ANALYSIS AND RESEARCH OF PISTON WORKING CONDITIONS OF COMBUSTION ENGINE IN HIGH THERMAL LOAD CONDITIONS

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Abstract

Explanation of phenomena occurring in pistons of combustion engines which appear during heating and cooling processes in reference to standard materials and composite materials of high material proprieties is aim of the paper. Bring over researches were mostly directed on measurements of difference dimensions which appear during the piston work in the combustion engine.

The paper concentrates on phenomenon of different proprieties of materials. The thermal stresses and shocks differ. In the thermal shock, thermal stresses are caused by instantaneous temperature gradients which appear at high engine speed. These stresses are determined thro temperature distribution and they do not differ from stresses in steady-state conditions. Researches concerning thermal expansions were performed by means of sensitive dilatometer which can work in simple and differential system. Changes of dimensions versus temperature function were measured with inductive sensor and the sensitive Pt-PtRh thermocouple, and results were referred to reference material-Platinum.

Research results are illustrated on diagrams of different courses of changes of the of thermal expansion coefficient during heating and cooling of standard and composite materials. Values of the thermal expansion coefficient α for the heating and cooling are smaller for composite alloys. The course of the coefficient á during cooling can be higher or lower from the coefficient á during heating. Similar values were also received. Maximum differences were of 10%. Smaller values of the coefficient á for composite alloys cause that for such the same thermal loads temperature gradients will be smaller for composite alloys. Courses of changes of the coefficient á have a different characteristics suited from chemical composition of alloy, granularity of the composite component and thermal treatment.

Keywords: *combustion engine, piston, thermal load, thermal expansion, thermal shock*

1. Introduction

Explanation of phenomena occurring in pistons of combustion engines which appear during heating and cooling processes in reference to standard materials and composite materials of high material proprieties is aim of the paper. Bring over researches were mostly directed on measurements of difference dimensions which appear during the piston work in the combustion engine. Objects of the paper are research novel composite aluminum alloys of intended on high load elements of combustion engines. The elements have to accomplish high requirements concerning functional proprieties connected with keeping of suitable dimensions (gaps) in elevated conditions and high temperatures. Besides the elements have to accomplish high requirements concerning resistances on variable mechanical and thermal loads under the circumstances of high temperatures. Enlarging along with the development of combustion engines through usage of the high supercharging loads thermal and mechanical enforces explorations novel materials. Such requirements can accomplish elements performed from composite alloys, based on the aluminum alloys. However the usage of composite alloys causes the new situation in which the essential part has the resistance on thermal shocks. Research results of functional proprieties of novel composite alloys designed on high load pistons of combustion engines concerning thermal expansion and the difference of thermal expansions during heating and cooling, test results of materials and thermal shocks which are essential not only in connection with high thermal piston loads, but also because of usages of composite materials are an object of research. In work out researches the essential influence of the process of materials preparation on proprieties functional and endurance of crowds working in conditions of high loads thermal and mechanical loads are showed.

2. Thermal loads

Functional proprieties of pistons define not only data materials in environment conditions, but first of all data materials in working piston conditions, i.e. in conditions of high temperatures and during heating and cooling. Besides functional piston proprieties are connected not only with temperature values but with the appearance of the kind temperature, i.e. from this if the temperature appears in during heating or cooling process. When the material is submitted to temperature gradient or when composite material of two or more kind of material having different thermal expansion coefficients is heated homogeneously or heterogeneously, different component elements of composite material incline to expand in different manner, according to instantaneous temperature and the thermal expansion coefficient proper to the given material and temperature range. Additionally phenomena concerning different proprieties of the material referring to process of the heating and cooling appear. To make possible keeping of continuity structural element, thermal stresses and associated with them strains have to perform. They are dependent from the element shape and temperature distribution. If the material will not be resistant on strains, it will follow the element damage. Fragile and plastic materials react into the different manner on thermal loads. Fragile materials can adopt only slight strains before crack, whereas plastic materials can adopt considerably greater strains. Because heat stresses depend in principle from material abilities for absorption inducing necessary strain maintainable of the continuity at thermal gradients, fragile materials cannot easily adopt additional deformations and at last the damage can appear, especially when there are number of temperature cycles. The thermal shock resistance can be theoretically calculated by the thermal stress parameters:

$$R_1 = \frac{\sigma_b(1-\mu)}{\alpha E}, \tag{1}$$

$$R_2 = R_1 * \lambda, \tag{2}$$

where:

R_1 and R_2 - material constant,
σ_b - bend strength,

E - Young's modulus,
M - Poisson's Number,
α - thermal linear coefficient,
λ - thermal conductivity.

