

## RESEARCH OF ENGINE PISTONS FROM POINT OF VIEW OF THERMAL SHOCKS

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### **Abstract**

*Experimental test results of thermal shocks for heavy duty pistons of combustion engines are presented in the paper. The range and the level of thermal loads were diverse and dependent from working engine conditions as well as the temperature ranges were adapted for real conditions in which pistons of the combustion engine work. Temperature measurement results on crown and skirt of a piston during an engine operating under different conditions are presented in the paper.*

*Measured temperature differences during engine operating were greatest in areas, where appeared greatest piston temperatures. Researches of thermal shocks were realized on the special testing device. The device this is automatic, controlled a computer, makes possible the realization of the cycle of research of thermal shocks in the necessary range of the temperature. Test results showed that in following cycles of thermal shocks took place stable changes of dimensions of the piston too. Main factors effecting on the resistance of piston materials on thermal shocks are presented in the paper, at this essential parameters influent on the resistance of materials on thermal shocks are coefficients of thermal expansion and Young's modules. In particular thermal shock resistance of the different piston alloys, dependence of dimensional thermal tensions versus the undimensional heat flux, Basic parameters of the composite material AK12 +20%Al<sub>2</sub>O<sub>3</sub> and standard, values of heat conductivity coefficient the and temperature on the composite piston surface, values of stresses due with the temperature field in piston, values strains in the composite piston due the temperature field, the example of the influence of the number of thermal shocks on the deformation of the piston sample are presented in the paper.*

**Keywords:** piston engines, piston composite alloys, thermal shocks, temperature measurements

### **1. Introduction**

With reference to parts and heterogeneous pistons, of bimetal, and e.g. in case of ceramic coats, temperature gradients will be more greater, what is due different properties of materials, so the problem of thermal shocks with reference to such pistons will be worse essential. Especially, the influence of thermal shocks with reference to composite materials is essential. Thus thermal shocks refer both for heterogeneous warming or the cooling of homogeneous parts, and homogeneous heating or cooling of heterogeneous (bimetal or with coatings) materials. In consideration of different coefficients of thermal expansion of materials its is possible to state that heating up of group of two materials with different coefficients of the thermal linear expansion makes for exceed of strength and damage of the structural member or by now at first heating, or as result of following heating, when will appear fatigue damages. One ought to underline that even with reference to the

homogeneous material and the homogeneous to heating or the cooling can appear thermal stresses because of complex shape of the parts working in conditions of high temperatures [1-6].

The special disadvantageous situation takes place when along with thermal loads influence the mechanical loads, e.g. compressive forces and inertias ones in combustion chamber.

## 2. Thermal shocks

When the piston is exposed to temperature gradients or when complex piston folding of two or more materials having different coefficients of lineal thermal expansion is heated in the way homogenous or disuniform, this takes place stresses because of the different expansibility of each fragment. Here occurs chiefly the occurrence continuity than it deprivation, what is effective occurring stress. The problem of heat stresses has capital importance with reference to high load combustion engines. Present designs of combustion engines involve bigger resistance on high temperatures and applying resistant materials on the influence of high temperatures. But one feature fundamental of these materials, is absence of the plasticity. From this reason, thermal stress is one of most essential criteria made allowance for in the usage of these materials. However thermal stresses have also essential importance with reference to plastic materials and occurring damages of these materials it is possible to refer to occurring thermal shocks.

Thermal stresses ought to distinguish from thermal shocks. With reference to thermal shocks thermal stresses are caused by high-frequency temperature gradients, usually they are instant (shock) activities. For example, if parts initially of the constant regularly lain down temperature is suddenly dipped in environment of other temperature, then brought out is the effect of the thermal shock. In facultative moment stress are defined by the field of the temperature. But the temperature gradients which appear in the temporary condition are in general much higher than these which appear steady-state and because thermal shocks are so essential by reason of existence greatly higher stresses with reference to usual thermal stresses.

