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RESEARCHES OF NOVEL COMPOSITE PISTONS FOR COMBUSTION ENGINES

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Abstract

Novel composite material was worked out based on experiences and researches realized in the Institute of Aviation, the Lodz Technical University and PZL WOLA Company. Actually applied silumins on the pistons secure them high-quality for durability, low Rm and HB values at increased temperature, high hysteresis of the coefficient α during heating and cooling, high clearance between the piston and the cylinder, increased oil consumption, blow-through and obtainment relatively low-power engine. Thereby works concerning elaborations of novel composite material based on the standard silumin with better from at present applied on the piston properties are presented. Novel composite material on the pistons has mechanical properties in the ambient temperature: Rm ≥ 400 MPa; $Rp_{0.2}$ ≥ 330 MPa; A5 ≥ 3.5%; HB ≥ 130 and in the temperature 250°C: Rm ≥ 320 MPa; $Rp_{0.2}$ ≥ 240 MPa; A5 ≥ 5%; HB ≥ 90. Metallographic and ATD researches, the researches of the hardness, the researches of Rm, $Rp_{0.2}$ and A_5, the researches of the coefficient of thermal expansion "α", engine researches were performed. Curves ATD and the microstructure the alloy are presented. Test results of the S12-U diesel engine engine are introduced too.

Keywords: *combustion engines, engine pistons, composite alloy, thermal expansion, hysteresis, engine test*

1. Introduction

The mass modern military vehicles is more and more greater, what connects with the usage of the optional extras improving the efficiency of the work, an usage covers, an usage of the additional reactive armour and screens against cumulative. Besides contemporary military vehicles must have greater maneuvering opportunities on the battlefield. These two above mentioned factors extort the necessity increasing of the power of combustion engines applied in military vehicles, so usages of high-load engines both mechanically, as and thermally. The most loaded elements of combustion engines is the piston, which has to meet growing functional and durability requirements. The elaboration of the pistons from the novel of generation of composite materials with high strength properties in condition of high temperature and functional consisting mainly on minimizing of the difference in the thermal expansion during heating and piston cooling, increases the resistance of the design of the piston on fatigue damages both mechanical, as and thermal and increases the resistance of the piston on thermal shocks [3, 4, 5, 6, 9].

2. Elaboration of composite material

Actually applied silumins on the pistons secure them high-quality for durability, low Rm and HB values at increased temperature, high hysteresis of the coefficient α during heating and cooling, high clearance between the piston and the cylinder, increased oil consumption, blow-through and obtainment relatively low-power engine. Thereby works concerning elaborations of novel composite material based on the standard silumin with better from at present applied on the piston properties were undertaken. Novel composite material was worked out based on experiences and researches realized in the Institute of Aviation, the Lodz Technical University and

PZL WOLA Company [1, 2, 4, 7, 8].

It was established that novel composite material on the pistons should have following mechanical properties in the ambient temperature: Rm ≥ 400 MPa; $Rp_{0.2}$ ≥ 330 MPa; A5 ≥ 3.5%; HB ≥ 130 and in the temperature 250°C: Rm ≥ 320 MPa; $Rp_{0.2}$ ≥ 240 MPa; A5 ≥ 5%; HB ≥ 90.

A next assumption was the obtainment of the small hysteresis of the coefficient α of the thermal expansion within the range temperatures 50-300°C.

A following assumption was obtainment of the pistons with casting technology t in the metal mould that is eliminations of the labour-consuming and expensive forging.

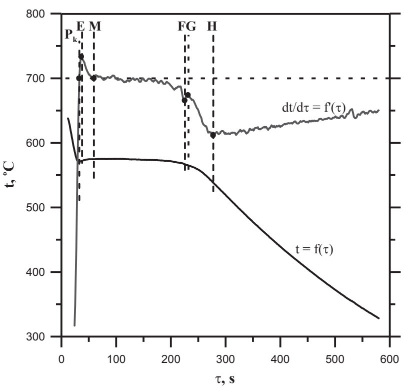
Carried out initially the researches showed that one could obtain above mentioned higher properties introducing to standard silumins chemical elements already applied, but added in the greater quantity, i.e. nickel and copper and till now out-of-use in piston-silumins, i.e. chromium, vanadium, molybdenum and tungsten. These elements create high-melting, small-dispersion intermetallic phases, which should assure high useful properties. Formed multiple small-dispersion intermetallic phases grant to piston-silumins of the feature of composite material, from here was accepted the name applied in the further part of the work as composite (composite silumin) material [10, 11, 12].

