PRELIMINARY RESEARCH NOVEL COMPOSITE MATERIALS WITH SMALL HYSTERESIS AND HIGH FUNCTIONAL PARAMETERS FOR COMBUSTION ENGINES PISTONS

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Abstract

Pistons of internal-combustion engines are the most loaded elements of internal-combustion engines, belong to these specialistic elements, which have essential influence on the ecological properties of engines, their durability and reliability. The object of paper is pistons manufactured from the standard material and from new research alloy. The investigations were performed with dilatometer permitting on the registration of changes of the dimensions of sample in the function of temperature and time. The measurements are possible in straight system and in differential system. Exemplary results of investigations are presented in the paper. During the piston heating, period preutectic phases succumb the partial dissolution in solid solution α, but in the cooling process they secrete again. As a consequence the piston partial deformation occurs, which by result is gradual growth of difference between its expansibility during the warming and contraction in the process of cooling (so-called hysteresis occurs). The characteristics of the new piston silumin alloys give possibility of clearances minimalization and the obtainments of a correct engine performance in the full range of engine rotational velocities and loads. The effect are the decrease of the oil expenditure, the decrease of the emission of hydrocarbons in exhaust gases, the decrease of blowbys to crankcase, the decrease of the expenditure of piston rings grooves wear and the piston skirt wear, the decrease of the piston deformation and the increase of engine durability and reliability.

Keywords: *combustion engines, engine pistons, thermal expansion, hysteresis*

1. Introduction

Development of internal-combustion engines, the application of which brought progress in world economy, is directed above all on the solution of such three problems, like: the fulfilling of sharper and sharper demands relating to exhaust emissions and elimination of threats for natural environment, the decrease of fuel expenditure, therefore the decrease of emission of carbon dioxide and protection of natural earth resources, diversification of used fuels. Hence the aim of manufacturers is to produce engines fulfilling even sharper demands relating to the emission of the exhaust elements with the assurance of a great durability and reliability of engines.

Wider and wider application of biofuels, which in the countries European Union, in the year of 2020 have to be determined at the level at least 30% of all used up fuels, they lay new challenges on the manufacturers of internal-combustion engines. Hitherto existing development of engines occurred with the application of mineral hydrocarbons fuels, physical and chemical properties of which differ significantly from the properties of fuels of the renewable biological origins. The best properties, as fuel, among these substances are characterized by alcoholic fuels, which the different physical and chemical properties can cause essential change in the performance of the elements and engine assemblies, in this they can have essential influence on engines ecological properties and on correct functioning of engines elements, their durability and reliability.

2. Pistons of internal-combustion engines and their materials

Pistons of internal-combustion engines are the most loaded elements of internal-combustion engines, they belong to these special elements, which have essential influence on the engines ecological properties, like their durability and reliability. From a new generation of pistons are required the high durability properties in elevated temperatures and the functional properties, relying principally on minimalization the difference in of thermal expansibility during the piston heating and cooling, that increases the fatigue resistance of design both mechanical and thermal and increases the resistance of pistons on thermal shocks. Materials on pistons ought to be characterized by the good strength properties and small hysteresis of the coefficient of thermal expansion α in the whole range of work temperature, large obliterations resistance, small abrasive wear, small coefficient of friction, the good functional properties. The application of biofuels causes the change in piston and combustion chamber temperature distribution, that results among others from a different combustion temperature and changing heat transfer conditions between exhaust gases and the combustion chamber. It is moreover necessary to accept the deterioration of the lubrication conditions in the piston – cylinder assembly, because alcohols have the property of the dilution of the lubricating oil layer. The assurance of appropriate material properties will permit to manufacture pistons, which performance in the engine can assure the small toxicity of emitted exhaust and the small fuel expenditure, which is counted as decisive parameter to the ecological properties of internal-combustion engines.

The essence of the new composite piston materials is occurrence in them of intermetallic compound phases, crystallizing in the high temperature, before the crystallization of eutectics α+β (Al+Si). The intermetallic compound phases, crystallizing as the first ones in the cooling phase of piston casting process, cause the creation of the natural (in situ) composite material with the best functional properties.

Multi-phase of the microstructure and lack of the dissolvability of alloys component elements in aluminum causes the crystallization of compound phases with the high fragmentation, because the place of nucleation and subsequent growth phase is the interphase border of previously crystallized phase and liquid. Multiphaseability of microstructure, its considerable fragmentation and presence of Si in some phases causes the decrease of its liberation quantities, and as a consequence obtainment of high useful properties.