The undimensional thermal stresses σ are defined by the dependence:

$$\sigma = \frac{\sigma_0(1-\mu)}{E\alpha(T-T_0)}, \tag{3}$$

where:

σ_o - initial stresses,
μ - Poisson's modulus,
E - Young's modulus,
α - thermal expansion coefficient,
T - temperature,
T_o - reference temperature.

The influence of basic parameters on the resistance on thermal shocks defines the dependence:

$$\Theta = \frac{kt}{\rho\ c\ h^2}, \tag{4}$$

where:

Θ - undimensional time,
k - heat transfer coefficient,
t - time,
ρ - density,
c - specific heat,
h - half plate thickness,

The problem of the thermal stresses has a great importance in currently developed combustion engines heavy loads, especially high load turbocharged engines. Besides the present trend for the temperature increasing demands of uses composite materials resistant on high temperatures. However the distinctive attribute of these materials is the ductility absence. From this reason, the thermal stress is one of most important criteria of design in the use of resistant materials on high temperatures. The thermal stresses have also an essential meaning with reference to plastic materials exposed to variable during change temperature cycles, with reference to these materials it is essential the thermal fatigue damage. The problem grows more intense when along with cyclical temperature changes, cyclical changes of the thermal expansion coefficient will appear. Researches of authors showed that changes of thermal expansion coefficient could be very large during heating and cooling, as well as during following cycles of the piston of the combustion engine heating and cooling. The paper concentrates on phenomenon of variable different proprieties of materials occurring during heating and cooling processes. The thermal stress and shocks can differ, that in the thermal shock the thermal stresses are due instantaneous temperature gradients occurring at high speed. These stresses are determined by temperature distribution and they do not differ from stresses in steady-state conditions. However temperature gradients which appear in instantaneous state are generally a lot higher than steady-state gradients. So thermal shocks cause greater stresses than thermal loads. Other distinction between the thermal loads and the thermal shock consist in that in the thermal shock the speed of stress increasing is very big. Some plastic materials have proprieties of fragile materials, what is reflected especially at high rate of stresses. Because these materials under the circumstances cannot adopt stresses of thermal shocks which would be able to be adopted in conditions of the low rate stresses. It is also necessary that to distinguish between the single cycle of the thermal stresses and the thermal fatigue. When the damage is due by many repeatable thermal cycles stresses, then takes place the thermal fatigue. Analyses of authors let on the identification phenomena occurring in the heating and cooling processes which appear during of the piston combustion engine work.

3. Experimental researches

Composite materials of alloys on the basis of the aluminum and the silicon approx. eutectic and overeutectic and silicon carbide SiC were an object of researches. Tab. 1 gives composition of alloys, whereas Tab. 2 contains strength proprieties of the Ak11 alloy and composite alloy on the basis of this alloy.

Table 1 Percentile share of composite alloys

No	Si	Mg	Cu	Ni	Fe	Mo	Cr
1	12.33	1.52	3.22	3.39	0.51	0.48	0.48
2	11.89	1.38	3.36	3.21	1.28	0.89	0.65
3	17.85	1.42	3.92	4.01	0.42	0.56	0.71

The chemical constitution was investigated with a spectrograph method, strength researches were performed with the INSTRON machines, hardness researches were performed with the Brinell method. Principle researches concerning thermal expansions were performed by means of sensitive dilatometer liable to work in simple and differential system. Changes of dimensions were measured with an inductive sensor. Material samples were placed in the quartz-pipe, changes of their length were transferred thru quartz-rods. The temperature of tested materials was measured by means of the Pt-PtRh thermocouples.

