COEFFICIENT OF THERMAL EXPANSION AS A COMPONENT QUALITY ESTIMATION OF ALLOYS ON PISTONS OF COMBUSTION ENGINES

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Abstract

The aim of realized works in the area of materials on pistons is: low thermal expansion, small differences of coefficient of thermal expansion between heating and cooling, high stiffness at elevated temperatures, high hardness and wear resistance. Changes in thermal expansion coefficient during heating and cooling may be very large, as well as during subsequent cycles of heating and cooling of an internal combustion engine piston with respect to standard silumin alloys used for pistons of internal combustion engines. The paper presents: coefficient of linear expansion α for the AlSi standard alloy, coefficient of linear expansion α for the AlSi alloy with the α positive differences between cooling and heating, coefficient of linear expansion α for the AlSi alloy with the α negative differences between cooling and heating, coefficient of linear expansion α for the AlSi alloy with the α positive and negative differences between cooling and heating, coefficient of linear expansion α for the AlSi alloy with the α positive, negative and positive differences between cooling and heating, coefficient of linear expansion α for the AlSi alloy with the very small α differences between cooling and heating, coefficient relative elongation as a function of temperature with the positive elongation differences between cooling and heating, coefficient relative elongation with the very small elongation differences between cooling and heating, coefficient the course of derivative as a function of temperature (T) during heating and cooling with the positive elongation differences.

Keywords: *combustion engines, engine pistons, thermal expansion, coefficient of thermal expansion*

1. Introduction

For materials that are isotropic, i.e. uniform in all directions, the material undergoes thermal expansion as a whole: that is its volume expands. For materials that are not isotropic such as an asymmetric crystal for example, the thermal expansion can have different values in different directions. Thermal expansion can also vary with temperature so that the degree of expansion depends not only on the magnitude of the temperature change, but on the absolute temperature as well. Suppose an object of length l_0 undergoes a temperature change of magnitude ΔT. If ΔT is sufficiently small, the change in length, Δl, is proportional to l_0 and to ΔT. Stated mathematically:

$$\Delta l = \alpha \cdot l_0 \cdot \Delta T \,, \tag{1}$$

$$\alpha = \frac{\Delta l}{l_0 \cdot \Delta T} \,, \tag{2}$$

where:
Δl - length increment,
α - coefficient of linear thermal expansion for the material,
l_0 - initial rod length,
ΔT - temperature increment.

For an isotropic material, α will be the same in all directions so it may be defined by measuring the change in length of a rod of the material. The values obtained for the coefficient of linear thermal expansion will be compared with commonly accepted values to determine the composition of each rod. Generally materials expand when they are heated in a temperature range that does not produce a change in phase. The added heat increases the average amplitude of vibration of the atoms in the material, which increases the average separation between the atoms. Although this effect is small, it is very important in any application that involves using different materials in an environment where they are heated and cooled. Such example is a piston of the combustion engine. That is why measurement of the coefficient of linear thermal expansion for the piston alloy are very important and key for estimation of functional proprieties , and especially thermal pistons proprieties for combustion engines. Most materials expand when they are heated through a temperature range that does not produce a change in phase. The added heat increases the average amplitude of vibration of the atoms in the material, which increases the average separation between the atoms. Thermal expansion is an effect of anharmonic terms in a classical oscillator potential energy on the mean separation of a pair of atoms at a temperature T. The average displacement can be calculated using the Boltzmann distribution function, which weights the possible values of the displacement according to their thermodynamic probability. The average inter-atomic distance scales positively and linearly with temperature. For a macroscopic system, these increased inter-atomic distances will accumulate into an easily observable change in the sample's sizes as a function of temperature.

During piston heating and cooling the coefficient of expansion of thermal changes its value, what has reflection in the curve course during heating and cooling. An ideal course is such course, where the curve for the heating ties in with curve for the cooling. Materials on pistons do not belong to such-like materials.

2 Research Equipments

Investigations are performed with use of a precise dilatometer, which permits on the registration of the changes in specimen dimensions in the function of temperature and time.
The measurements in the straight and differential coordinate system are possible. The tests of investigated and reference materials take place in the same conditions, and measurements in differential coordinate system are performed in the same equipment. Heating and cooling takes place in the special equipment, which realizes temperature program of specimen heating and cooling. The dimension changes are measured with the inductive transducer. Temperature is measured with the Pt-PtRh thermocouple. The advantage of the used method is the continuous measurement of change in absolute or relative elongation as a function of time and temperature, as a function of temperature depending on the straight or differential measurement application. T

3. Results and Discussion

Test results of materials on pistons are presented on Fig. 1-10.

