COMPOSITE ALLOY FOR IC ENGINE PISTONS

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Abstract

Aluminum is the most popular matrix for the metal matrix composites The Al alloys are attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high damping capacity. The characteristics of metal matrix composite materials are determined by their microstructure and internal interfaces, which are affected by their production and thermal mechanical treatment. Investigations to improve the combustion piston engines are leading to improve the working process performance by increase of its parameters, especially the average temperature of the thermodynamic cycle.

New piston consists of two parts manufactured of standard and composite materials are presented in the paper. Composite alloy has chemical composition of short fibre with Al_2O_3 was following, in the mass percentage: 96% Al_2O_3, 4% SiO_2. As the binder the colloidal silica was used in quantity 5%. The volume of fibres in the insert was 22±2% by volume. Bending strength of the insert was 0.5 MPa. Temperature and stresses distribution in standard piston and different versions of composite pistons are introduced in the paper. The paper presents the resistance of investigated materials on thermal shocks. Experimental verification of manufactured composite pistons in the engine proved the larger exhaust temperature for about 20-70°C, in comparison with the engine with standard pistons (that gives the greater effectiveness of turbo charging application), proved the lowering of a individual volume of gases blow-bys to the crankcase, the lowering of noise level, larger resistance on thermal loads

Keywords: *combustion engines, engine pistons, composite alloys, thermal analysis*

1. Introduction

A composite is a material made with several different constituents intimately bonded. Aluminum is the most popular matrix for the metal matrix composites The Al alloys are attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high damping capacity. Al alloys offer a large variety of mechanical properties depending on the chemical composition of the Al-matrix. They are usually reinforced by Al2O3, SiC, C, SiO2, B, BN, B4C, AlN. The aluminum matrices are in general Al-Si, Al-Cu. Metal composite materials have found application in many areas of daily life for quite some time. Often it is not realized that the application makes use of composite materials. These materials are produced *in situ* from the conventional production and processing of metals. Materials like cast iron with graphite or steel with high carbide content, as well as tungsten carbides, consisting of carbides and metallic binders, also belong to this group of composite materials. Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications. From this potential, metal matrix composites fulfil all the desired conceptions of the designer. This material group becomes interesting for use as constructional and functional materials, if the property profile of conventional materials either does not reach the increased standards of specific demands, or is the solution of the problem. However, the technology of MMCs is in competition with other modern material technologies, for example powder metallurgy.

The characteristics of metal matrix composite materials are determined by their microstructure and internal interfaces, which are affected by their production and thermal mechanical treatment. The microstructure covers the structure of the matrix and the reinforced phase. The chemical composition, grain and/or sub-grain size, texture, precipitation behaviour and lattice defects are of importance to the matrix. The second phase is characterised by its volume percentage, its kind, size, distribution and orientation. Local varying internal tension due to the different thermal expansion behaviour of the two phases is an additional influencing factor.

The thermal expansion coefficient is determined by the thermal treatment of the composite materials, which results from the production and the application. Essentially the internal strain exercises influence. With the monolithic materials the expansion coefficient increases with increasing temperature. The same applies to the composite material with a fibres oriented perpendicular to the level of the planar-isotropic distribution of the fibres (90°). Since the fibres there are not optimally effective a lower reduction in the expansion develops. With increasing temperature the difference between the reinforced and the nonreinforced matrixes becomes less. In the case of an orientation parallel to the fibre level (0°) stronger reduction effect results, this increases with increasing temperature.

2. Combustion engine pistons

Investigations to improve the combustion piston engines are leading to improve the working process performance by increase of its parameters, especially the average temperature of the thermodynamic cycle. This increases the demands on the elements surrounding the engine combustion chamber, mostly pistons, which already belong to the much stressed structures. Another requirement of environmental standards posed on internal combustion engines used to power automobiles is the low level of noise emitted to the environment.

The noise decrease can occur through the decrease of clearances mainly in the crank-piston system, particularly between piston and cylinder, which are its principal source. These expectations cannot be gratified without an essential progress in perfecting of the engine parts design and the quality of materials applied in their manufacture. Such solution is the application of new composite materials.

The composite materials presently determine the most promising and developing itself group of materials to the piston applications of internal-combustion engines.