One examined the influence of the chemical constitution on the crystallization, the microstructure, mechanical properties, the coefficient α and parameters of the heat-treatment – solutioning and aging of composite silumins of the chemical constitution given in the Tab. 1.

Tab. 1. Chemical constitution investigated composite silumins

Chemical composition, % mas.									
Si	Cu	Mg	Ni	Fe	Mn	Cr	Mo	W	V
11.5-12.5	3.0-4.0	0.3-0.6	4.0-5.0	≤ 0.50	0.20-0.35	0.05-0.8	0.05-0.8	0.05-0.8	0.05-0.8

a)



Points	τ, s	t, °C
P_K	32	570
E	36	572
M	59	575
F	225	567
G	231	565
H	277	539

b)

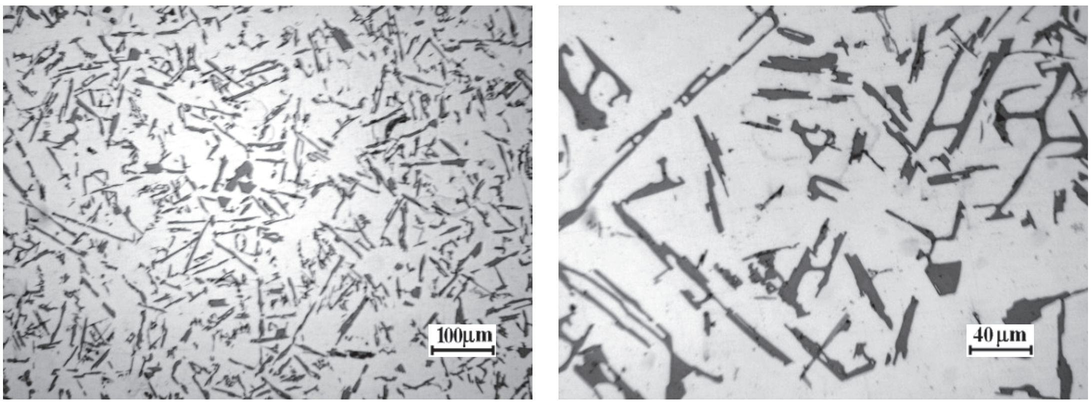


Fig. 1 (a, b). ATD curves – (a) silumin AlSi12 and its mikrostrukture – (b). Phases: eutectic α+β, Mg_2Si

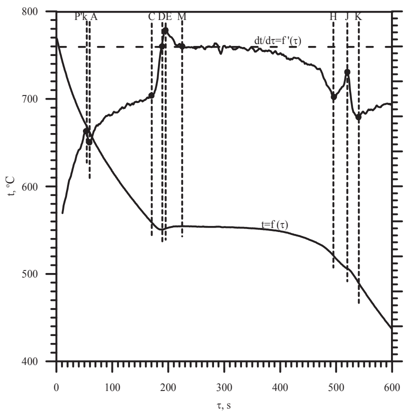
Additives Cr, Mo, In and V can be applied synergetic or in different combinations, depending on requirements of the property of the piston [13, 14, 15, 16]

3. Test results

Metallographic and ATD researches, the researches of the hardness, the researches of Rm, $Rp_{0.2}$ and A_5, the researches of the coefficient of thermal expansion "α", engine researches were performed. ATD example test results and microstructures for the alloy in reference are are represented on Figs. 1a and 1b.