Fig. 1 presents coefficient of linear expansion α for the AlSi standard alloy in a raw state during heating and cooling.

Fig. 2 presents coefficient of linear expansion α for the AlSi alloy during heating and cooling with the α positive differences between cooling and heating.

Fig. 3 presents coefficient of linear expansion α for the AlSi alloy during heating and cooling with the α negative differences between cooling and heating.

Fig. 4 presents coefficient of linear expansion α for the AlSi alloy during heating and cooling with the α positive and negative differences between cooling and heating.

Fig. 5 presents coefficient of linear expansion α for the AlSi alloy during heating and cooling with the α positive, negative and positive differences between cooling and heating.

Fig. 6 presents coefficient of linear expansion α for the AlSi alloy during heating and cooling with the very small α differences between cooling and heating.

Fig. 7 presents coefficient relative elongation as a function of temperature for the new composite material during heating and cooling with the positive elongation differences between cooling and heating.

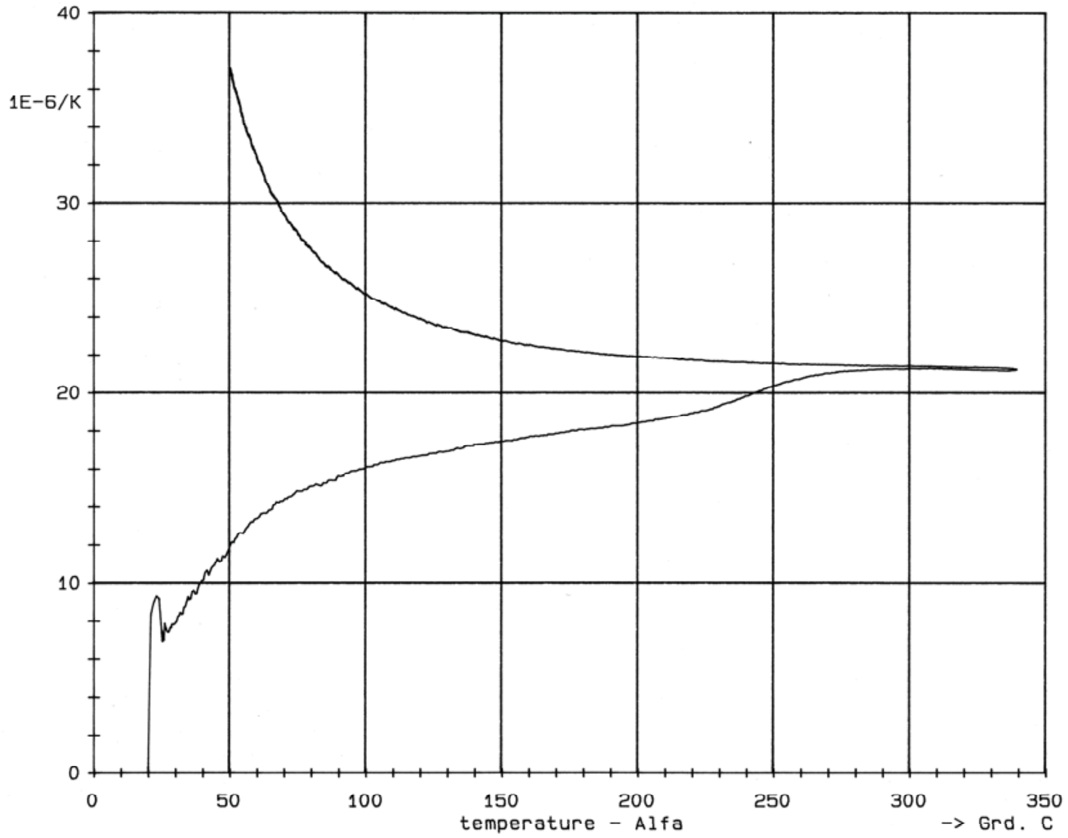

Fig. 1. Coefficient of linear expansion α for the AlSi standard alloy in a raw state during heating and cooling