3. Experimental

The new piston consists of two parts manufactured of standard and composite materials. Tab. 1 contains the basic parameters of investigated materials and for the comparison the parameters of the standard material.

Chemical composition of short fibre with Al2O3 was following, in the mass percentage: 96% Al2O3, 4% SiO2.

As the binder the colloidal silica was used in quantity 5%. The volume of fibres in the insert was 22±2% by volume. Bending strength of the insert was 0.5 MPa.

The thermal conductivity in direction parallel to the fibres: 0.45 for 300°C, 0.42 for 500°C, 0.39 for 700°C and 0.38 W/mK for 900°C. In perpendicular direction eligibly: 0.17, 0.18, 0.18 and 0.18 W/mK.

The ceramic inserts served to the reinforcement of composite piston upper parts (near the crown zone).

Figure 1 presents the performs of two kinds, and Fig. 2 presents the schema of pistons with inserts.

Tab. 1. Parameters of materials on pistons

Parameter	Composite AK12/22% $Al._2O_3$	Standard Silumin Ak12
Density, g/cm^3	2.711	2.721
Electric conductivity, MS/m	11.5-11.8	18.0-19.0
Thermal conductivity, W/m·K	90.5	150.5
Thermal expansion coefficient, x10^{-6}/·K	18.51	21.86
Young modulus, GPa	90-94	73-75
Tensile strength, MPa	330-345	310-320
Hardness, HB	175-190	120-130
Yield point [N/m^2]·10^8	2.89	2.25
Specific heat [J/kg·K]	1010	960
Poisson number [-]	0.22	0.28

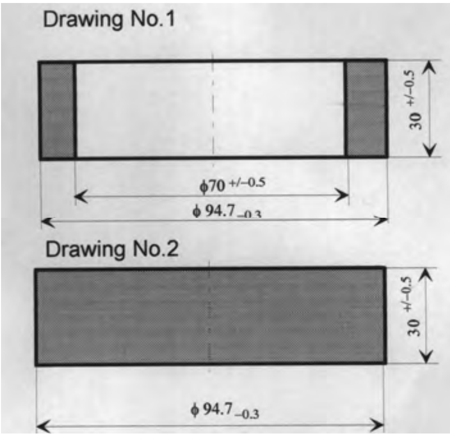

Fig. 1. Drawings of the inserts for local pistons reinforcements

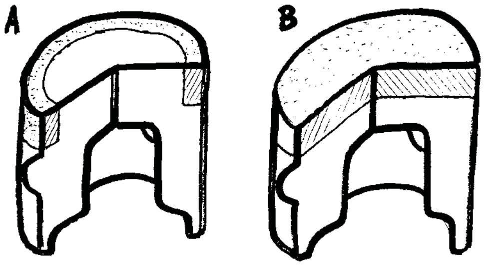

Fig. 2. Schemas of a installed local piston reinforcements with composite ceramic inserts of two types

Figure 3 presents the example of composite piston pressed in liquid state, reinforced locally with composite.

Researched samples had cube shape with the length of the edges equal to 10 mm. Samples were applied to variable thermal cycles loads according to a special program.

The specimens from the materials with properties given in Tab. 1 were assembled on the thin, susceptible to deformations tapped tubes, within which the thermocouples Ni-Cr-Ni were mounted.

Standard piston (A2) and different versions of composite pistons C1, C2, C3, C4 are presented in Fig. 4.

