SOME PROBLEMS PISTONS MADE FROM COMPOSITE MATERIALS WITH SMALL HYSTERESIS TO COMBUSTION ENGINES

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Abstract

Novel composite materials on the pistons are characterised that they occur in them multiple intermetallic phases which crystallize in the high temperature, before crystallization of the $\alpha+\beta$ (Al+Si) eutectic. For forming of pre-eutectic phases, chromium and molybdenum are introduced to silumins, and for derivation of multiple increased concentration of nickel and copper and decreased concentration of magnesium are accomplished. On the basis of evaluations of mechanical and thermal loads of combustion engines pistons applying essence of composite materials of combustion engines pistons, as well requirements for combustion engines pistons, especially high loaded engines are expressed. Test results of hardness, influence of temperature of casting, test results of mechanical properties, friction coefficient and coefficient of thermal expansion are presented in the paper.

The special attention devoted to so called hysteresis coefficient of thermal expansion and hysteresis of the relative elongation in function temperature and time. Courses of coefficient of thermal expansion for standard and composite material are presented. Differences of the α coefficient during heating and cooling in function temperature are relative to kind of heat treatment. Two-stage heat treatment is beneficial for the obtainment small values of the α coefficient.

Keywords: *combustion engines, combustion engine piston, composite alloys, thermal expansion, hysteresis*

1. Introduction

Most loaded elements of combustion engines are pistons which have to accomplish rising requirements functional and of durability. Applied at present and standard materials on pistons, are piston-silumins having the following chemical constitution: 11.0-20,0% Si, 0.7-1.5% Mg, 0.5-1.5% Ni, 0.5-1.5% Cu, 0.2-0.5% Mn, 0.3-0.5% Fe. Alloy additives: Mg, Ni, Cu, Mn and Fe They constitute in silumins following intermetallic phases: Mg_2Si, Al_3Ni, Al_2Cu, AlFeMnSi. These phases crystallize after finished process crystallization of the eutectic α+ (Als+Si). They cause strengthen of the silumin. Mechanical properties in the ambient temperature of piston-silumins comprise themselves in the following range: Rm = 200-360 MPa, Rp0.2 = 160-320MPa, A5 = 0.2-2,5%, HB = 80-100 and E = 80-85GPa. For example in temperature 250ºC they are following: Rm = 120-140 MPa, Rp0.2 = 95-85MPa, A5 = 0.9-8.5%, HB = 40-50 and E = 73-75GPa. Mentioned intermetallic phases occurring in microstructure of piston-silumins are not stable. During heating piston in the engine they undergo partial dissolution in the α solid solution, and in process of its cooling they are emitted again. Essence novel composite materials on pistons is occurrence in them multiple phases intermetallic, crystallizing in the high temperature, before the crystallization of the eutectic α+β (Al+Si). For producing of pre-eutectic phases, chromium and molybdenum, and for the obtainment them multiple remains enlarged concentration of the nickel and copper and the lowered content of the magnesium are introduced to silumins.

2. Requirements for combustion engines pistons

During working, the highest temperatures of the piston are under conditions of highest loads and rotational speeds which occur on crown of the piston and run up to 700K. Minimum temperatures occur in lower part of the piston skirt and run to approx. 450K. Mentioned temperatures on lower part of the piston are average temperatures during working cycle of the engine measured at depth of 0.1 - 0.2 mm. mechanical Loads of pistons come from gas and mass forces and from forces of friction. Thermal loads and mechanical cause stress and strain state, what has an essential influence on ecological properties of engines. Essential ones are working clearances between the crowd and a cylinder, and particularly their changes during following heating and the cooling of the pistons, and also during changes of the rotational speed of the engine. Large clearances between the crowd and the cylinder are large blow-throughs of combustion gas, great oil consumption, great working noise and great vibrations, so consequently great content of toxic components of combustion gas and particulate matters. Composite materials, in which to the metal-matrix different relationships characterizing a smaller friction coefficient and a greater resistance on seizure are introduced, admit of realizing idea in which the required strength secures by matrix material, however suitable tribology properties secure by materials uniformly allocated in the structure of the basic material. Decreasing of deformations of the piston and increasing its strength one can obtain through the additional *reinforce* of the piston skirt with fibres high tensile, e.g. with metallic filaments (steel, titanium, boron) or of non-metal (carbon filaments). Moving to matrix material such additives, as graphite, ferrous sulphide affects favourably the tribology property pistons not causing worsening of other properties. The pistons have to accomplish high requirements concerning properties of functional connected with maintenance of suitable dimensions (clearances) under conditions of elevated and high temperatures. In addition the pistons have to accomplish high requirements concerning resistances on variable mechanical and thermal loads under conditions of elevated temperature. Together with development of combustion engines, through employ of the high supercharging increase considerably both mechanical as and thermal loads of pistons.

