THERMOMECHANICAL FE ANALYSIS OF THE ENGINE PISTON MADE OF COMPOSITE MATERIAL WITH LOW HISTERESIS

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Abstract

The main purpose of the preliminary analyses presented in the paper was to compare the behaviour of the combustion engine piston made of different type of materials under thermal load. A thermomechanical FE analysis of the engine piston made of composite material was shown. A selected engine is installed in one of the popular polish tanks. The proposed new material is characterized by a low hysteresis – the differences of the coefficient of thermal expansion for heating and cooling are not significant. The results obtained for the piston made of a new material were compared with those for the current standard material. The piston was loaded by a temperature field inside it. Appropriate averaged thermal boundary conditions such as temperatures and heat fluxes were set on different surfaces of the FE model. FE analyses were carried out using MSC.Marc software. Development of the FE model was also presented. Geometrical CAD model of the piston was developed based on the actual engine piston, which was scanned using a 3D laser scanner. A cloud of points obtained from the scanner was processed and converted into a 3-dimensional solid model. FE model of a quarter part of the piston was developed for the preliminary analysis presented in the paper. 4-node tetrahedron finite elements were applied since there was no axial symmetry of the considered object. The temperature field inside the piston was determined and presented in the form of contour bands. Contours of displacement and stress in a radial direction were shown as well.

Keywords: *engine piston, composite piston, coefficient of thermal expansion, thermal analysis, FE analysis*

1. Introduction

A total weight of modern military vehicle has been still increased due to additional equipment, armours, shields etc. Moreover, today's military vehicles are supposed to be able to better manoeuvre on the battlefield. Therefore, increasing the power of internal combustion engines used to drive such vehicles is necessary.

The engine pistons are the most loaded elements of the internal combustion engine. They must satisfy the requirements concerning durability and functionality. Therefore, a new type of material with high strength properties at high temperatures is still searched. In addition, the new materials should be characterized by a low hysteresis – the differences of the coefficient of thermal expansion for heating and cooling are not supposed to be significant. It allows increasing the piston resistance to fatigue damage and thermal shock.

2. A research object

A piston of the S12U diesel engine was selected as a representative for the study. Such engines are installed in one of the popular polish tanks – PT-91 *Twardy*. The engine is a 12-cylinder engine. It is worth to mention that the V-configuration of the S12U engine is not fully symmetric. Its left and right row of cylinders is slightly different. The main and visible difference is related to the length of the blade connecting rod, which is shorter for the row with the master connecting rods and longer for the second row including the articulated connecting rods. Therefore, the compression ratios and - consequently - the power and the torque, are different. Selected technical data for the S12U engine is provided in Tab. 1. A view of the piston in shown in Fig. 1.

Tab. 1. Selected technical data for the S12U engine [4]

Parameter	Unit	Value
Nominal Engine Speed	[rpm]	2000
Bore	[mm]	150
Stroke	[mm]	180.0 [1)] 186.7 [2)]
Displacement	[ccm]	38,880
Power	[kW] [KM]	625 850
[1)] for the rows with master connecting rods [2)] for the rows with articulated connecting rods		

Fig. 1. A view of the piston of the S12U engine. Some markers used during a 3D laser scanning are visible

3. Development of a geometrical and a FE model

A geometrical model of the piston was developed based on geometry of the actual object, which was scanned using a three dimensional laser scanner. An obtained cloud of points was processed and converted into triangular surfaces (Fig. 2a). The outer surfaces of the piston had to be converted into the 3D solid geometrical model. A function of matching the cloud points to the corresponding solids, surfaces and interfaces was applied (Fig. 2b). Reading the respective properties of the geometrical objects allowed determining such parameters as the piston diameter, the diameter of the piston pin hole, dimensions of the piston ring grooves, etc. An ovalization of the piston skirt was not taken into consideration at this stage of analysis.

The next step was to develop the solid geometrical model according to the dimensions obtained from the laser scanning and the processed cloud of points. A final CAD model is presented in Fig. 3. In this model, a certain geometric simplification was assumed – including missed bends with a small radius on the edge of crown and lateral surface of the head of the piston.