Fig. 3. Composite piston locally reinforced

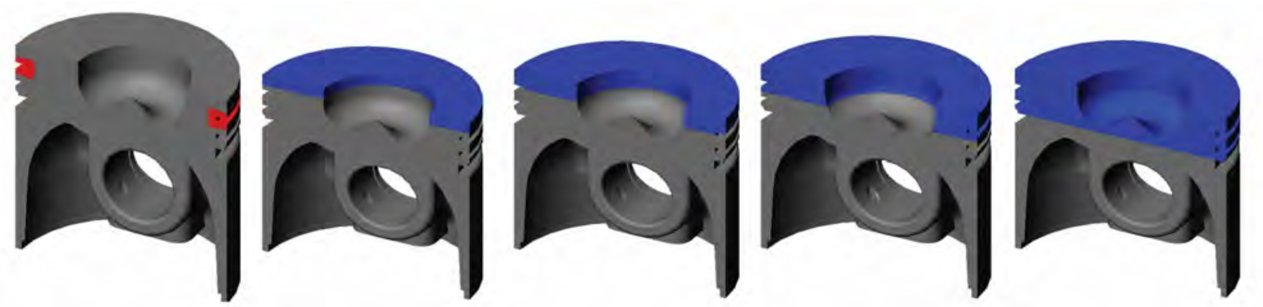

Fig.4. Five versions of engine pistons, on the left: standard piston (A2), the next: composite pistons (C1, C2, C3, C4)

Temperature distribution in standard piston A2 and different versions of composite pistons C1, C2, C3, C4 are presented in Fig. 5.

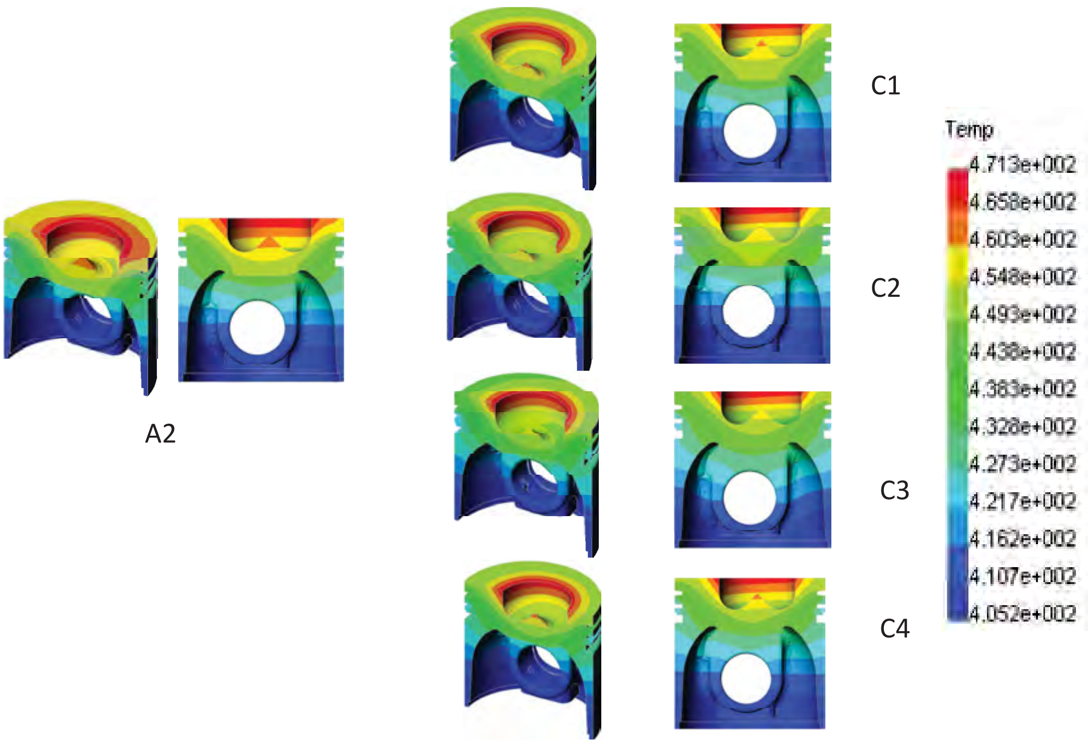

Fig. 5. Temperature distribution in standard piston A2 and different versions of composite pistons C1, C2, C3, C4

Stresses distribution in standard piston A2 and different versions of composite pistons C1, C2, C3, C4 are presented in Fig. 6.