3. Composite materials on pistons

Composite materials are defined multiple materials from synthetic substances in which fibres from different materials are allocated in matrix of synthetic substance. Multiple composite material can compound as matrix pure metal, alloy, synthetic substance or ceramics, and in matrix other phases with strictly determined geometric properties and almost completely different from physical, chemical and mechanical properties of matrix material are allocated. Composite materials are compound with several components differing in the fundamental manner with the chemical constitution which are separated by clear border. Properties of composites are other than properties forming its compounds. They characterized homogeneous macrostructure and heterogeneous microstructure. It brings out that the more general usage of composite materials performs on running into applications to more complex systems of material designs. To composites in which material of the matrix reinforced with fibres belong metals of Al, Cu, Mg, Pb reinforced with carbon fibres, Al and Ti reinforced with boric fibres , superalloys reinforced with fibres of molybdenum and wolfram, Al, Pb and Mg reinforced with fibres of aluminium oxides, Al and Ti reinforced with silicon carbide fibres. Composites reinforced with fibres are characterised with very large strength, especially in the direction of fibres and therefore they are applied mainly on designs requiring very large directional strength.

Composites reinforced with particles are applied in designs in which they are aimed to decreasing friction coefficient, increasing of resistance on seizure, decreasing of the abrasive wear. In number these composites one can mention composites Al and Cu reinforced with particles of the graphite, composites Al and Cu reinforced with particles SiC, SiO_2, ZrO_3, composites Al and Cu reinforced with particles Al_2O_3, ZrO_2, SiC, B_4C, composites Al and Cu reinforced with particles mica, Pb and C. From these composites there are formed elements of machines resistant on abrasive wear, elements of machines resistant on adhesion, tools cutting off, heat-proof elements, elements of machines requiring very small friction coefficients.

Accomplishment of composite material on of combustion engines pistons which will accommodate demand the high strength at big dimension-stability, the small abrasive wear, small friction coefficient and big resistance on seizure is possible. Thereby that ferrous (FeS) sulphide causes decreasing friction coefficient, decreasing abrasive wear and decreasing of resistance on seizure, samples of materials based on piston-silumins containing as the FeS additives performed. Samples from of casting aluminium alloy with different content of the silicon: AK9, AK11, AK12, AK20 and with different grain coarseness and contents FeS were prepared, then preliminary research were performed involving coefficient of thermal expansion α, resistances on seizure and wear with association with the anti-sample 55 steel of 55 HRC hardness, strength on extension and hardness of composite material (performance of samples and investigations were carried out at co-operation with Lodz University of Technology). In these investigations obtainment of better parameters of the linear thermal expansion and dimension stability and tribology parameters was most essential.

4. Test results

Investigated samples of materials casting temperature from 953 to 1203K were applied. The quantity of added FeS carried out 6 %. At high casting temperatures, exceeding 1073K the effect of the demodification of the silumin appeared, and after excess temperature 1203K - complete absence modification appeared. These investigations referred to composite material on the basis of alloy AK.

Investigations of the hardness of casting samples of 10 and 50 mm diameter in section perpendicular to the axis of the sample in two mutually perpendicular planes performed. Investigations of the influence of the grain coarseness and the quantity FeS on the hardness in reference to samples performed with alloy AK9 with time mixing and refinement of 3 min in casting temperature 953 - 1003K were performed. On Fig. 1 example course hardness in the casting sample in temperature of 953K is presented. Test results influence of temperature on the hardness in Tab. 1 is placed. In Tab. 2 findings of the strength on expansion are presented. In Tab. 3 findings of the durability and friction coefficient are presented. In Tab. 4 test results of the coefficient of thermal expansion are placed.