3. Results of investigations

3.1. The object of investigations

As the investigations object were the pistons manufactured from the standard material and pistons from the research alloy, the principal elements of which are presented in Table 1.

Table 1: Chemical composition of investigated silumins

No.	Chemical Composition, %					
	Si	Mg	Cu	Ni	Cr	Mo
Standard Alloy	12.5	0.37	5.0	4.15	-	-
Novel Research Alloy	12.25	0.22	3.5	0.015	0.03	0.22

3.2. Research equipment

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 site are submitted on Fig. 4, where Fig. 1 presents the schema of research site, Fig. 2. - the view of measuring head in straight system, Fig. 3 - the view of measuring head in the differential system, Fig. 4 - general view of research site.

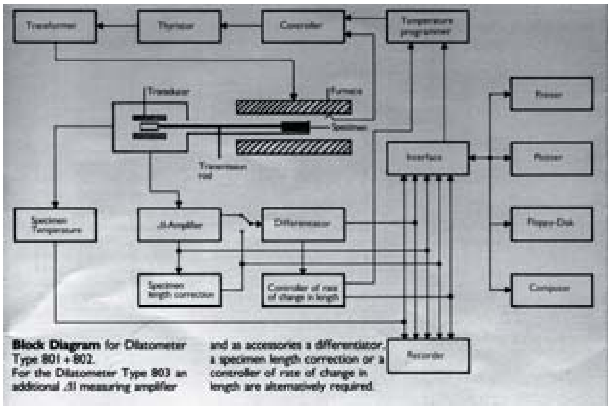
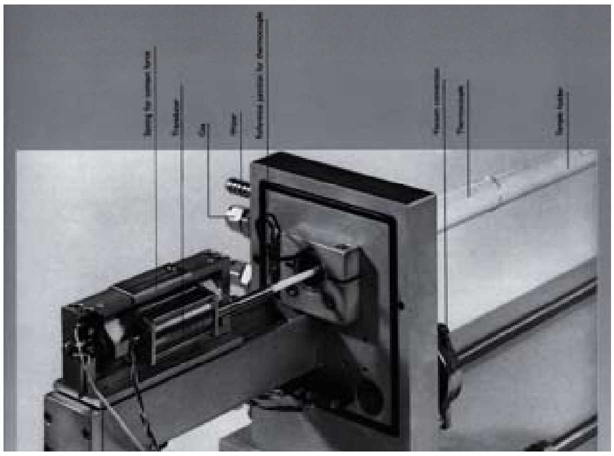


Fig.1. The schema of the research site



Figs. 2. View of the measuring head in straight system

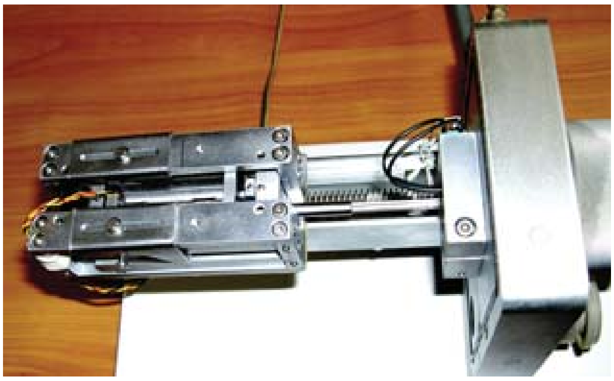


Fig.3. The view of measuring head in the differential system

Fig. 4. General view of the research site

4. Results of investigations

Exemplary result of research is presented on Figs. 5-10, where Fig. 5 introduces the course of the relative elongation in function of time during alloy material ageing in the 200°C temperature. Fig. 6 introduces segment picturing the increase of a relative piston elongation in the function of time, which during a first section of ageing is equal to 0.031%, and during a second ageing is equal to 0.008%. The entire relative increase of piston dimensions is equal to 0.411% that with the 100 mm piston diameter is equal to 0.419 mm. Fig. 7 introduces the change of the linear expansion coefficient in the function of temperature during the heating and the cooling of piston sample with respect to the standard material. Fig. 8 presents the change of the linear expansion coefficient in the function of temperature during the heating and the cooling of piston sample after the additional ageing - thermal processing in the temperature 200°C during 8 hours. However, after such thermal processing the differences in the values of coefficient α during piston heating and cooling are appearing.