Table 2. Mechanical Properties of the AK11 and AK11-SiC Alloys

Material	d, μm	Vp %	R_m, MPa	E, GPa	HB	K (P=10N mm^3/m
AK11	-	-	180	76	880	2,195
AK11-SiC	30	10	82	59	700	1,91
AK11-SiC	63	10	98	56	810	1,46
AK11-SiC	100	10	96	72	720	1,016
AK11-SiC	320	10	162	70	680	0,348

Research of thermal shocks are based on unique research devices, measuring equipment allowing on measurement strains in the area high temperatures, and the advanced computer simulation of the finite element method (FEM) and the ANSYS software.

The research device lets on keeping equal and repeatable temperature necessary for research realization. The temperature in the chamber is obtained with combustion of fuel. Samples of the research pistons are heated in the stream of combustion gases, and then cooled a compressed air also by given period. The temperature of samples is checked with a thermo vision camera and kept with the high accuracy. Stand operation is controlled with a computer control system which keeps the established temperature of samples and the rotational speed of the system of fastening of samples and controls terms of heating and cooling.

4. Test Results

Investigated composite alloys had higher strength parameters with reference to extension strength approx. 50% and approx. 40% with relation to the reference materials. Fig. 1 and Fig. 2 show research results of the thermal expansion coefficient of the AK20 standard aluminum alloy. Fig. 3 - Fig. 7 show research results of the thermal expansion coefficient of the composite aluminum alloy (the Date Just 3 from the Table1). Research results of thermal analysis for composite alloys showed that the thermal expansion coefficient in the function of the temperature is lower with relation to of the standard-alloy. Moreover differences of the value of the thermal expansion coefficient α for heating and cooling are generally lower for composite alloys. The above-situation causes that for such the same thermal loads temperature gradients will be lower for composite alloys. In connection with of above the thermal loads of composite pistons will be lower from loads of thermal pistons performed from standard-materials which work in such the same conditions. From the same reasons the resistance of composite pistons performed from composite materials is higher than pistons performed from standard-materials.

Research results are illustrated on below diagrams illustrating different courses of changes of the thermal expansion coefficient during heating and cooling of standard and composite materials.

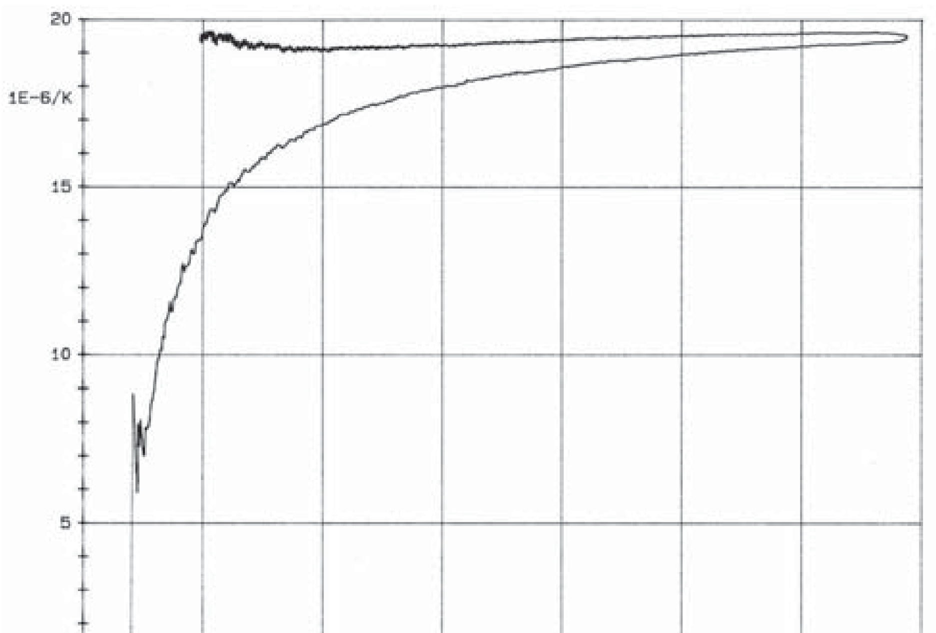

Fig. 1. The coefficient of expansion of thermal α in the function of the temperature during heating and cooling for the standard-alloy of the overeutectic aluminum silicon AK20

Presented results on Fig. 1 and Fig. 2 show that differences in course of dependence of the thermal expansion coefficient α in the function of temperature are not high and the thermal expansion coefficient α during heating is lower than during cooling. It regularity appears also during following cycles of the heating and cooling although differences in following cycles are decreasing.