Curves ATD (a) and the microstructure (b) the alloy AlSi12Cu4Ni4Mg0.5CrMoWV of modified strontium is represented in Fig. 2 (a-b).

a)



Points	τ, s	t, °C
P_K	53	670
T	59	663
C	170	559
D	189	551
E	195	552
M	225	554
H	496	520
J	520	506
K	540	490

b)

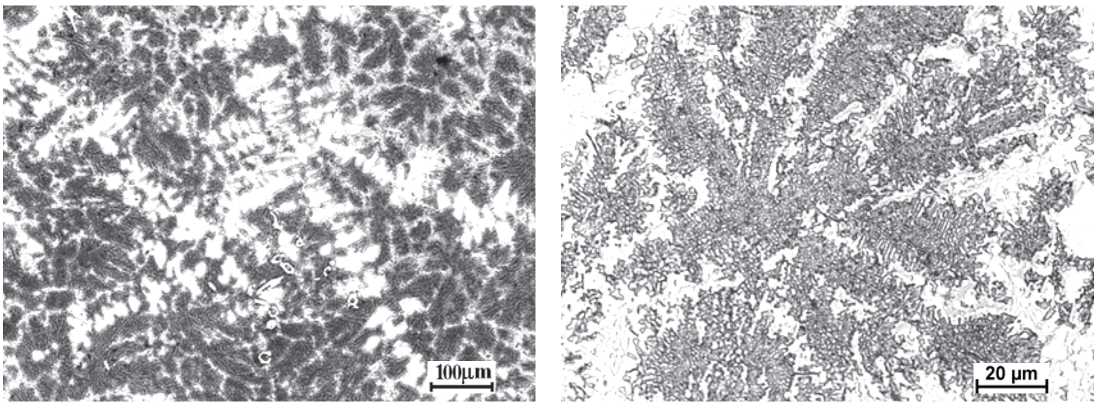
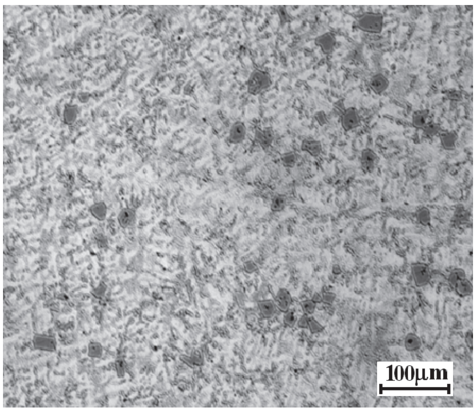


Fig. 2. (a b). ATD curves (a) AlSi12Cu4Ni4Mg0.5CrMoWV alloy modified strontium and its microstructure. Phases: β. eutectic α+β+AlSiNiCuMgCrMoWVTiFe, α+β+Al_3NiCu

The microstructure of the AlSi12Cu4Ni4Mg0.5CrMoWV silumin plus antimony after the solutioning in the temperature 540°C is shown on Fig. 3.



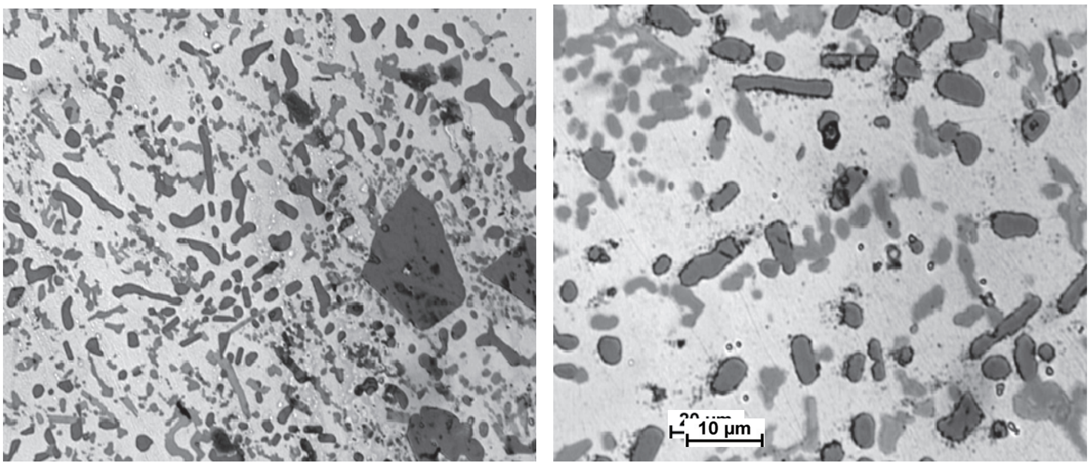


Fig. 3. Microstructure of the AlSi12Cu4Ni4Mg0.5CrMoWV silumin with additive of antimony after the solutioning at temperature 540°C.