Other factor discriminating the thermal stresses from thermal shocks is the speed of stress growth which is very high with reference to thermal shocks, and many materials which are exposed of this high speed initiation stresses cannot these stresses absorb. Because also some fragile materials during fast initiation stresses cannot them absorb without the damage in consequence thermal shocks realized at high speed that, if would be introduced gradually, would be able to remain absorbed.

There is also vital distinction of the single cycle of the thermal shock of the causing thermal stresses from the thermal fatigue. When the damage is due by the realization of several similar cycles of thermal stresses, and not by the single cycle, that process has reference to the thermal fatigue [7-12].

Value of thermal stresses depends, beside temperatures, of volume of heat flux and of running time of the heat flux on parts, whereat the occurring moment of maximum stresses appears the earlier the heat flux is bigger. Besides there were observed the different influence of the single thermal shock, and periodic influence of repeated thermal shocks. Example maximum undimensional stresses in the function of the undimensional the heat flux represents Fig. 1, whereat the maximum undimensional tension is a relation of the thermal stress occurring in a part subjected to operate of the temperature to the stresses, when the thermal expansibility of the given element is dead blocked. The aim of research in the area of thermal shock is obtainment of good thermal shock stability and improvement of thermal shock resistance. Dependences of Thermal shock resistance of the different piston AlSi12CuMgNi alloys and for different fibres ( $Al_2O_3$ ) contents are presented in Fig. 1 [2].

From plot presented in Fig. 2 follows that the change of the maximum stresses is almost lineal with reference to small values of the heat flux and asymptotically tends to unity with reference to big values of the stream flux. The generally undimensional thermal stress  $\sigma$  can be expressed dependence:

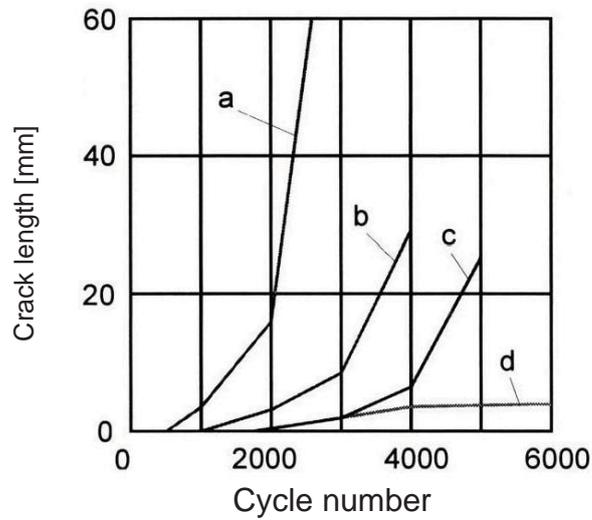


Fig. 1. Thermal shock resistance of the different piston AlSi12CuMgNi alloys and for different fibres (Al<sub>2</sub>O<sub>3</sub>) contents a) standard, b) 12 vol. % Al<sub>2</sub>O<sub>3</sub>, b) 17.5 vol. % Al<sub>2</sub>O<sub>3</sub>, c) 20 vol. % Al<sub>2</sub>O<sub>3</sub> [2]