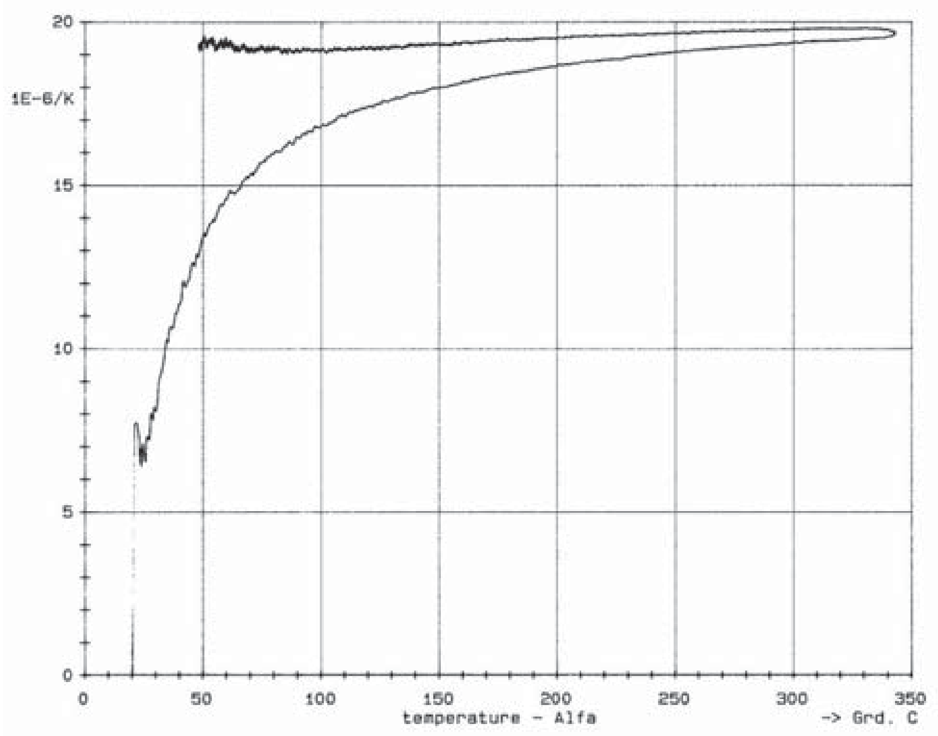

Fig. 2. The coefficient of expansion of thermal α in the function of the temperature during heating and cooling for the standard-alloy of the overeutectic aluminum silicon AK20