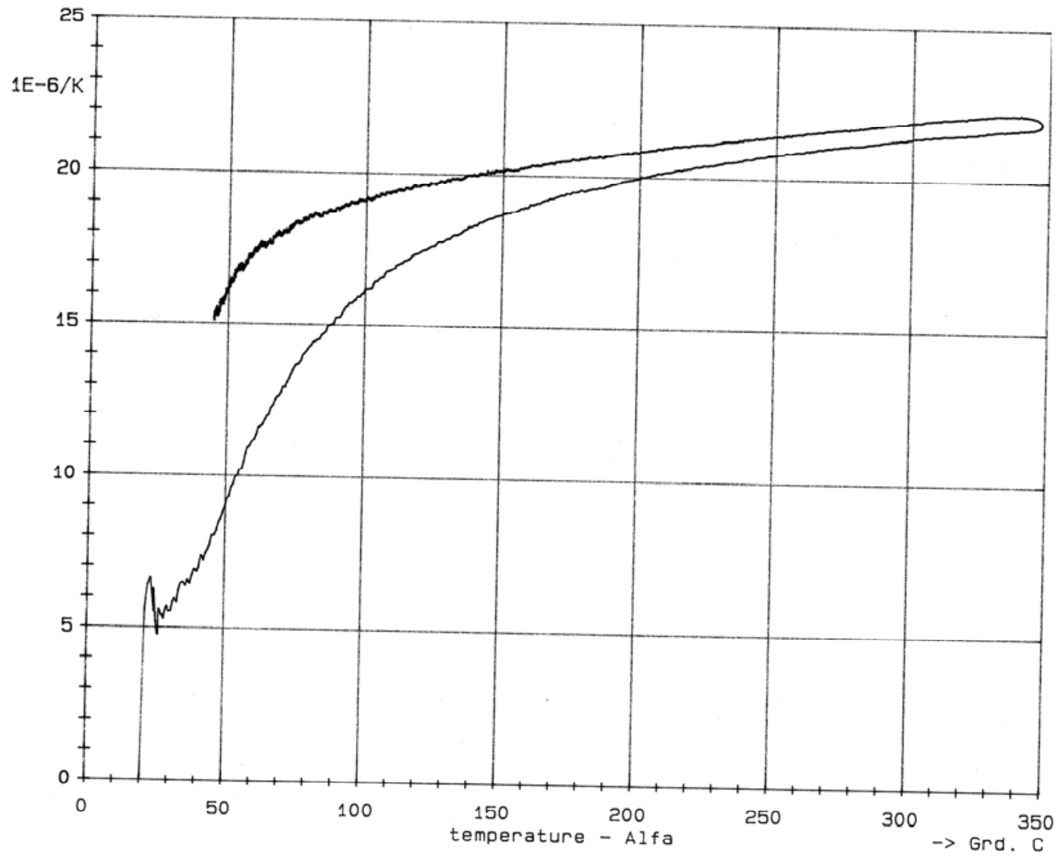

Fig. 2. Coefficient of linear expansion α for the AlSi alloy during heating and cooling with the α positive differences between cooling and heating