Finally, the geometrical model was discretized into 4-node tetrahedron finite elements. Such elements had to be applied due to a complex shape of the piston and the lack of the axial symmetry. The size of finite elements was different in respective sections of the piston – larger elements were used for the piston crown and skirt, whereas the smaller ones were employed close to the oil channels. The total number of nodes and elements of the quarter piston FE model was equal to 36 824 and 190 600, respectively. Fig. 4 shows the FE discrete model of the piston.

a) b)

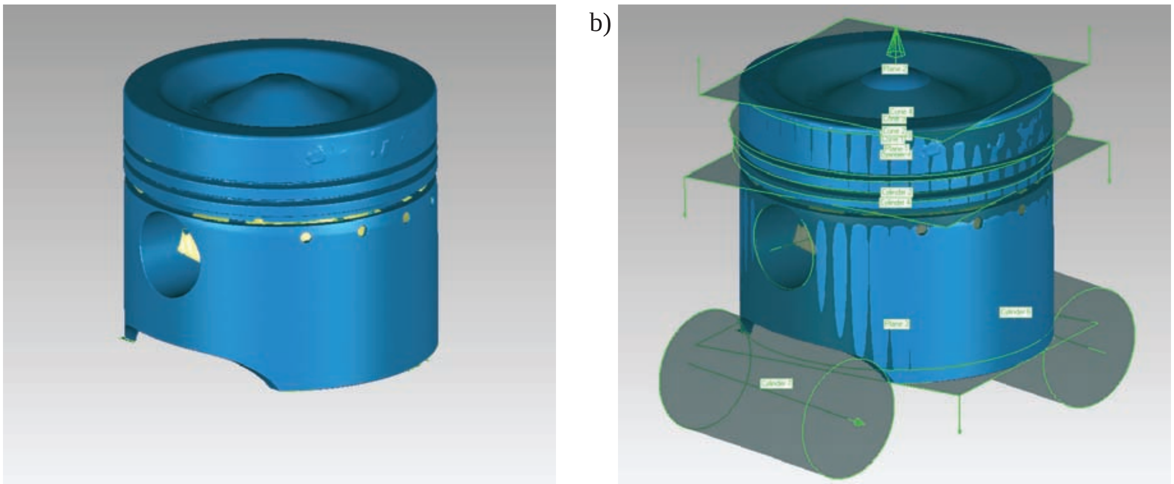

Fig. 2. A scan view of the piston (a) and selected geometrical objects matched to the cloud of points (b)

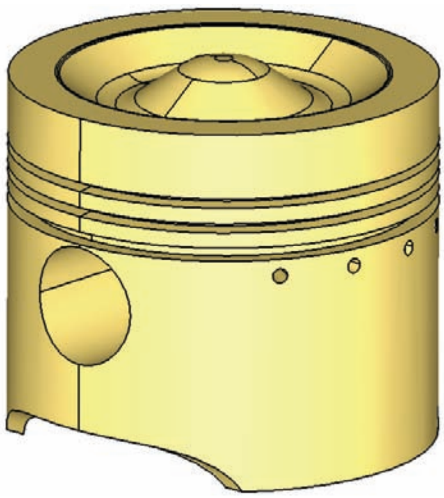

Fig. 3. A geometrical model of the piston

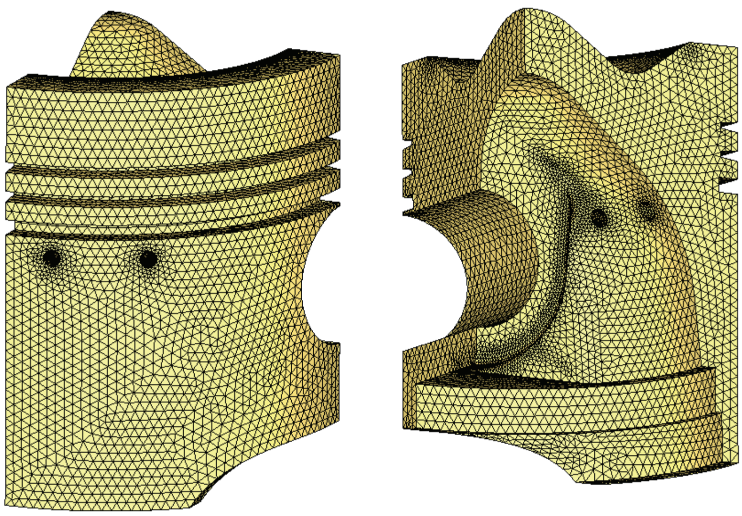

Fig. 4. FE model of the quarter of the piston

4. Material properties

The original pistons of the S12U engine are made of PA12 aluminum alloy. Its material properties, necessary from a thermomechanical analysis viewpoint, were provided in Tab. 2. Moreover, a new composite material with low hysteresis was also considered. Such material allows reducing the differences of the coefficient of thermal expansion for heating and cooling, and it improves a dimensional stability of the piston, consequently. Courses of changes of the coefficient of thermal expansion for both materials, the PA12 aluminum alloy and the new composite material, are depicted in Fig. 5.