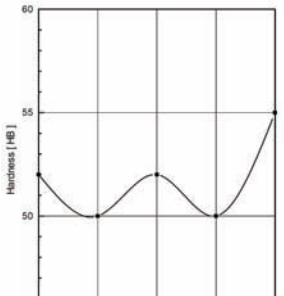

Fig. 1. Hardness of the AK9 silumin across diameter, pouring temperature 953K

Tab. 1. Influence of temperature casting of composite on the basis of AK9 alloy of content of 4 % FeS with the grain coarseness of 300 - 400 μm on distribution of the hardness in section of cross sample

No.	Casting temperature	Hardness
	[K]	[HB]
1	953	53 - 55
2	1003	57 - 59
3	1053	60
4	1063	62 - 72
5	1073	62 - 69
6	1083	48 - 60
7	1093	50 - 59
8	1103	61 - 52
9	1153	56 - 63
10	1203	74 - 84

Tab. 2. Test results static strength on extension

Sample Diameter	Sample strength [MPa] FeS grain coarseness [μm] 56 - 100	100 - 200	200 - 400
mm	MPa	MPa	MPa
10	80 - 90	120 - 130	90 - 100
30	60 - 80		

Tab. 3. Test results durability and friction coefficient base materials (AK9 and AK11) and composites, at load of 1000N and press of 299MPa

No.	Kind of alloy and case	FeS Content	Grain Coarseness	Working time to wear	Friction coefficient
			μm	s	
1	AK9			168	0.060
2	AK9 After HT			480	0.050
3	AK9	6	300 - 400	2016	0.047
4	AK11			686	0.080
5	AK11 After OC			1435	0.060
6	AK11	4	200 - 400	2704	0.095
7	AK11 After HT	4	200 - 400	2548	0.060
8	AK11	6	56 - 100	1622	0.026
9	AK11 After HT	6	56 - 100	2912	0.025

Heat treatment (HT): supersaturate 793K/4 h and aging 453K/8h

Tab. 4 Test results coefficient of thermal expansion α during heating and cooling for investigated composite alloy in the area of 323 - 602K temperature

No.	Tested material	FeS Content	FeS Grain Coarseness	Coefficient $\alpha \cdot 10^6$ [K]$^{-1}$		Notes
		%	μm	373 [K]	573 [K]	
1	AK20	2	56 - 100	15.96 17.79	18.46 18.84	Heating Cooling
2	AK20	6	56 - 100	16.28 20.28	19.85 20.28	Heating Cooling
3	AK20	6	200 - 400	16.31 20.59	19.88 20.47	Heating Cooling
4	AK20 After HT I	6	200 - 400	16.15 17.88	18.74 19.13	Heating Cooling
5	AK20 After HT II	6	200 - 400	15.96 16.34	19.13 19.23	Heating Cooling
6	AK12			20.26 20.92	21.84 22.17	Heating Cooling
7	AK12 After HT II	6	200 - 400	16.05 17.82	18.68 19.08	Heating Cooling

Heat treatment (HT) I: supersaturate and aging
Heat treatment (HT) II: supersaturate and aging and warming in the temperature of 489K

5. Test results of hysteresis

Test results of linear thermal expansion of materials on pistons represent on after-mentioned figures. Fig. 2 represents course coefficient of thermal expansion of standard material piston in the function temperature. The difference coefficient of thermal expansion between heating and cooling for temperature of 473K is 2.62 1E-6/K. Fig. 3 represents course of the coefficient of thermal expansion of standard material piston in function temperature. The difference of the α coefficient between heating and cooling for the temperature of 473K is 2.62 1E-6/K. Fig. 4

represents course relative elongation for standard material piston in function temperature. Fig. 5 represents course relative extension for standard material piston in time function. Fig. 6 represents course relative extension for standard material piston in time function for first-stage of the thermal treatment. Fig. 7 represents course relative extension for composite material of the piston in function temperature. Differences of the relative elongation are minimum ones. The maximum difference for temperature of 293K is 0.01%. Fig. 8 represents course of the relative extension for composite material piston in function temperature. Differences of the relative extension are minimum ones. The maximum difference for temperature of 293K is 0.01%. Fig. 9 represents course coefficient of thermal expansion of composite material piston in function temperature. The maximum difference coefficient of thermal expansion for temperature of 493K is 0.12 1E-6/K.