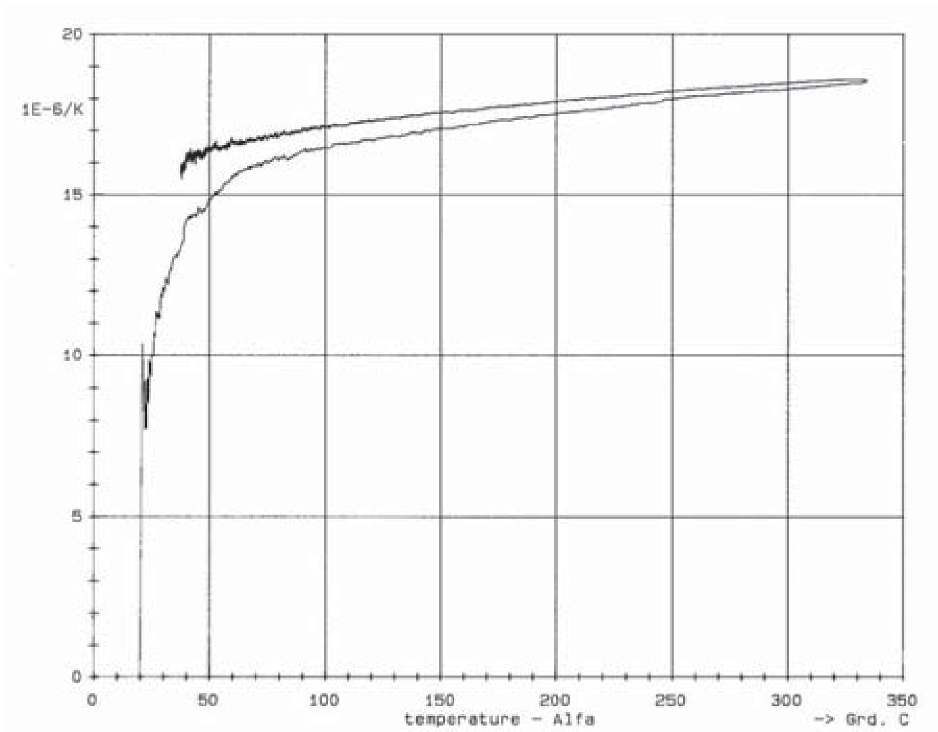

Fig. 3. The coefficient of thermal expansion α in the function of the temperature during heating and cooling for the composite alloy on the basis of the overeutectic alloy the aluminum - siliconAK20 (Tab. 2 No. 3).

Research results of the thermal expansion coefficient with reference to composite alloys are different than for standard alloys. Dependences of this coefficient in the function of the temperature run in different way and are fundamentally are relative to grain sizes of the alloy-addition, the content of alloying components and from the kind of the thermal treatment. Example courses of the thermal expansion coefficient are represented on Fig. 3 - Fig. 7. Fig. 3 shows the same kind of the course of the *α* coefficient as for standard-alloys but with lower differences during heating and cooling at such the same values of the temperature. The maximum difference of the coefficient *α* exceed 1.5 x 10-6 /K what makes about 10%.

Fig. 4 presents compound course of the coefficient *α* during cooling diverse from represented one on Fig. 3. Within the range temperatures from maximum of occurring in the engine of 615 K to about 550 K the coefficient *α* is lower from this coefficient during heating in such the same range of the temperature. Whereas in lower temperatures from 550 K to 323 K this coefficient is higher during cooling than during heating in such the same range of the temperature. The maximum difference of the coefficient *α* does not exceed 0.5 x 10-6 /K at the change of the course character of the coefficient *α* during cooling and is within the range of 3% what is a good result with reference to changes of the coefficient thermal expansion coefficient α.