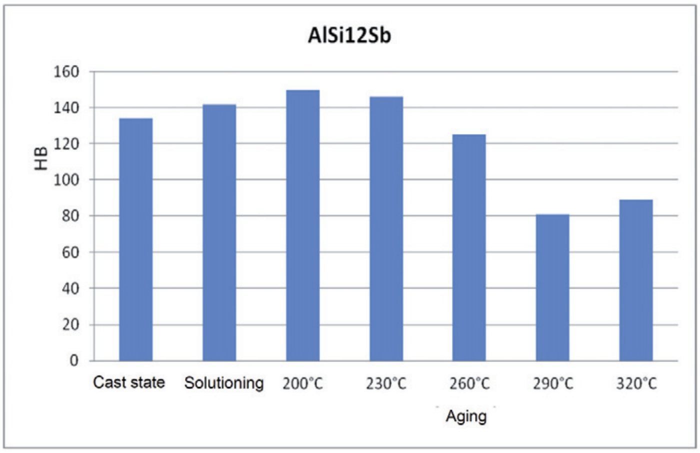


Fig. 4. Hardness of the AlSi12Cu4Ni4Mg0.5CrMoWV silumin with additive of antimony depending on its condition

The microstructure AlSi12Cu4Ni4Mg0.5CrMoWV of the silumin with additive of antimony after the solutioning at temperature 540°C is shown on Fig. 3.

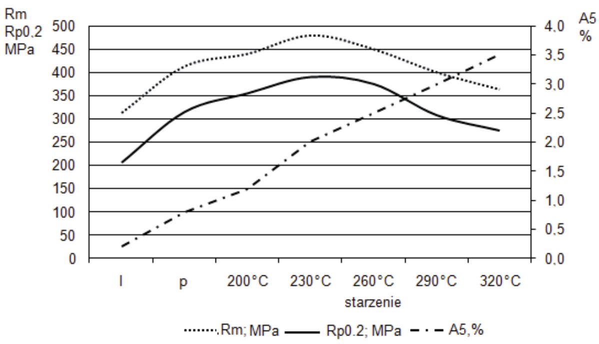


Fig. 5. Influence of heat treatment on Rm, $Rp_{0.2}$ and A_5 AlSi12Cu4Ni4Mg0.5CrMoWV alloy after modification with strontium

The microstructure AlSi12Cu4Ni4Mg0.5CrMoWV of the silumin with additive antimony after the solutioning at temperature 540°C is shown on Fig. 3.

Test results of engine introduced on Fig. 7-10 for the external characterization of the S12-U diesel engine. Fig. 8 introduces the course of the power in the function of RPM for engines with the standard and with novel composite alloy pistons.

For of the same piston alloys, Fig. 8 introduces the torque run vs. rotational speed, Fig. 9. – BSFC and Fig. 10 – HC emission level vs. rotational speed of the engine [17, 18, 4]

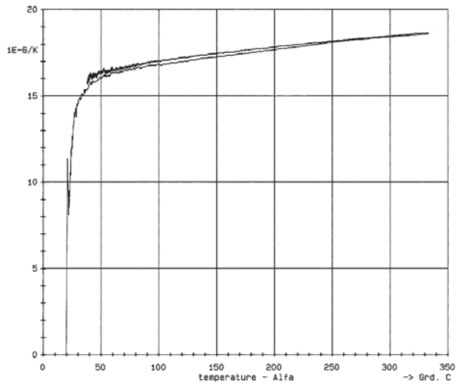


Fig. 6. Course of thermal expansion coefficient AlSi12Ni4Cu4Mg0.5CrMoWV silumin after heat treatment

