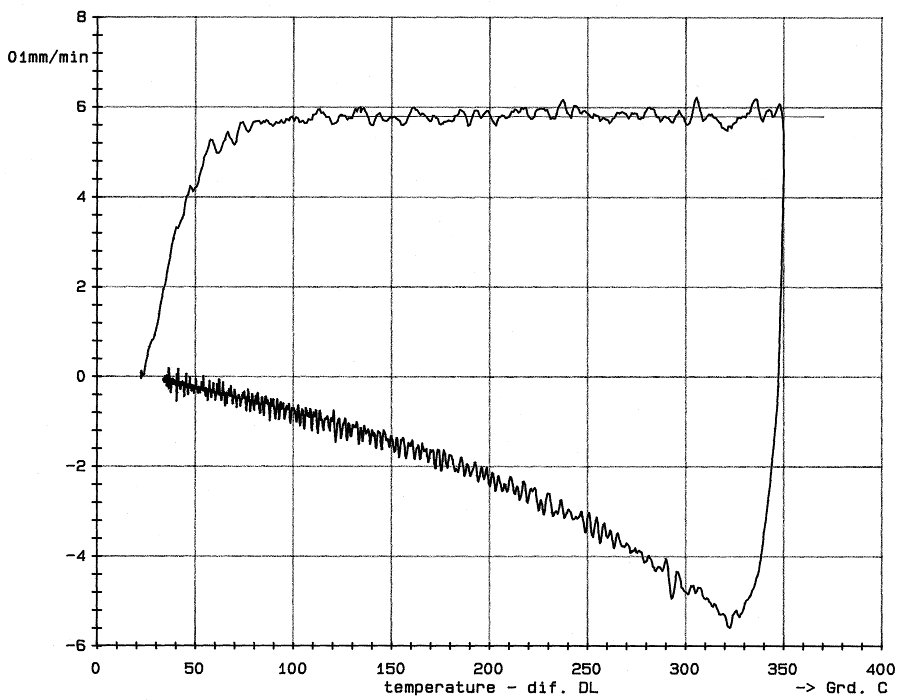

Fig. 10. Course of the derived function of the extension in relation to time dL/dt versus temperature during heating and cooling for the composite alloy on pistons

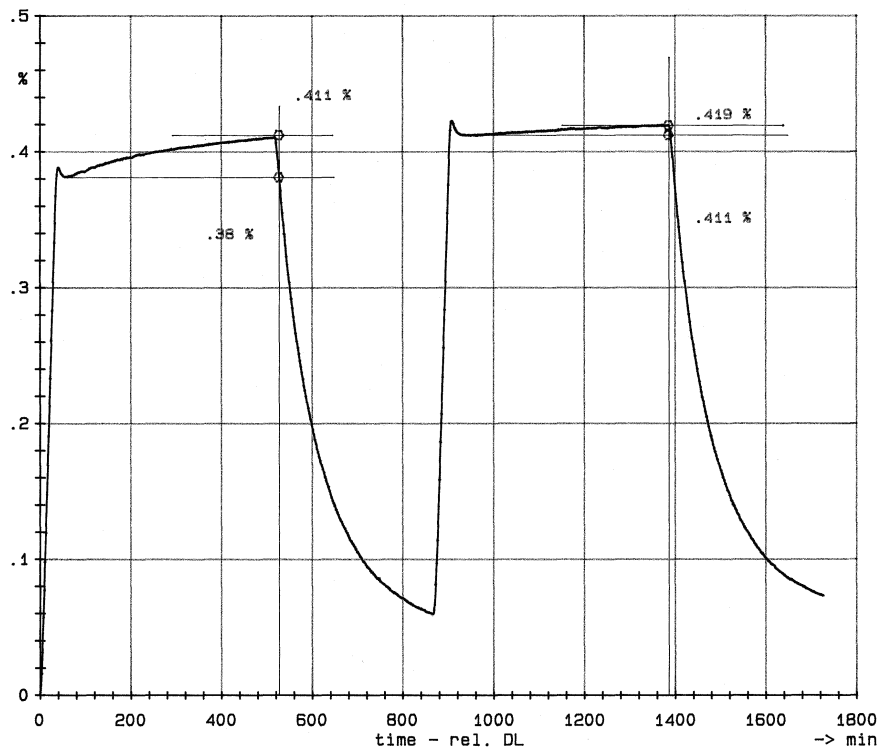

Fig. 11. Course of the relative elongation in function of time during ageing of composite alloy at the temperature of 200°C with two-stage ageing process