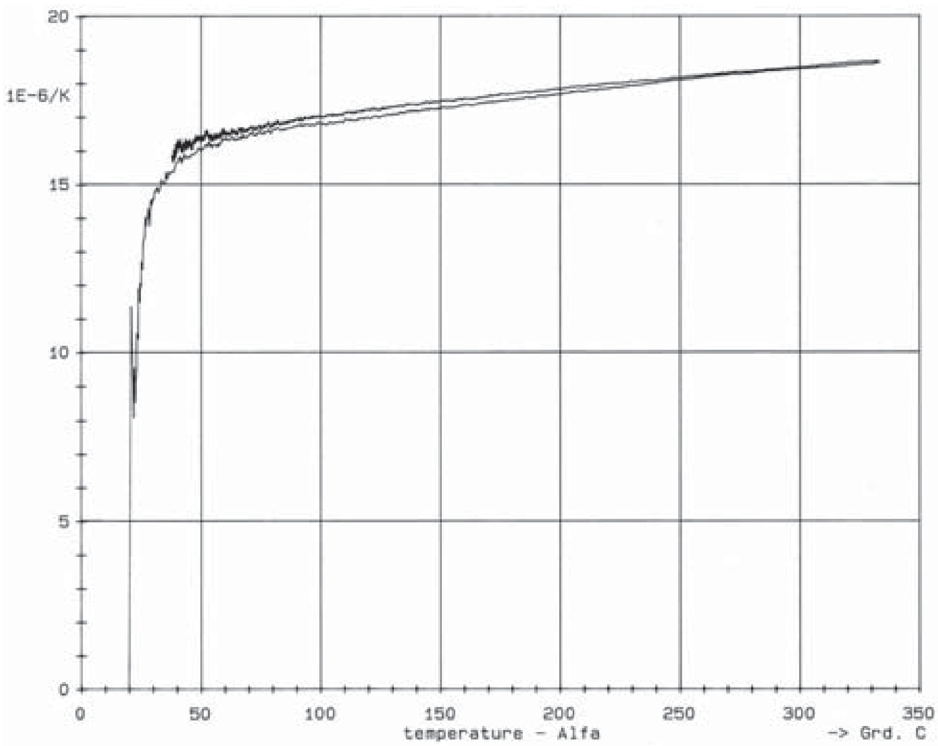

Fig. 4. The coefficient of expansion of thermal α in the function of the temperature during heating and cooling for the composite alloy on the basis of the overeutectic alloy the aluminum silicon AK20 (Tab. 2 No. 3)

Fig. 5 presents the course of the coefficient *α* during cooling diverse from represented on Fig. 3. Within the range temperatures from maximum of occurring in the engine of 615 K to approx. 350 K the coefficient *α* is the same as the coefficient during heating in such the same range of the temperature. However below temperatures from 350 K to 320 K this coefficient is lower during cooling than during heating in such the same range of the temperature. The maximum difference of the coefficient *α* does not exceed of 0.5 x 10-6 /K, at the change of the character of the course of the coefficient *α* during cooling and are within the range of 3% what is also a good result with reference to changes of the thermal expansion coefficient *α,* especially that values of this coefficient are practically covered within the range of piston work.

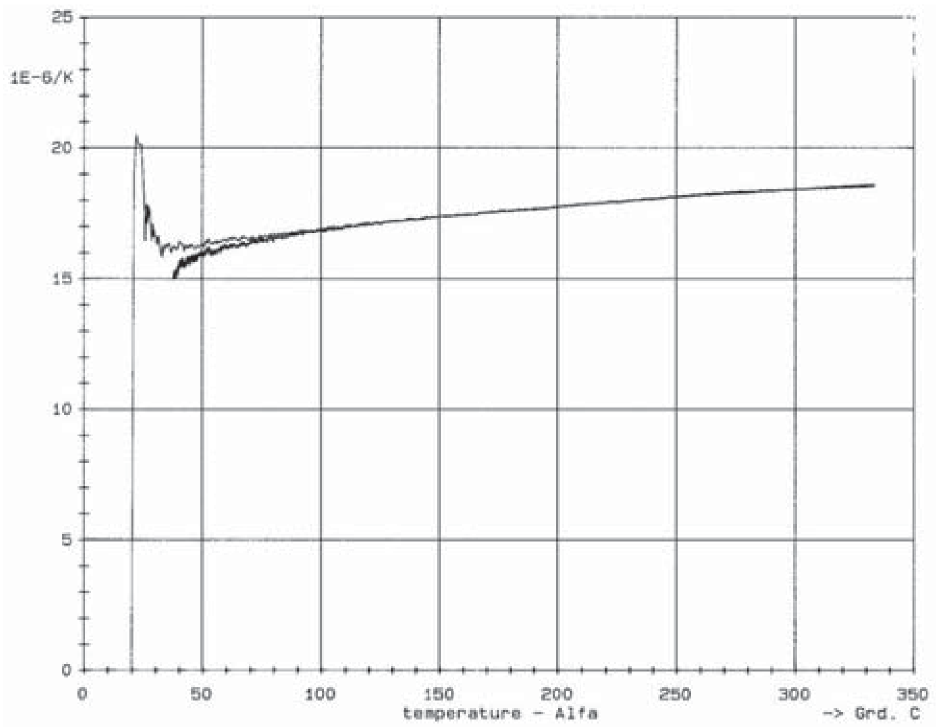

Fig. 5. The coefficient of expansion of thermal α in the function of the temperature during heating and cooling for the composite alloy on the basis of the overeutectic alloy the aluminum silicon AK20 (Tab. 2 No. 3)

Fig. 6 presents compound course of the coefficient *α* during cooling. Within the temperature range from maximum of occurring in the engine of 615 K to about of 570 K the coefficient *α* is higher from the coefficient during heating in such the same range of the temperature. However below temperatures from 570 K to 323 K the coefficient α is lower during cooling than during heating in such the same range of the temperature. The maximum difference of the coefficient *α* does not exceed of 2.0 x 10-6 /K at the change of the course character of the coefficient *α* during cooling and contains within the range of 9%.