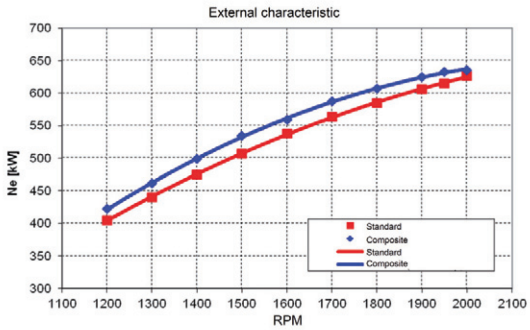


Fig. 7. Run power vs. RPM for external characteristics of the engine

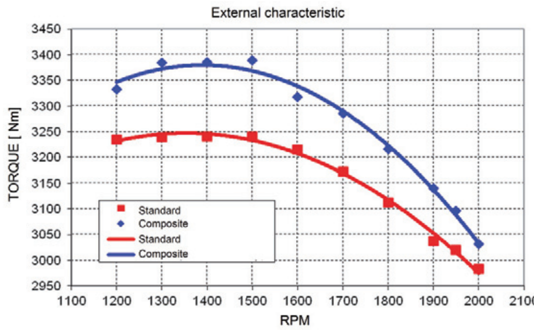


Fig. 8. Run torque vs. RPM for external characteristics of the engine

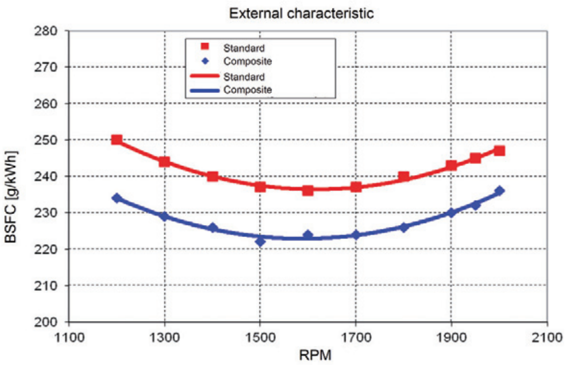


Fig. 9. Run BSFC vs. RPM for external characteristics of the engine

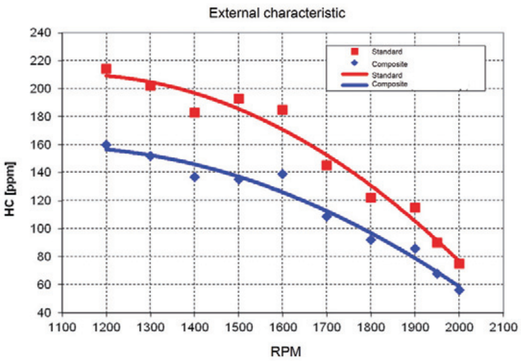


Fig. 10. Run HC concentration *vs. RPM for external characteristics of the engine*

4. Conclusions

- Eutectic crystallization in silumins modified antimony takes place at higher temperatures of about 4-5 °C in comparison to silumins modified strontium (553-524°C);
- Modified strontium silumins reduces the time from the start of crystallization of α phase to the beginning of crystallization of the eutectic α + β compared to silumins modified antimony;
- The addition of antimony, eutectic point moves towards greater concentration of silicon The microstructure silumins after aging is greater than the amount of silicon which is spherical and close to spherical, strontium modified test silumins causes more fragmentation β phase in the as-cast and after solutioning and aging;
- Silumins additives: Cr, Mo, W and V are characterized by high hardness within a range of 80-180 HB;
- Strengthening precipitation increases tensile strength Rm, yield strength and elongation A_5 $Rp_{0.2}$ compared to the shell, and contributes to the decline in HB;

- It is possible to obtain low hysteresis coefficient α of thermal expansion during heating and cooling silumins after aging at 230°C.
- Engine test performance for composite alloy are better than for standard alloy.