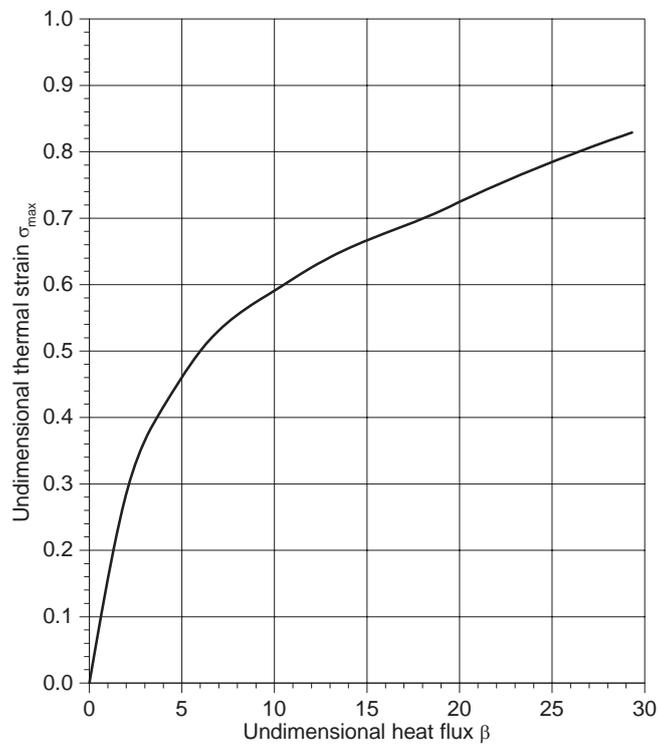


Fig. 2. The dependence of dimensional thermal tensions  $\sigma_{max}$  versus the undimensional heat flux  $\beta$

$$\sigma = \frac{\sigma_o(1 - \mu)}{E\alpha(T - T_o)}, \quad (1)$$

where:

$\sigma_o$  - initial stress,

$\mu$  - Poisson's Number,

E - Young's modulus,

$\alpha$  - thermal linear coefficient,

T - temperature in stress place,

T<sub>o</sub> - reference temperature.

### 3. Research stand

Methodics of research is based on unique research devices, measuring equipment allowing on measurement strains in the area high temperatures, and the advanced computer simulation of the method of element finite (MEF) and the ANSYS software.

The views of the device for the realization of research of thermal shocks present Fig. 3 and 4.

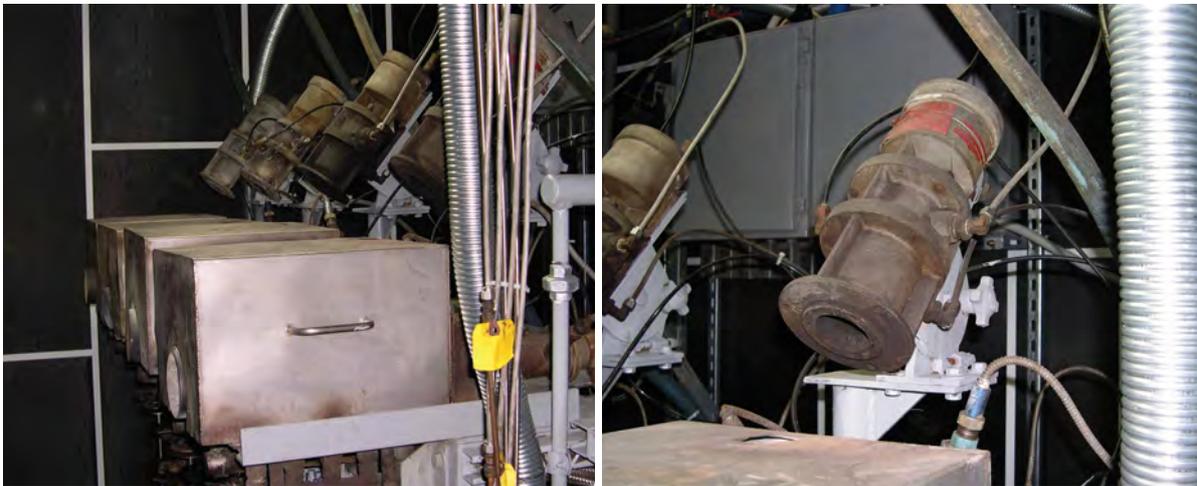


Fig. 3. The view of devices to the realization of thermal shocks: on the left - 4 combustion spaces, on the right the thermo vision device

The 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.

In the research are performed temperature measurements in different places investigated samples and strains by means of special strain gauges enabling on conduct of measurement in conditions of high temperatures. Obtained data from measurement constitute starting point for the advanced analysis with the method of elements finite (MEF) at the utilization computer system ANSYS.

Fig. 5. presents the views of the measuring- card set and the recording of the temperature controlled with the computer during research.

The research device is entirely automated and controlled with technical computer programme.