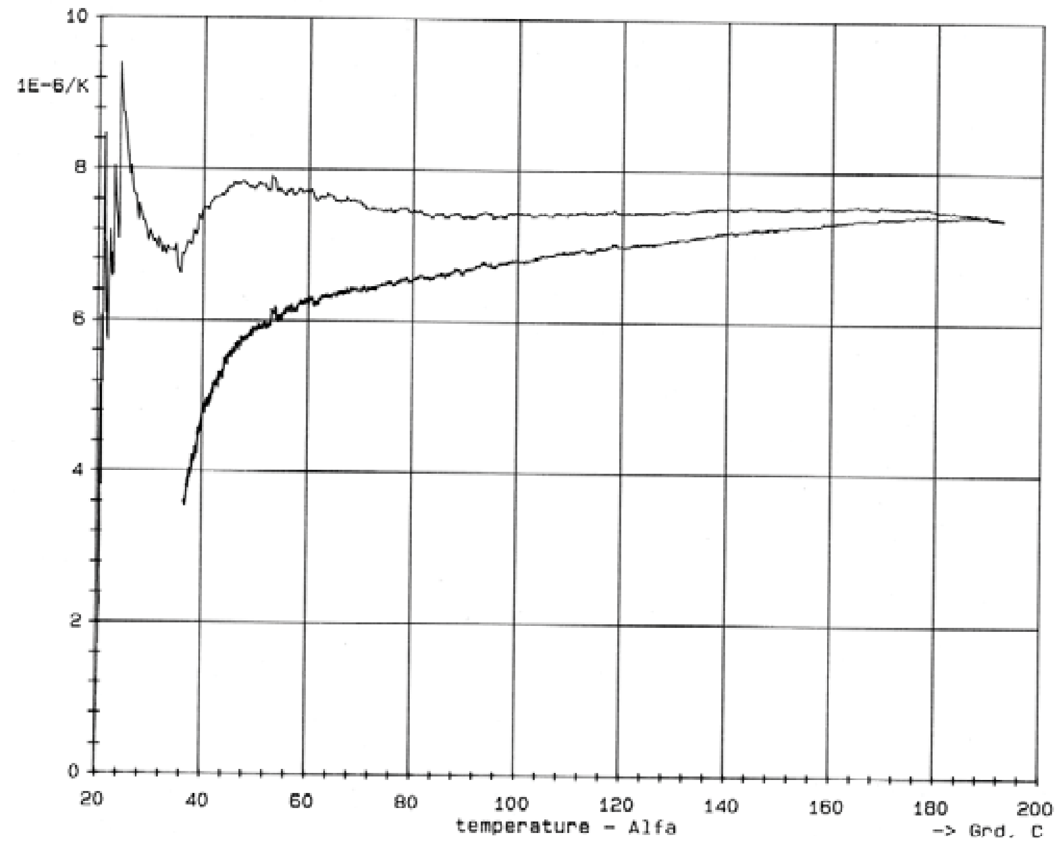

Fig. 3. Coefficient of linear expansion α for the AlSi alloy during heating and cooling with the α negative differences between cooling and heating

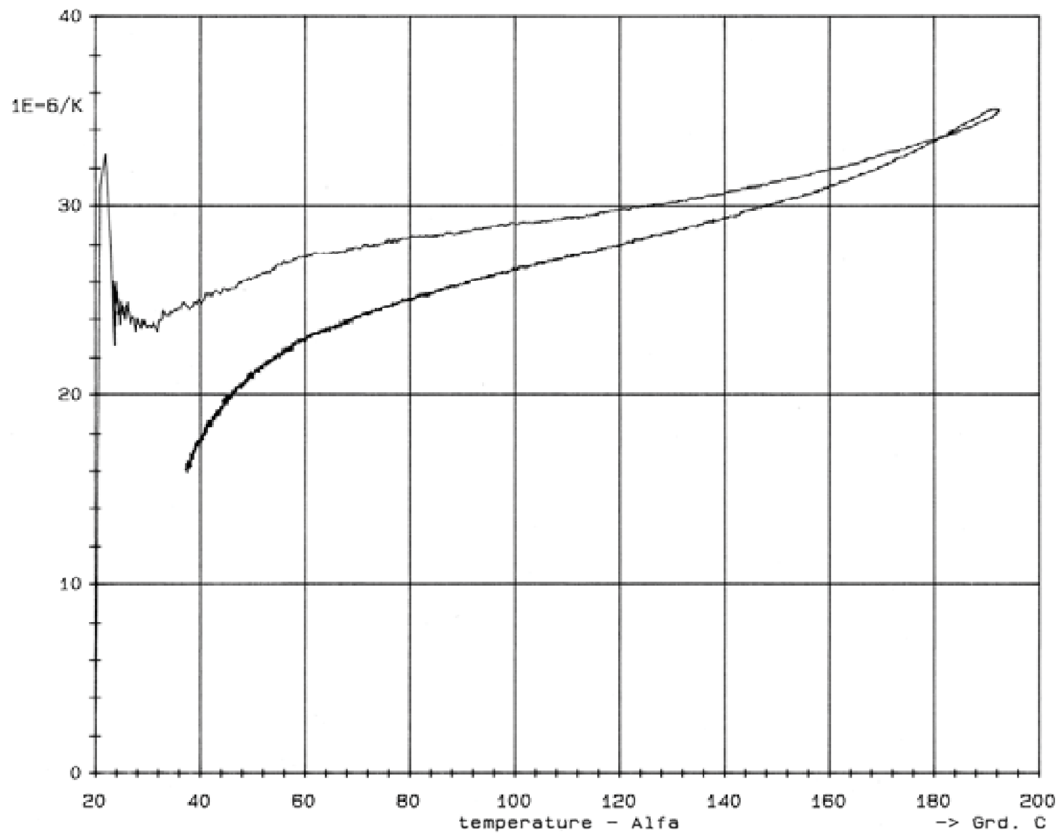

Fig. 4. Coefficient of linear expansion α for the AlSi alloy during heating and cooling with the α positive and negative differences between cooling and heating