Fig. 9 presents the change of the linear expansion coefficient in the function of temperature during the heating and the cooling of piston sample with respect to a new piston material. Fig. 10 presents the change of relative elongation in the function of temperature with respect to a new piston material.

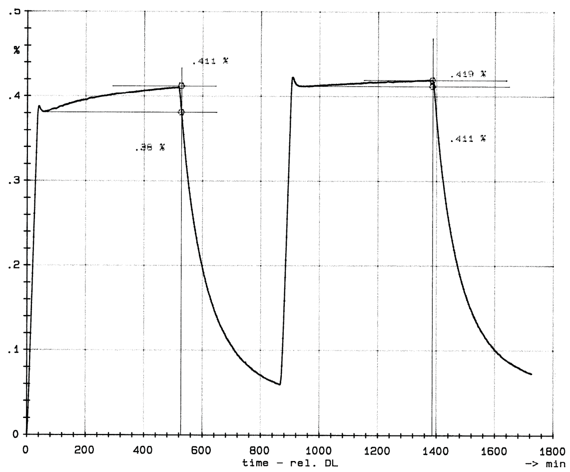
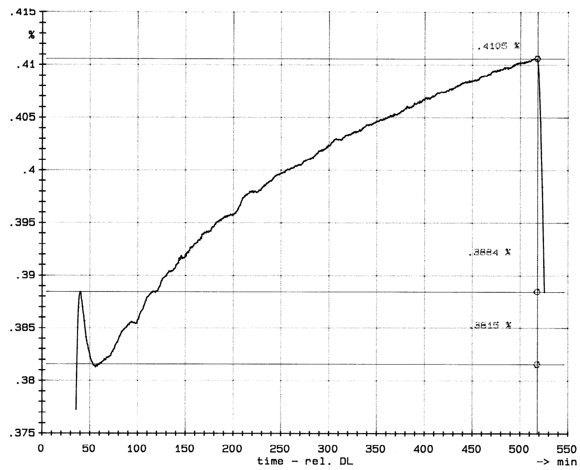
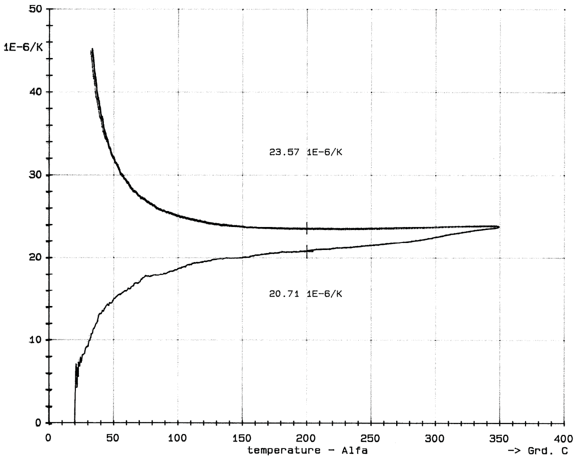


Fig. 5. The course of relative piston elongation in function of time with ageing in the temperature of 200°C



Figs. 6.The first phase section. The course of piston relative elongation in the function of time with ageing in the temperature of 200°C



Figs. 7 Change of the linear expansion coefficient in function of temperature during heating and cooling of piston sample with respect to the standard material

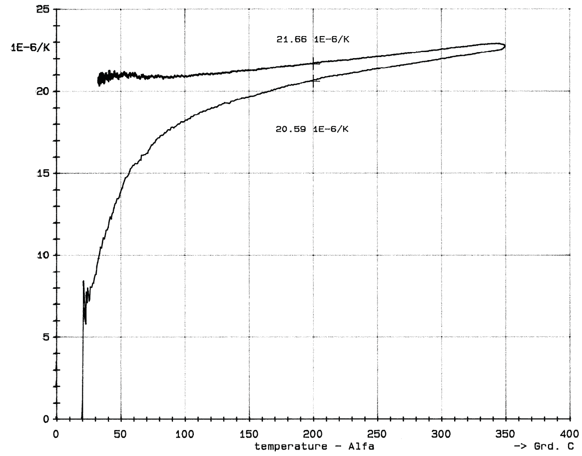


Fig. 8. Change of the linear expansion coefficient in the function of temperature during heating and cooling of piston sample with respect to standard material after the additional thermal processing