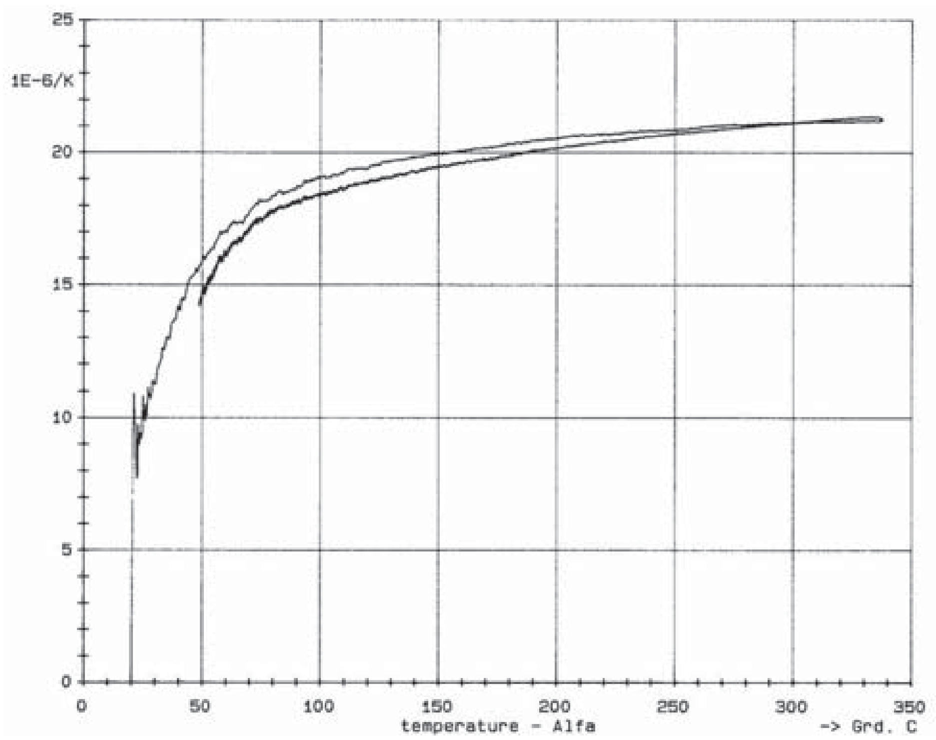

Fig. 6. The coefficient of thermal expansion α in the function of the temperature during heating and cooling for the composite alloy on the basis of approx. eutectic of the alloy the aluminum silicon

Fig. 7 presents compound course of the coefficient α during cooling. Within the temperature range from maximum of occurring in the engine of 615 K to approx. of 570 K the coefficient α is higher from this coefficient during heating in such the same range of the temperature. However below temperatures from 570 K to 323 K this coefficient is lower during cooling than during heating in such the same range of the temperature. The maximum difference of the coefficient α does not exceed of 1.8 x 10-6 /K at the change of the course character of the coefficient α cooling and contains within the range till 8%.