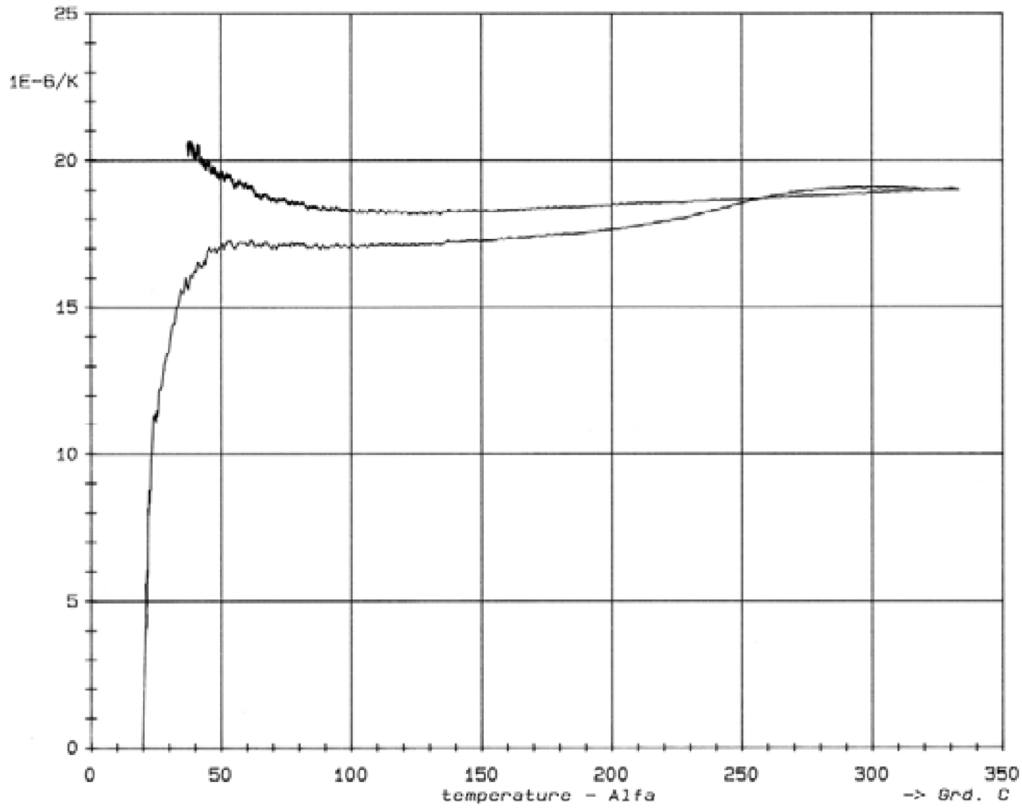

Fig. 5. Coefficient of linear expansion α for the AlSi alloy during heating and cooling with the α positive, negative and positive differences between cooling and heating