### 4. Composite materials on pistons

Composite materials, are substances, beings made up of group of two materials of different physical and mechanical proprieties. As metal matrix of composite materials are applied iron and his alloys and many metals and alloys not of iron such, aluminum, magnesium, copper, tin, lead, and titanium. The reinforcing phase composes particles, short fibres and long ones on the basis of graphite, carbon, boron, and oxides:  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{ZrO}_3$ , and  $\text{TiO}_2$ , carbides:  $\text{SiC}$ ,  $\text{TiC}$ ,  $\text{B}_4\text{C}$ , nitrides:  $\text{Si}_3\text{N}_4$ ,  $\text{TiN}$ . Besides, additives are introduced increasing wettability, in general to modifying the character of the oxide coat on the metal surface. The phase reinforcing is oxidized, copper-plated, nickel-plated or chromium-plated.

Basic parameters of the material composite and of standard one are presented in the Tab. 1.



Fig. 4. The view of automatic computer controlled device to the realization the heating and cooling, on the right - the air-compressor

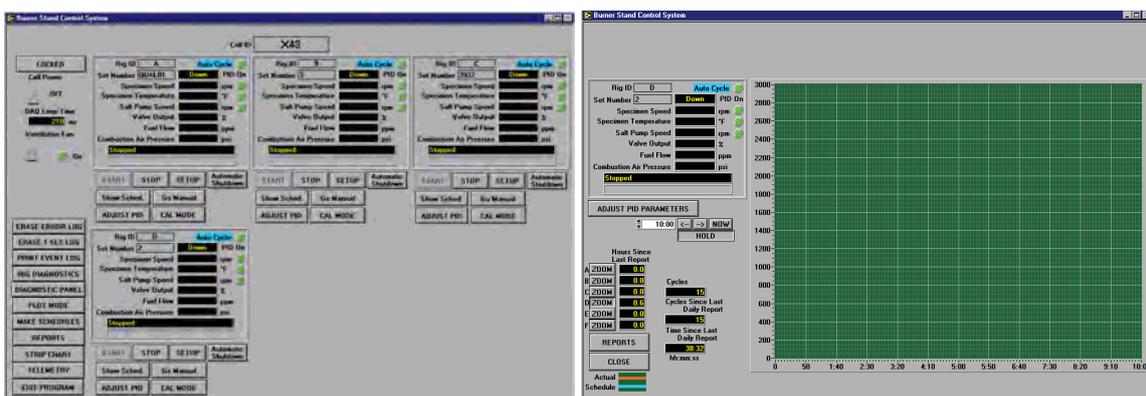


Fig. 5. The views of the measuring- card set and the recording of the temperature controlled with the computer during research

Tab. 1. Basic parameters of the composite material AK12 +20%Al<sub>2</sub>O<sub>3</sub> and standard one

Parameter	Composite material	Standard
Material	AK12+20% Al <sub>2</sub> O <sub>3</sub>	AK12
Specific density	1560 kg/m <sup>3</sup>	2700 kg/m <sup>3</sup>
Specific heat at 250°C	1010 J/kgK	990 J/kgK
Thermal diffusivity at 250°C	0.45 cm <sup>2</sup> /s	0.69 cm <sup>2</sup> /s
Coefficient of lineal expansion at 250°C	15*10 <sup>-6</sup> K <sup>-1</sup>	21*10 <sup>-6</sup> K <sup>-1</sup>
Thermal conductivity	98 W/m K	155 W/m K
R <sub>m</sub>	3.28*10 <sup>8</sup> N/m <sup>2</sup>	2.45*10 <sup>8</sup> N/m <sup>2</sup>
R <sub>p</sub>	2.89*10 <sup>8</sup> N/m <sup>2</sup>	2.25*10 <sup>8</sup> N/m <sup>2</sup>
As	0.35 %	0.5-1.5 %
Young's Modulus	98 GPa	80 GPa
Poisson Number	0.22	0.28
Shear Modulus	4.02 *10 <sup>10</sup> N/m <sup>2</sup>	3.05*10 <sup>10</sup> N/m <sup>2</sup>