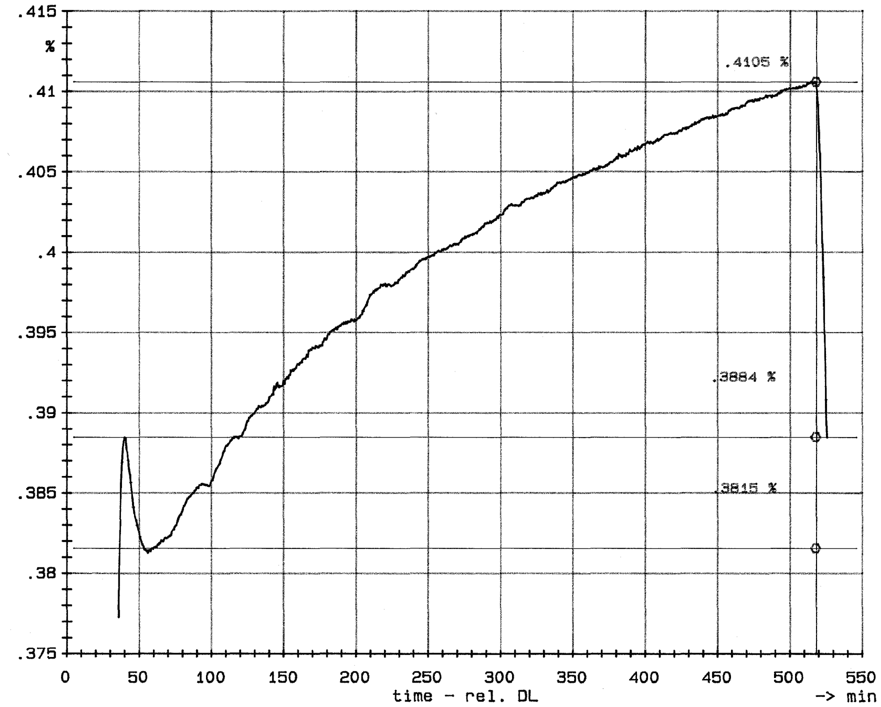

Fig. 12. Course of the relative elongation in function of time during ageing of composite alloy at the temperature of 200°C for the first stage

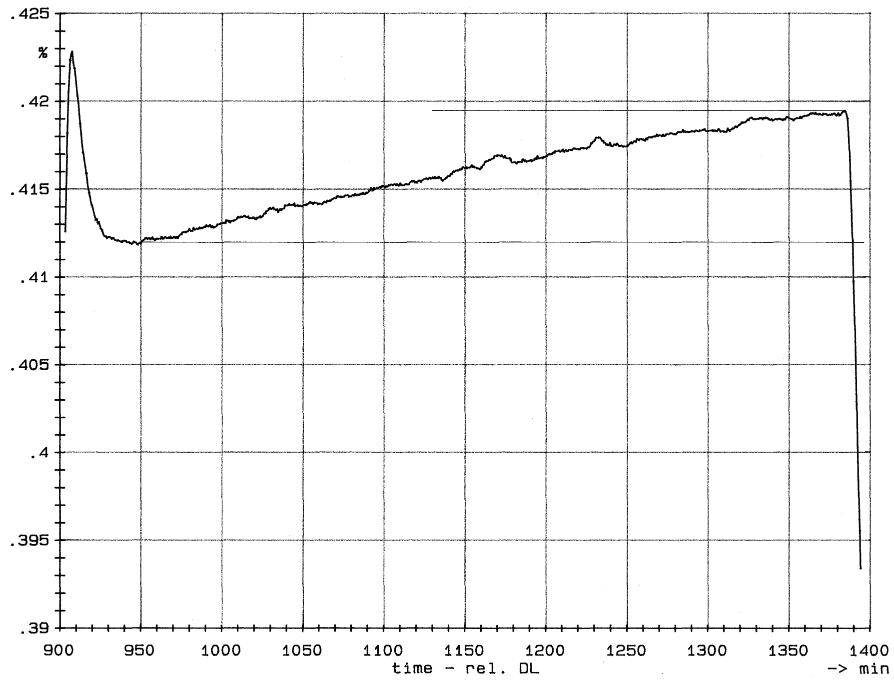

Fig. 13. Course of the relative elongation in function of time during ageing of composite alloy at the temperature of 200°C for the second stage

Fig. 12 shows a Course of the relative elongation in function of time during ageing of composite alloy at the temperature of 200°C for the first stage of the ageing.