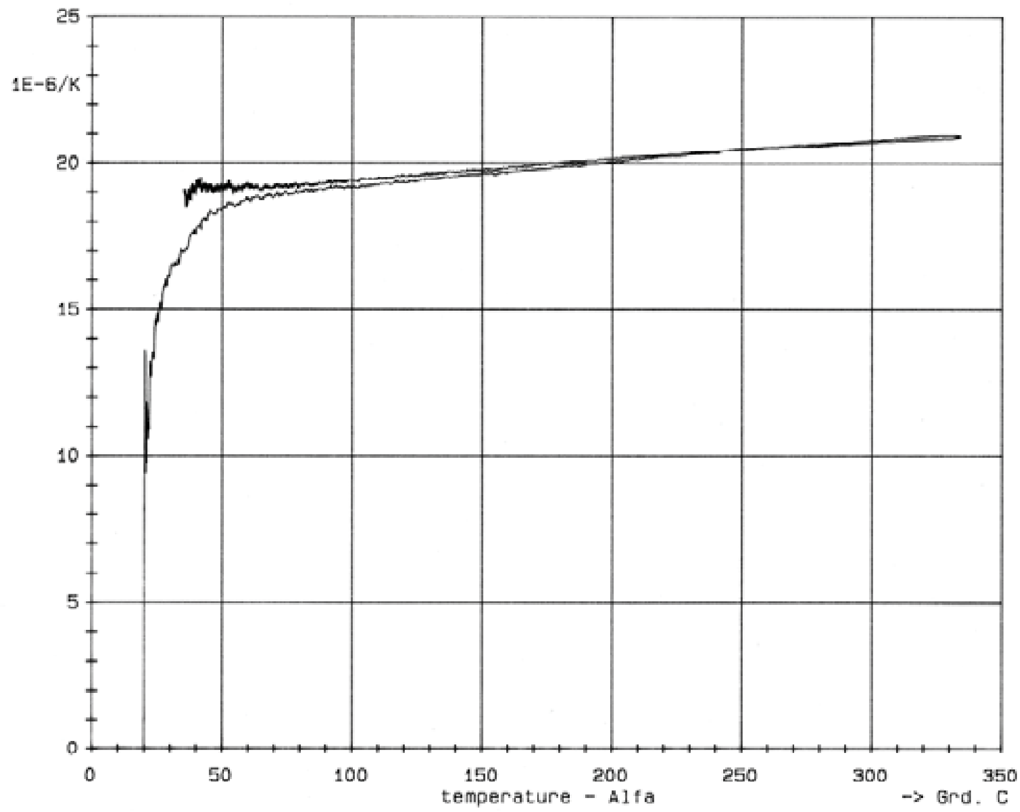

Fig. 6. Coefficient of linear expansion α for the AlSi alloy during heating and cooling with the very small α differences between cooling and heating

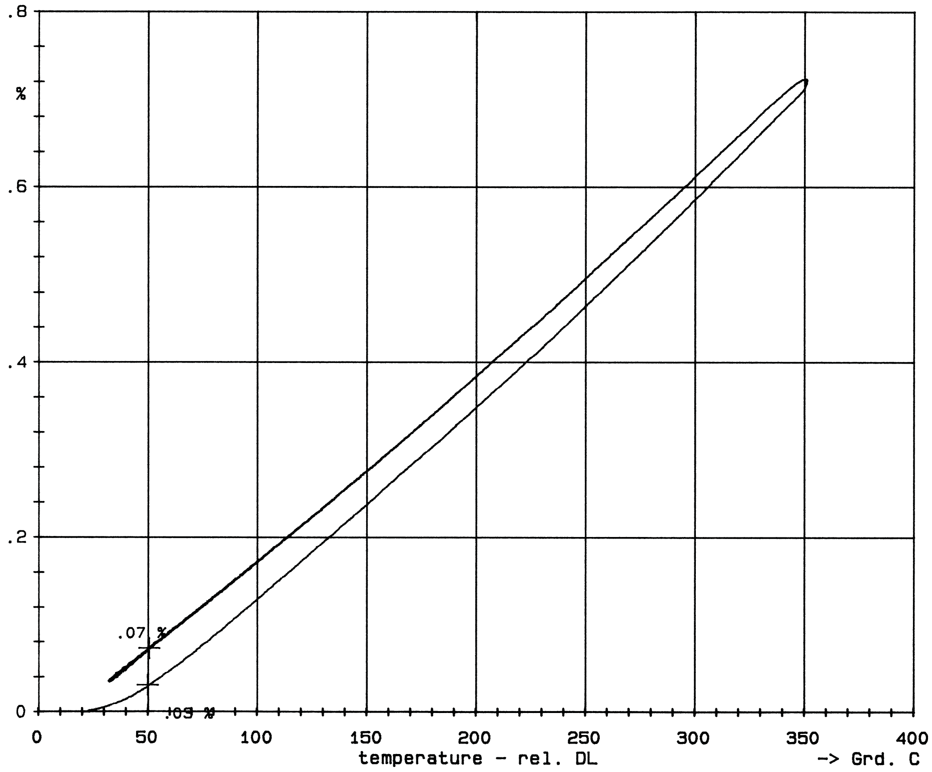

Fig. 7. Relative elongation as a function of temperature for the new composite material during heating and cooling with the positive elongation differences between cooling and heating