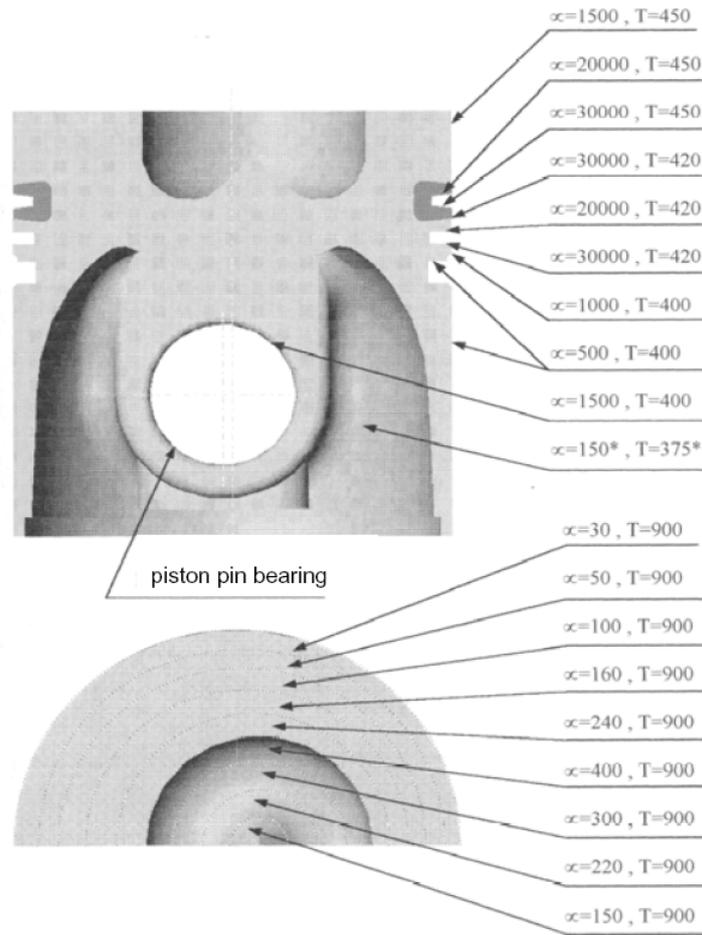


Fig. 6. Values of heat conductivity coefficient ( $\alpha$ ,  $W/m^2K$ ) the and temperature ( $T$ ,  $K$ ) on the composite piston surface