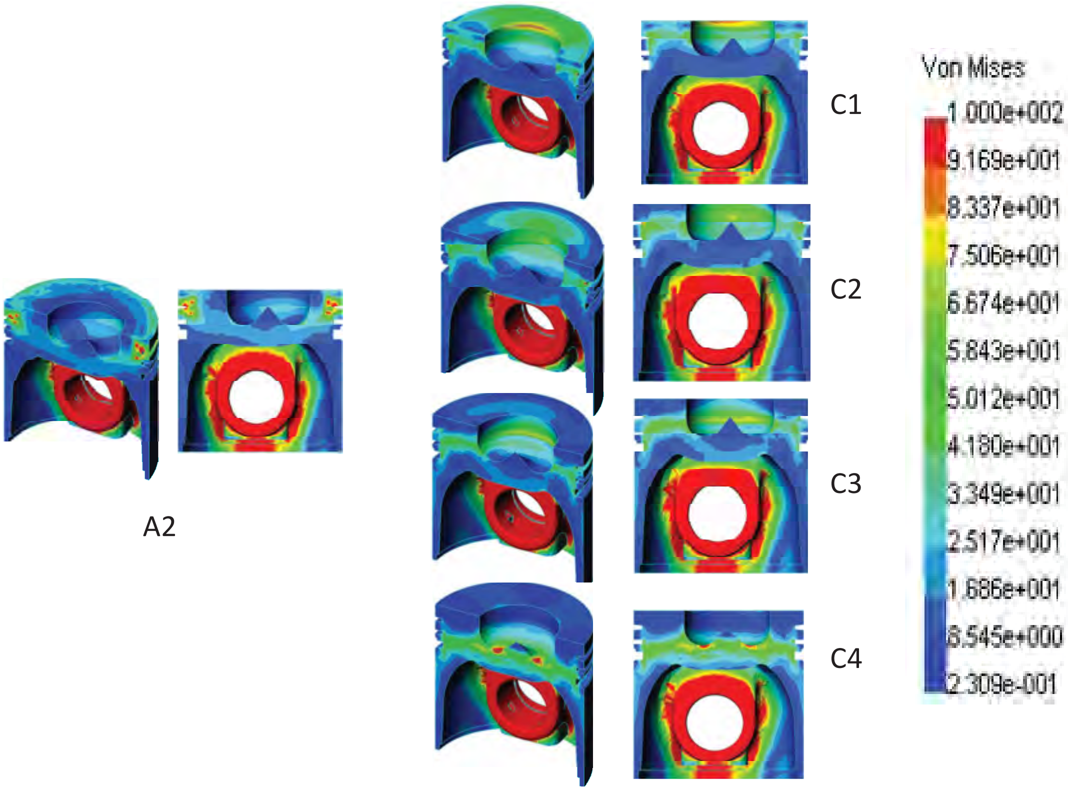

Fig. 6. Stresses distribution in standard piston A2 and different version of composite piston C1, C2, C3, C4

The changes of temperature within each specimen were recorded with the help of the acquisition system on the base of the PC computer. As a result of the measurements, were specified initially the guidelines of design changes going in the direction of the number of thermocouples increase in the event of a measuring chamber full load, the sealing of the heating chamber, in order to equal the measuring error based on the temperature deviation from the average temperature to the value of ±15°C.

4. Results and Discussion

The results of investigations of the two materials thermal shocks are presented on Fig. 7.

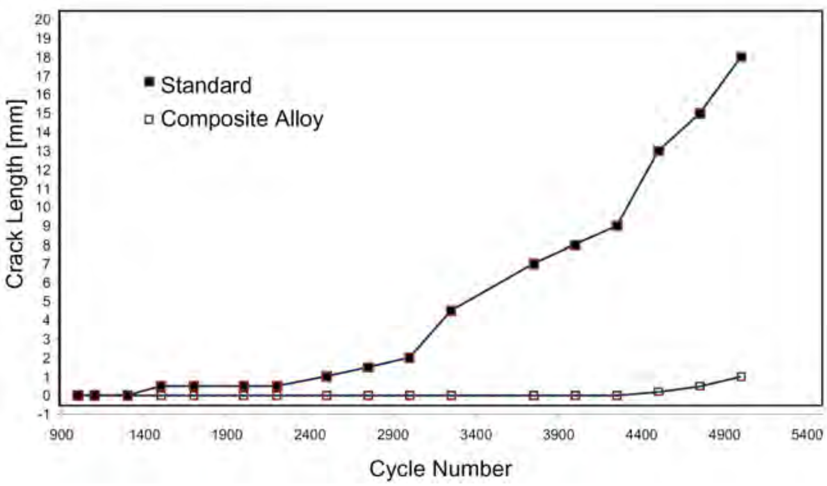

Fig. 7. The resistance of investigated materials on thermal shocks

The microstructure of the two materials presents Fig. 8 and 9.