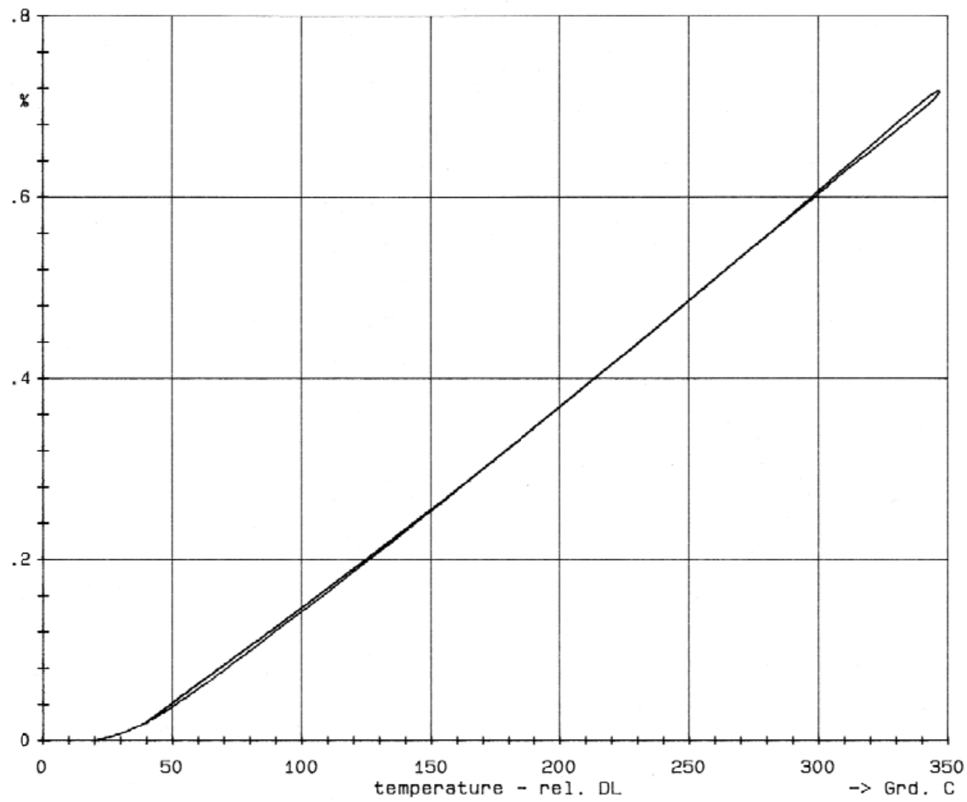

Fig. 8. Relative elongation as a function of temperature for the new composite material during heating and cooling with the very small elongation differences between cooling and heating

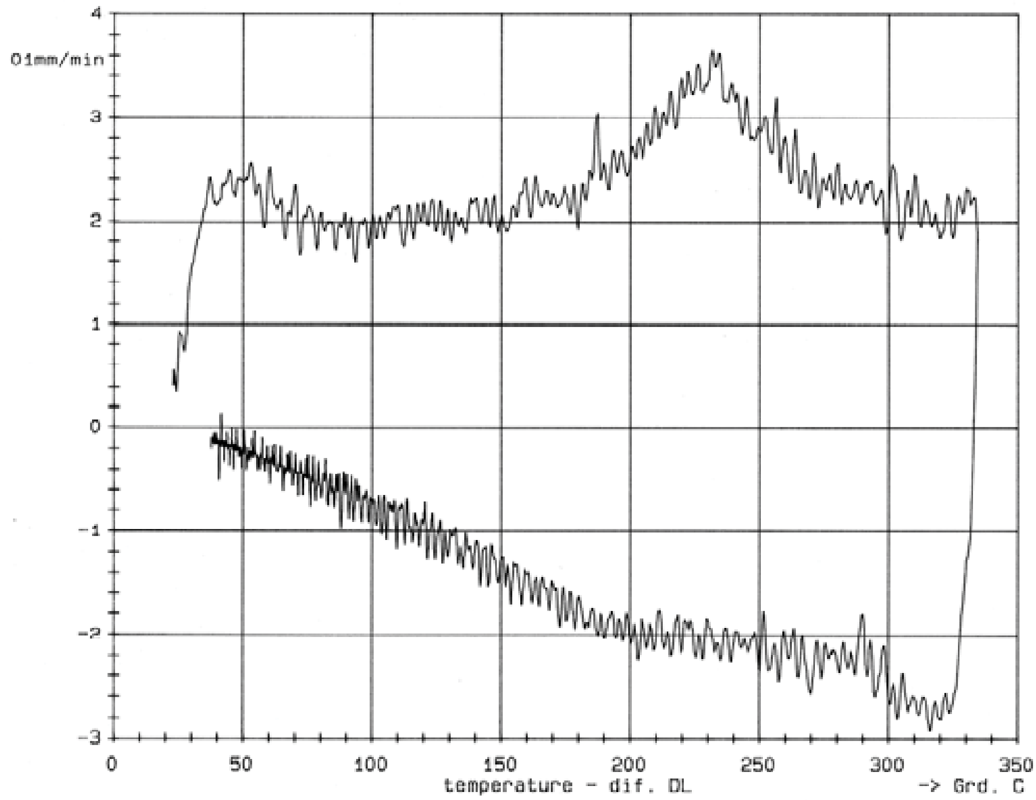

Fig. 9. The course of derivative of specimen dimension increase to the time as a function of temperature (T) during