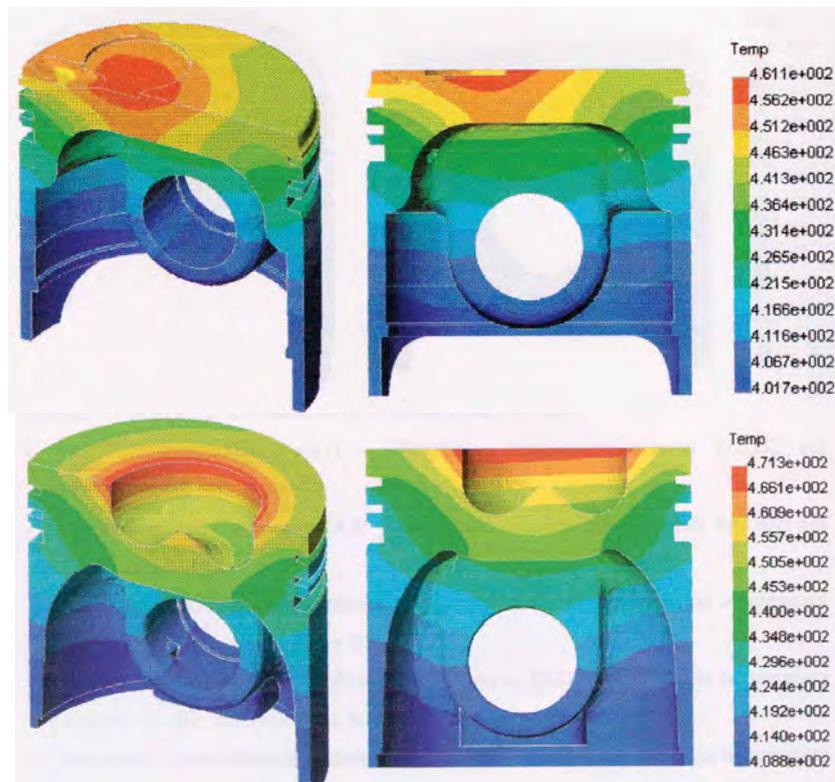


Fig. 7. Temperature ( $K$ ) field in the composite piston for two different designs of pistons

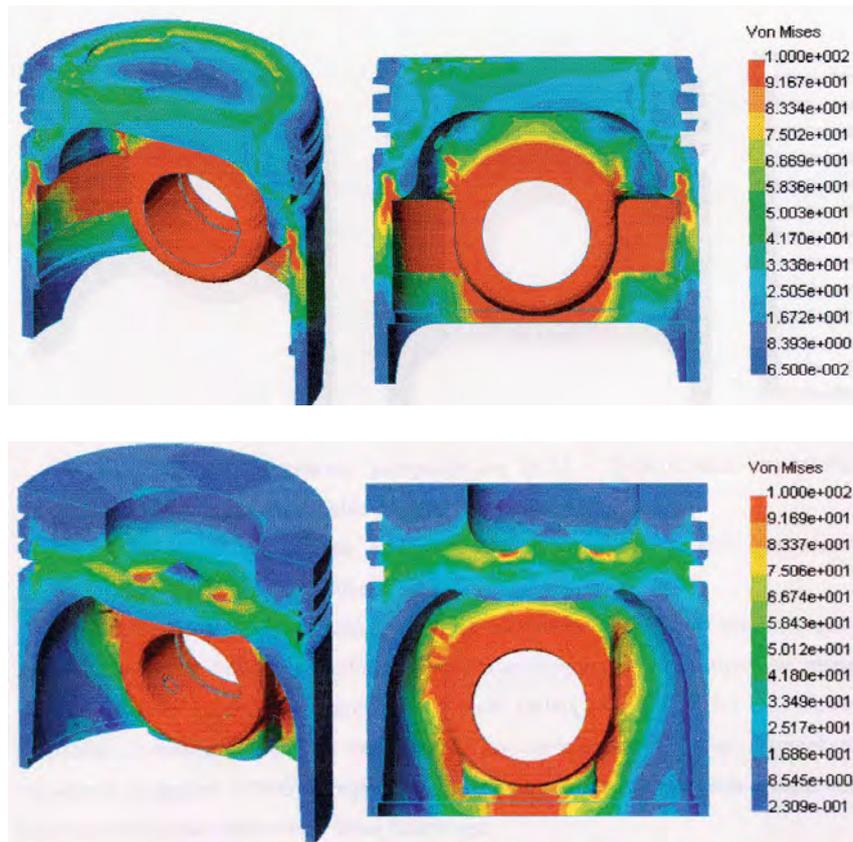


Fig. 8. Values of stresses (MPa) due to the temperature field in piston for two different designs of pistons

Values strains in the composite pistons due the temperature field presents Fig. 9.