References

[1] Combustion Engines 2003, Vol. 10, No. 3-4, Warsaw 2003.

[2] Donomoto, T., *Ceramic Fiber Reinforced Piston for High Performance Diesel Engines,* SAE Paper 860162, 1986.

[3] Jankowska-Sieminska, B., Jankowski, A., Slawinski, Z., *Composite Alloy for IC Engine Pistons,* Journal of KONES Powertrain and Transport, Vol. 17, No. 2, pp. 159-166, Warsaw2010.

[4] Jankowski, A., et al., *Elaboration of the Modern Technology of Composite Materials of the Novel Generation on the Pistons of Combustion Engines to Military Applications,* Report of the development project No. O R00 0052 05, Institute of Aviation, No. 3.45.250, 2011.

[5] Jankowski, A., *Heat Transfer in Combustion Chamber of Piston Engines*, Journal of KONES Powertrain and Transport, Vol. 17, No. 1, pp. 187-198, Warsaw 2010.

[6] Jankowski, A., Jankowska, B, Slawinski, Z., *The Resistance on Thermal Shocks of Combustion Engine Pistons*, FISITA Transactions, London 2007.

[7] Jankowski, A., *Laser Research of Fuel Atomization and Combustion Processes in the Aspect of Exhaust Gases Emission,* Journal of KONES Powertrain and Transport, Vol. 15, No. 1, pp. 119-126, Warsaw 2008.

[8] Jankowski, A., *Laser Research of Fuel Atomization and Combustion Processes in the Aspect of Exhaust Gases Emission,* Journal of KONES Powertrain and Transport, Vol. 15, No. 1, pp. 119-126, Warsaw 2008.

[9] Jankowski, A., Pietrowski, S., Sieminska, B., Szymczak, T., *High-quality silumin on pistons of combustion engines*, Journal of KONES Internal Combustion Engines, Vol. 16, No. 4, pp. 563-573, Warsaw 2009.

[10] Jankowski, A., Pietrowski, S., Sieminska, B., Szymczak, T., *High-Quality Silumin on Pistons of Combustion Engines,* Journal of KONES Powertrain and Transport, Vol. 16, No. 4, pp. 563-573, Warsaw 2009.

[11] Jankowski, A., Sandel, A., *Exhaust Emission Reduction Problems of Internal Combustion Engines Fueled With Biofuels*, Journal of KONES Internal Combustion Engines 2003, Vol. 10, No. 3-4, Warsaw 2003.

[12] Jankowski, A., Sandel, A., *Influence of Fuel Quality on Mixture Preparation and Exhaust Emissions from Diesel Engines with Common Rail System,* Journal of KONES Internal

[13] Jankowski, A., Sandel, A., Seczyk, J., Sieminska-Jankowska, B., *Some Problems of Improvement of Fuel Efficiency and Emissions in Internal Combustion Engines,* Journal of KONES Internal Combustion Engines 2002, Vol. 9, 3-4, pp. 333-356 Warsaw 2002.

[14] Jankowski, A., Sieminska, B., Slawinski, Z., *The Resistance on Thermal Shocks of Combustion Engine Pistons,* FISITA Transactions, London 2007.

[15] Jankowski, A., *Some Aspects of Heterogeneous Processes of the Combustion Including Two Phases*, Journal of KONES Internal Combustion Engines, Vol. 12, No. 1-2, pp. 121-134, Warsaw 2005.

[16] Jankowski, A., *Study of the influence of different factors on combustion processes (Part two),* Journal of KONES Internal Combustion Engines, Vol. 16, No. 3, s. 135-140, Warsaw 2009.

[17] Keribar, R., *An Investigation of Structural Effects of Fiber Matrix Reinforcement in Aluminum Diesel Pistons,* SAE Paper 900536, 1990.

[18] Kuroishi, M., Kawaguchi, A., Inagaki, M., Torii, H., *Computational Method of Piston Structure and Lubrication Using Flexible Multibody Dynamics Technique,* FISITA2006 Proc. F2006P359, Yokohama Japan 2006.