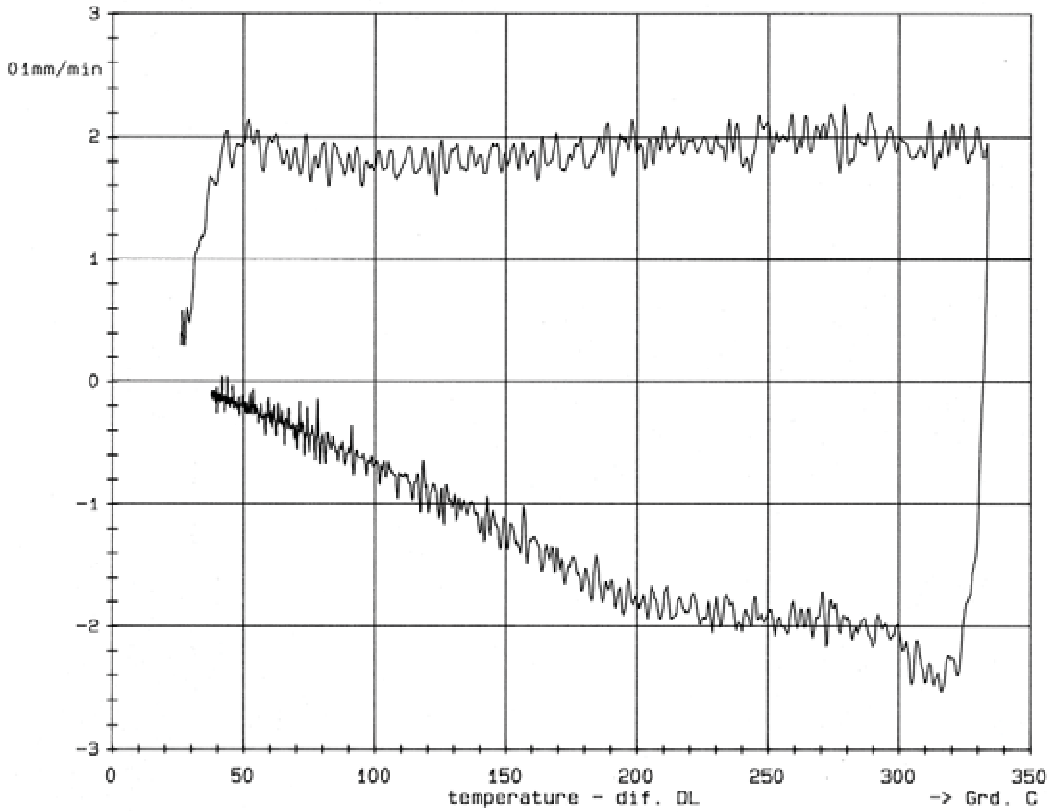

Fig. 10. Course of derivative of specimen dimension increase to the time as a function of temperature (T) during heating and cooling without phase transition during heating and cooling with the very small elongation differences between cooling and heating

Fig. 8 presents coefficient relative elongation as a function of temperature for the new composite material during heating and cooling with the very small elongation differences between cooling and heating.

Fig. 9 presents coefficient the course of derivative of specimen dimension increase to the time as a function of temperature (T) during heating and cooling with the positive elongation differences between cooling and heating.

Fig. 10 presents coefficient course of derivative of specimen dimension increase to the time as a function of temperature (T) during heating and cooling without phase transition during heating and cooling with the very small elongation differences between cooling and heating.

The aim of research was elimination of characteristic hump presented on Fig. 9. After receiving the course illustrated on Fig. 6, the minimized differences in the value of the thermal expansion coefficient during heating and cooling were obtained, as is shown on Fig.7.

The investigation results show a significant impact of alloy additions and heat treatment to ensure the small hysteresis of thermal expansion coefficient α.

The use of alloy additives alone does not provide a small hysteresis of thermal expansion coefficient α, as in the heating and cooling process the redevelopment of the inter-metallic phases in material occurs.

Only performing a multistage heat treatment may interrupt this process, stabilize the phases, which is reflected in the minimization of uncontrolled changes in thermal expansion coefficient α

4. Conclusion

Changes in thermal expansion coefficient at the time of heating and cooling may be very large, as well as during subsequent cycles of heating and cooling of an internal combustion engine piston with respect to standard silumin alloys used for pistons of internal combustion engines.

The best mechanical properties and dimensional stability, low hysteresis in thermal expansion coefficient, α, was obtained by the introduction of several elements to the alloy material, 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 coefficient of thermal expansion during heating and cooling.

Resuming, aim of realized works in the area of materials on pistons is:

- Low thermal expansion.
- Small differences of coefficient of thermal expansion between heating and cooling.
- High stiffness at elevated temperatures.
- High hardness and wear resistance.
- Enables improved engine efficiency and reduced emissions in combustion engine piston applications.
- Reducing piston weight and manufacturing costs.

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