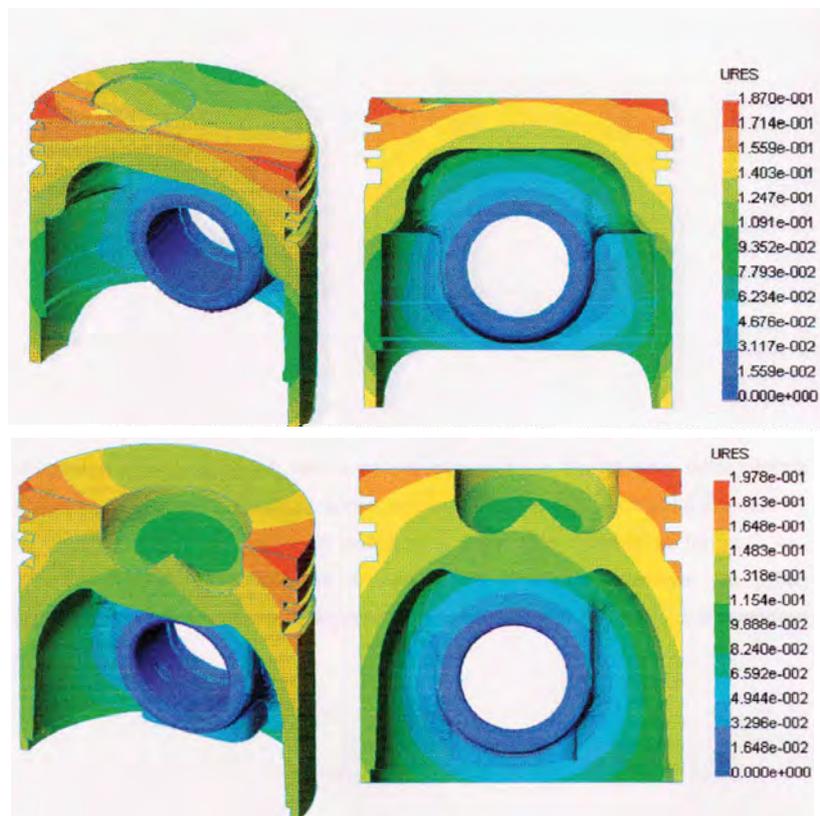


Fig. 9. Values of strains (mm) in the composite piston due to the temperature field for two different designs of pistons

## 5. Test results

Values of heat conductivity coefficient ( $\alpha$ , W/m<sup>2</sup>K) and temperature (T, K) on the composite piston surface calculated with the method FEM are presented in Fig. 6.

Examples of the temperature field in pistons present Fig. 7.

Values of stresses due with the temperature field in pistons are presented in Fig. 8.

Values of strains (mm) in the composite piston due to the temperature field for two different designs of pistons.

Figure 10. presents an example influence of number of thermal shocks on the strain of the piston sample made of the composite material of proprieties presented in the Tab. 1 on the basis of the silumin close to eutectic mixture and Al<sub>2</sub>O<sub>3</sub>. Conditions of research, because of their laboratory-realization, run away from real with reference to the staying term of the sample in the high temperature 360°C. One should to underline that conditions occurring in the combustion engine are not so drastically extreme, as in carrying research of samples.

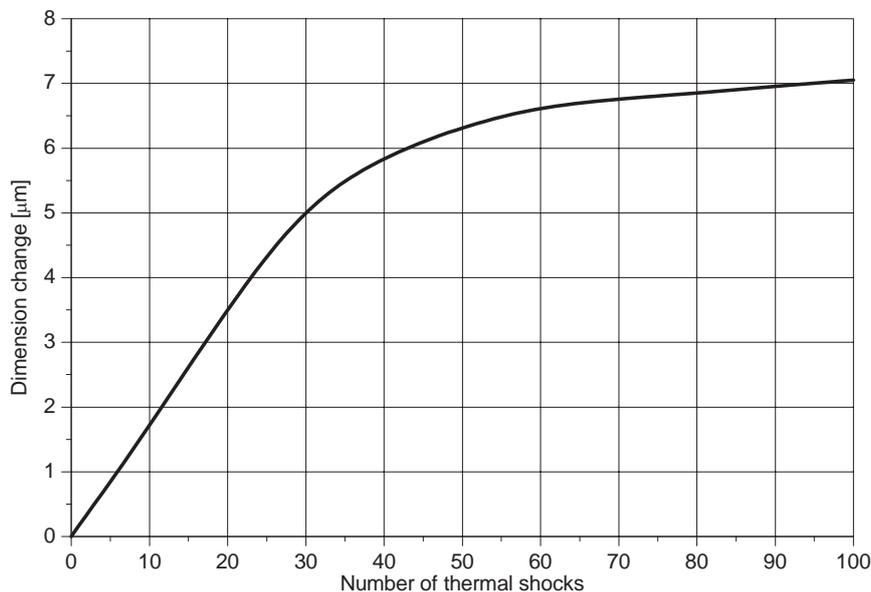


Fig. 10. The example of the influence of the number of thermal shocks on the deformation of the piston sample

The very essential influence has a thermal conductivity to the resistance on thermal shocks with reference to fragile materials.