Fig. 13 shows a course of the relative elongation in function of time during ageing of composite alloy at the temperature of 200°C for the second stage of the ageing.

The pistons manufactured from a novel alloy will be characterized by the smaller dimensional changes, particularly performing combustion engines in the heavy-duty conditions, like frequently changed rotational velocities and the engine loads.

The low contents of toxic exhaust elements is determined by different factors, among others by temperature in the combustion chamber, clearances in piston – cylinder assembly and by the form of the upper part of piston crown. The source of hydrocarbon can be the spaces with the very small dimensions, to which fuel-air mixture has access, where however the burnout of all fuel cannot be reached because of a small extinction distance. Clearances in piston – cylinder assembly cannot be only the cause of growth of exhaust toxicities but also noisiness of the engine performance, above all as a result of the side movements of pistons. Forces occurring with side movements will depend from the clearance size. Thus, piston clearance is essentially responsive for the hydrocarbon emissions, including, above all heavy hydrocarbons coming from the lubricating oil and noise emission.

On clearance of piston in cylinder, the decisive influence has the coefficient of linear thermal expansion α and its hysteresis. The pistons are in general produced from the aluminum alloys however cylinders are produced from cast iron, the coefficient of linear thermal expansion α of which is about twice smaller than the coefficient of linear thermal expansion α of the aluminum alloys. Moreover, temperature in the individual piston points during the work of engine is much higher than cylinder temperature. The gradients of piston temperature are greater than on cylinder, but therefore the participation of piston material in the clearance decrease between piston and cylinder is greater than of cylinder material. Because of a complex shape the piston and of large and different gradients of temperature in the separate elements the piston they originate the stresses, which can cause the unequal strains of the piston, leading to the deformation, which can cause the local or entire decrease of clearances and even can lead to the seizure. Value of clearance between piston and cylinder ought, therefore to be optimized so, from one side, in order to this clearance was sufficient for free deformations of piston – cylinder assembly in the whole range of thermal and mechanical deformations (piston shape deformation included), but from a second side, in order to not being too big that could adversely influence on the ecological parameters of the engine performance, such like exhaust toxicity (principally hydrocarbons), noisiness of work, the oil and fuel expenditure. The piston deformations, through which, in this case, is necessary to understand as deformation caused the uneven and unsymmetrical distribution of thermal and mechanical stresses and by the occurrence of piston material hysteresis, as a result of a constant heating and the cooling of pistons that particularly is disclosed in the transition states loads and engine rotational speed.

The results of investigations of the coefficient of linear thermal expansion α will be used to a final choice of the chemical composition material on pistons and selection of technological process. New material is characterized by smaller hysteresis of the coefficient of linear thermal expansion α, and some smaller value of the coefficient of linear thermal expansion α than standard silumin piston.

5. Conclusions

Composite alloys have, in automotive engineering, a high application potential in the engine area especially in oscillating construction units: valve train, piston rod, piston and piston pin; covers: cylinder head, crankshaft main bearing; engine block: part-strengthened cylinder blocks. The coefficient of linear thermal expansion α is determined by the previous thermal heat treatment of the composite alloys, which results from the production and the application. With the monolithic alloys, the coefficient of linear thermal expansion α increases with increasing temperature. With increasing temperature, the difference of coefficient of linear thermal expansion α becomes less. After a heat treatment, the increment values of the coefficient of linear thermal expansion α, particularly in the temperature range above the ageing temperature decreases.

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

Difference in coefficient α for the novel alloy is smaller than this difference for the standard alloy for the value of 0.12•1E-6/K at the temperature of 200^{O}C.

- The coefficient α for the novel alloy is smaller than this coefficient for the standard alloy for the value from 0.6 to 3.1•E-6/K that is – from 3 to 15% at the temperature of 200^{o}C.

The best mechanical properties and dimensional stability, low hysteresis in the coefficient of linear thermal expansion α, was obtained by the introduction of several elements to the alloy, which synergistic effect is far greater than separate effect of any single alloy element. During the heating of the engine piston, the alloy elements are partially dissolving in the solid solution α, and in the cooling process, they are giving off again.

Consequently, there is a partial plastic deformation of the piston, resulting in a gradual increase in the difference between the expansion during heating and shrinkage in the cooling processes (so-called hysteresis). However, the presence of pre-eutectic phases in Silumin microstructure reduced the difference in the coefficient of linear thermal expansion α during heating and cooling.

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