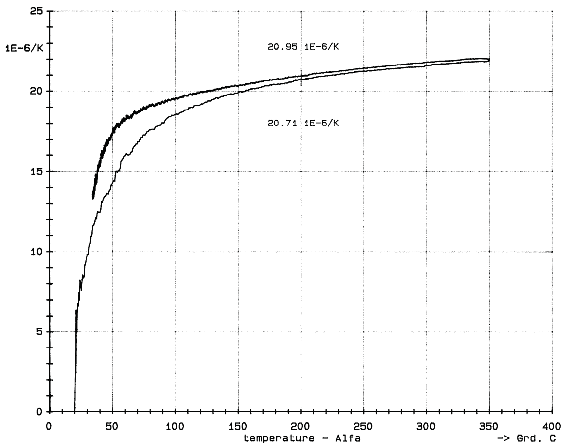


Fig. 9. Change of the linear expansion coefficient in the function of temperature during heating and cooling of piston sample with respect to the research alloy

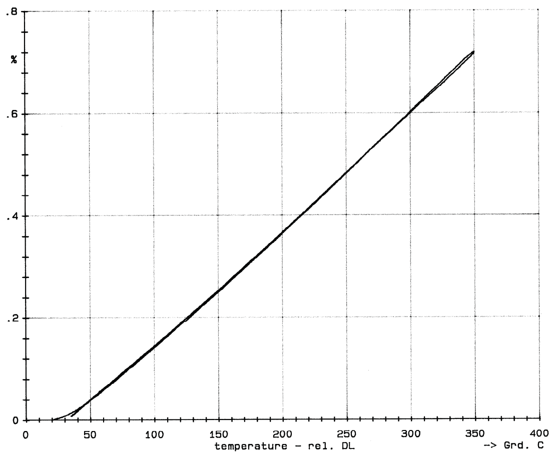


Fig. 10. change of a piston relative elongation in the function of temperature during heating and cooling of piston sample with respect to the research alloy

5. Overview of the results of investigations

The low contents of toxic exhaust elements is determined by different factors, among others by temperature in the combustion chamber (from what will depend principally the presence of the oxides of nitrogen and soot in exhaust gases), clearances in piston - cylinder assembly and by the form of the upper part of piston crown (from what – above all, will depend quantity of hydrocarbon emission). The source of hydrocarbon can be the spaces with the very small dimensions, to which fuel-air mixture has access, where however the burn-out of all fuel cannot be reached because of a small extinction distance. Clearances in piston - cylinder assembly can be not 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 thermal expansion α and its hysteresis. The pistons are in general produced from the aluminum alloys, however cylinders are produced from cast iron, the linear expansion coefficient of which is about twice smaller than the linear expansion coefficient 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 linear expansion coefficient ($\alpha(T) = \frac{\Delta L(T-20)}{L_n}$) 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 linear expansion coefficient α, and some smaller value of the linear thermal expansion coefficient than standard silumin piston. The pistons manufactured from a new material will be characterized by the smaller dimensional changes, particularly performing in the difficult conditions, like frequently changed rotational velocities and the engine loads.

6. Conclusions

- The changes of the linear thermal expansion coefficient can be very large during the heating and cooling, as well as in time of succeeding cycles of heating and cooling of the internal-combustion engine piston with respect to standard silumin alloy used in piston manufacture.
- During the piston heating period preutectic phases succumb the partial dissolution in solid solution α, but in the cooling process they secrete again. As a consequence the piston partial deformation occurs, which by result is gradual growth of difference between its expansibility

during the warming and contraction in the process of cooling (so-called hysteresis occurs). The characteristics of the new piston silumin alloys give possibility of clearances minimalization and the obtainments of a correct engine performance in the full range of engine rotational velocities and loads.

- The effect of the application of pistons from a new material with minimal hysteresis of the linear thermal expansion coefficient α are the decrease of oil expenditure, the decrease of the emission of hydrocarbon in exhaust gases, the decrease of blowbys to crankcase, the decrease of the expenditure of piston rings grooves wear and the piston skirt wear, the decrease of the piston deformation and the increase of pistons durability and reliability.

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