The dependence (2) represents the influence of basic parameters on the resistance on thermal shocks:

$$\Theta = \frac{kt}{\rho c h^2}, \quad (2)$$

where:

- $\theta$  - undimensional time,
- k - coefficient of thermal conductivity
- t - time,
- $\rho$  - density,
- c - specific heat,
- h - half of slab thickness.

In fragile materials the stress concentration is usually governing and makes for damages. So the stress concentration has decision the greatest importance in research of thermal shocks with reference to fragile materials. With reference to those materials, the stress concentration do not

have so essential meaning for the single loads, but has the essential meaning, when load is applied cyclically. The thermal damage in plastic materials appears in general after many thermal shocks. For that reason also the stress concentration has also capital meaning with reference to plastic materials. It is especially well visible with reference to such materials in which the metallurgical composition of the material is compactly dependent from the local plastic deformation.

From other parameters affecting the resistance on thermal shocks one should of course mention the coefficient of linear thermal expansion. With reference to fragile materials this resistance is inversely proportional to the coefficient of linear thermal expansion. The same refers also for plastic materials. Thus every decreasing of the coefficient of linear thermal expansion improves the resistance of the material on thermal shocks. Because research novel materials make allowance for decreasing of this coefficient. Certain alloys of materials can show even negative values of this coefficient. Thus materials of the zero-coefficient of expansion will be thermal ideal materials from the point view of the resistance of parts on thermal shocks with reference to fragile materials. Other parameter influencing on the resistance on thermal shocks is Young's modulus. Thus materials with small values of this modulus are more resistant on thermal shocks. With reference to plastic materials the influence of Young's modulus is not as essential as with reference to fragile materials.

## **6. Conclusions**

The resistance on thermal shocks of design parts of combustion engines depends essential in the way from the material properties from which the part is performed, mostly from this whether the material is numbered for the category of fragile materials, whether plastic.

For other parameters influencing on the resistance on thermal shocks one should number the thermal elongation which then the parameter essential in the way influences both on the resistance of fragile materials, and plastic ones.

Young's modulus influences in the way more essential on the resistance on thermal shocks of fragile materials, with this that his decreasing favourably influencing on the resistance.

Thermal shocks occur during heterogeneous heating or cooling with reference to homogeneous materials or homogeneous heating or cooling of heterogeneous materials. They appear also during homogeneous to heating homogeneous materials of complicated configuration.

The criterion of the resistance on thermal shocks with reference to fragile materials is the difference of the temperature at which follows the destruction of the material during one cycle. With the second criterion can be the terminal number of cycles of thermal within the range settled differences of the temperature for fatigue destruction.

In most cases the thermal shock can be improved by growths thermal conductivity. This should also be underlined that equations can be applied only for the infinite flat plate, but similar equations would be able to probably to be deduced the same method for other cases concerning the one-dimensional heat transfer. Similarly, this should be underlined that equations are adequate only, when the duration shock appears enough long, so that the maximum stress is obtained. When the duration shock is small, then criteria do not have uses. With reference to the pistons of combustion engines the duration thermal shock is short and from different consideration the better resistance on thermal shocks has materials on the basis of alloys aluminum than alloys of the cast iron.

There was presented a number of essential parameters which can bear on the improvement of the resistance on thermal shocks. Realized researches should be fastening on decreasing of the stress concentration and minimalizing of limitations in free elongation of the part, and also, what is excessively essential, on the introduction of profitable initial stresses, as well as of protective coatings.

Observed phase transformations during research of the thermal expansibility which occurs within the range operating temperatures the piston of the combustion engine modify conditions of the resistance on thermal shocks.

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