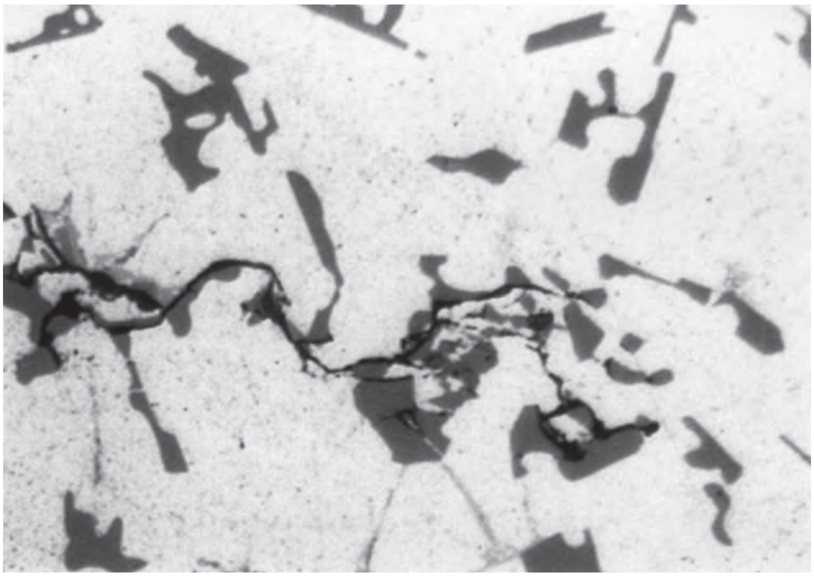

Fig. 8. The microstructure of standard alloy AK 12 after investigations of the material resistance on thermal shocks. Magn. 500x

5. Conclusion

Experimental verification of manufactured composite pistons in the engine proved the larger exhaust temperature for about 20-70°C, in comparison with the engine with standard pistons (that gives the greater effectiveness of turbo charging application), proved the lowering of a individual volume of gases blow-bys to the crankcase, the lowering of noise level, larger resistance on thermal loads.

The positive effect of composite pistons usage is the lowering level of the solid particles emission and the combustible matter in exhaust as a result of the rise of a working process average temperature.

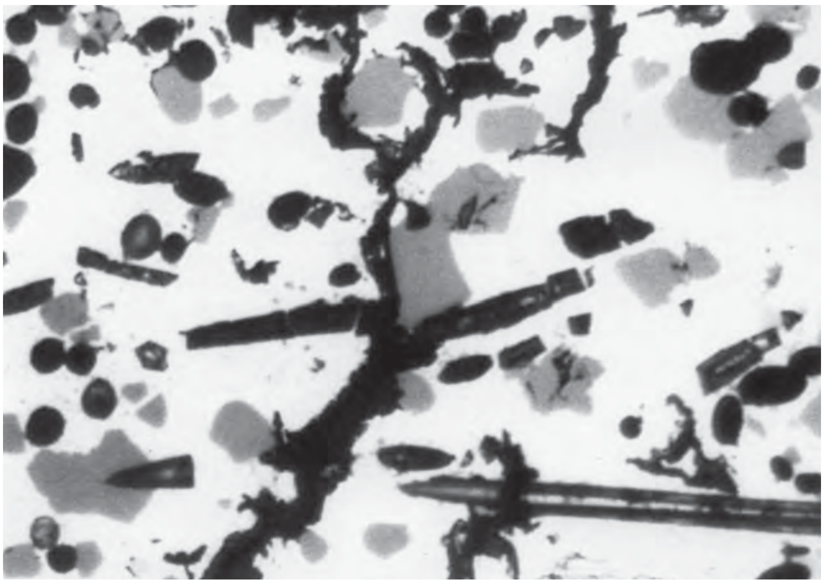

Fig. 9. The microstructure of composite alloy after investigations of the material resistance on thermal shocks. Magn.500x

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