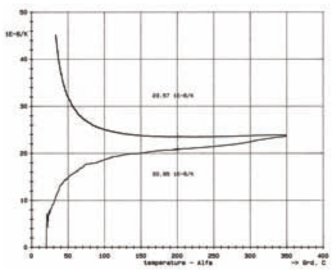

Fig. 2. Course coefficient of thermal expansion of linear of standard material piston in function temperature

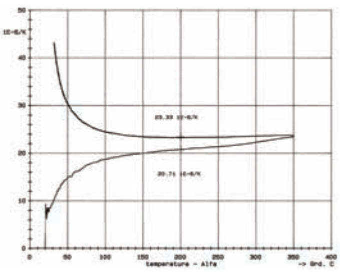

Fig. 3. Course coefficient of thermal expansion of linear of standard material piston in function temperature

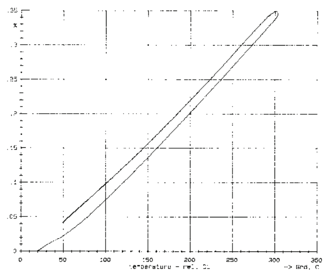

Fig. 4. Course relative extension for standard material piston in function of temperature

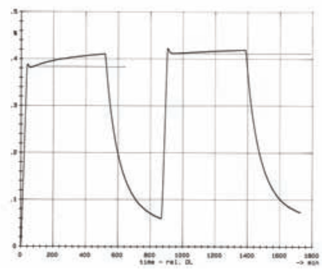

Fig. 5. Course relative extension for standard material piston in time function

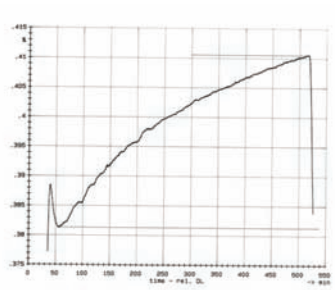

Fig. 6. Course relative extension for standard material piston in time function for first-stage of HT

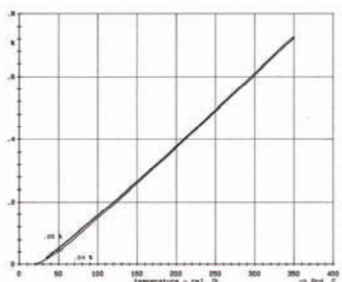

Fig. 7. Course relative extension for composite material piston in function temperature

5. Conclusions

1. Beneficial effects of composite materials obtained as result of input additives to base alloy will let on the obtainment of effects ecological and exploitive in form of decreasing fuel consumption and entire emission of combustion gases and toxic components in combustion gases.
2. Favourable tribology properties were received in laboratory-research without worsening of other parameters of composite materials.
3. Performed investigations demonstrated that dimension stability of composite materials in reference to some variants had been better than base materials. This gives chances to obtainment better results in reference to the oil consumption, blow-throughs of combustion

gases, noise and vibration, and consequently to decreasing emission of hydrocarbons, also as result of better programming of working clearances between the piston and the cylinder.

4. Investigated composite materials characterized greater durability than base materials (from 4 to 10 times).
5. Strength on expansion of composites is relative to diameter cast and FeS grain coarseness.
6. The hardness of composite materials was dependent both from temperature of casting, as and from the content and the granularity FeS grain coarseness.
7. Test results of laboratory showed that existed possibility of the elaboration of composite material on pistons of combustion engines which will let on fulfilment of requirements of both functional and ecological.

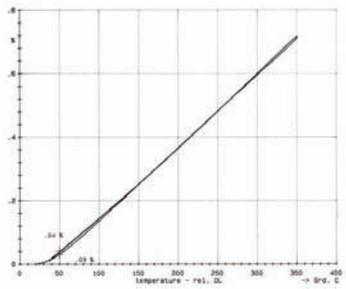

Fig. 8. Course relative extension for composite material piston in function temperature

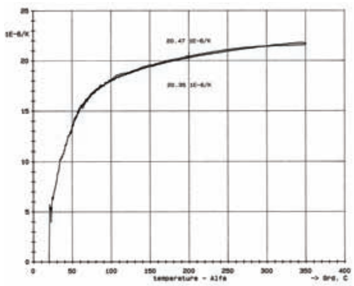

Fig. 9. Course coefficient of thermal expansion of linear of composite material piston in function temperature

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