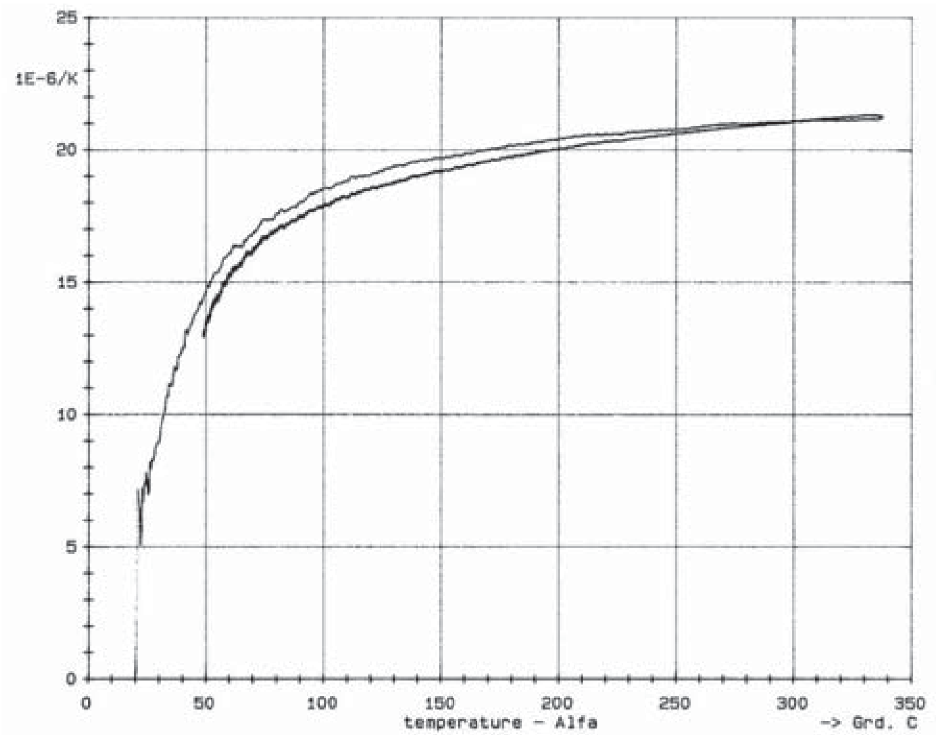

Fig. 7. The coefficient of thermal expansion α in the function of the temperature during heating and cooling for the composite alloy on the basis of approx. eutectic of the alloy the aluminum silicon

5. Conclusions

Performed researches let on the disclosure of essential not only of the temperature influence of on functional piston proprieties but also the difference in values of the coefficient of the thermal expansion. New composite materials having higher strength properties can have lower resistance on the activity of variable thermal loads. It is connected with the higher fragility of composite materials, then standard materials having higher ductility maintain as fragile materials at the occurring high speeds of the of the temperature increasing, what is connected then with the rotational speed of the combustion engine. The novel material on pistons has a chemical constitution different from standard piston silumins and is characterized unique strength proprieties, with small differences of the coefficient of expansion of thermal α.

The presence of alloy-elements influences on neutralization of adverse effect of presence of iron in silumins. These chemical elements create intermetallic relationships with the iron having crystals about the profitable shape and dimensions which take seats on borders of grains and cause rally of the material.

Characterizations of novel materials give possibilities of minimalizing of gaps and obtainment better engine work in full range of rotational speeds and loads. Additionally possibilities of decreasing of mechanical piston loads may be created.

Performed researches showed that the tensile strength and hardness of composite materials were higher than reference materials without composite additions and strength properties are relative to grain sizes of the composite addition, silicon carbide.
Thermal expansion coefficients of composite materials were lower than the coefficients for materials without composite additions.

Considerably better results were obtained for pistons performed from overeutectic alloys than for eutectic alloys. The obtainment approximate values of the thermal expansion during heating and cooling gives good results for decreasing of influence of the temperature on thermal shocks and thermal loads of the pistons of high load combustion engines.
The resistance on thermal shocks of composite materials is higher than materials without composite additions what issues lower values of thermal expansion coefficients and lower differences of the coefficients in cycles of the heating and the cooling. Fragile and ductile materials answer in different way on thermal loads. Ductile materials can tolerate considerably greater thermal and strains than fragile ones. High thermal loads demand novel materials of high resistance on loads in high temperature. Such materials are composite alloys. However the distinctive property of composite alloys is low ductility. Novel composite material has small differences of thermal expansion coefficient α. Properties novel materials give chances of clearance minimalizing and obtainment of correct combustion engine work in full range of rotational engine speeds and loads. Additionally this makes up possibilities of decreasing of mechanical loads of pistons. Coefficients of thermal expansion of composite materials were less than these coefficients for materials without composite additions. Fewer differences of thermal expansion coefficients for composite alloys were observed in cycles to heating and cooling. Less differences of thermal expansion are main reason why novel materials have they have a higher resistance on thermal shocks in spite of lower elasticity.

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