Tab. 2. Material properties of the PA12 aluminum alloy [1]

Parameter	Values in SI units	Values in FEA units
Young's modulus, E	$69 \cdot 10^9$ [Pa]	69 000 [MPa]
Poisson's ratio, ν	0.33 [–]	0.33 [–]
Density, ρ	2710 [kg/m^3]	$2.71 \cdot 10^{-9}$ [Mg/mm^3]
Thermal conductivity, κ	171 [W·m^{-1}·K^{-1}]	171 [mW·mm^{-1}·K^{-1}]
Specific heat, c	890 [J·kg^{-1}·K^{-1}]	$890 \cdot 10^6$ [mJ·Mg^{-1}·K^{-1}]
Coefficient of thermal expansion, α	see Fig. 5	

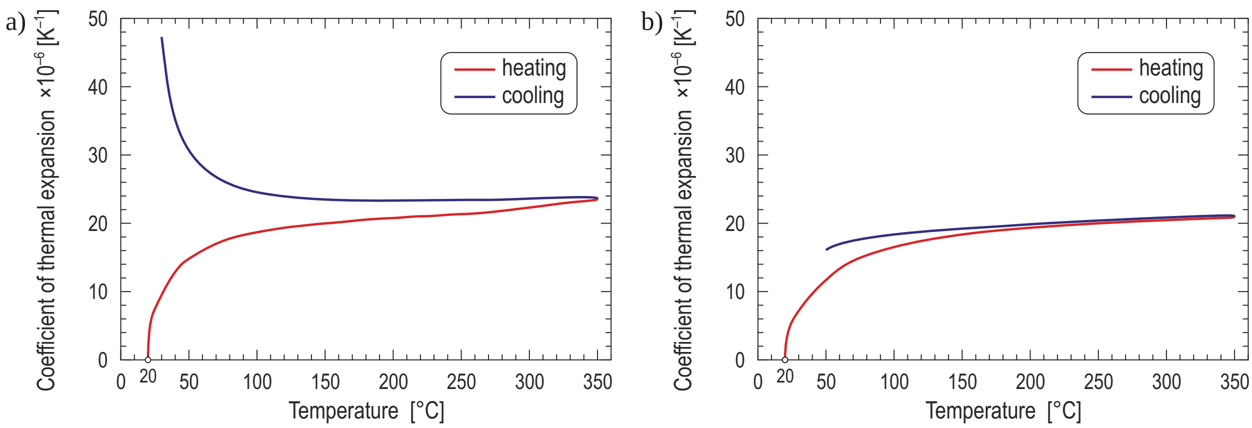

Fig. 5. Changes in coefficient of thermal expansion for the PA12 aluminum alloy (a) and the new composite material (b)

5. Thermal and mechanical boundary conditions

Thermal boundary conditions – the temperatures and the heat fluxes – were identified based on data provided in [1, 2]. However, for the oil channels and the piston pin hole, it was necessary to estimate the thermal boundary conditions on the basis of [3]. The adopted thermal boundary conditions are presented in Fig. 6.

Mechanical boundary conditions were related to the assumed symmetry in vertical planes. Hence, displacements in respective directions were fixed.

Figure 7 shows the temperature contour bands for the piston loaded according to the thermal boundary conditions from the Fig. 6.

6. Thermomechanical FE analysis

FE analyses were carried out using MSC.Marc software in two stages. In the first stage, the piston FE model was heated from the initial temperature of 50°C (323 K) to the maximum temperature resulted from the thermal boundary conditions (see Fig. 6). Afterwards, the final conditions – obtained for the last time step from the first stage – were set as the initial conditions to the second stage of the analysis. In this stage, the piston was cooled to the temperature of 50°C. The temperature range from 50°C to the maximum values was determined on the basis of changes in the coefficient of thermal expansion depicted in Fig. 5.

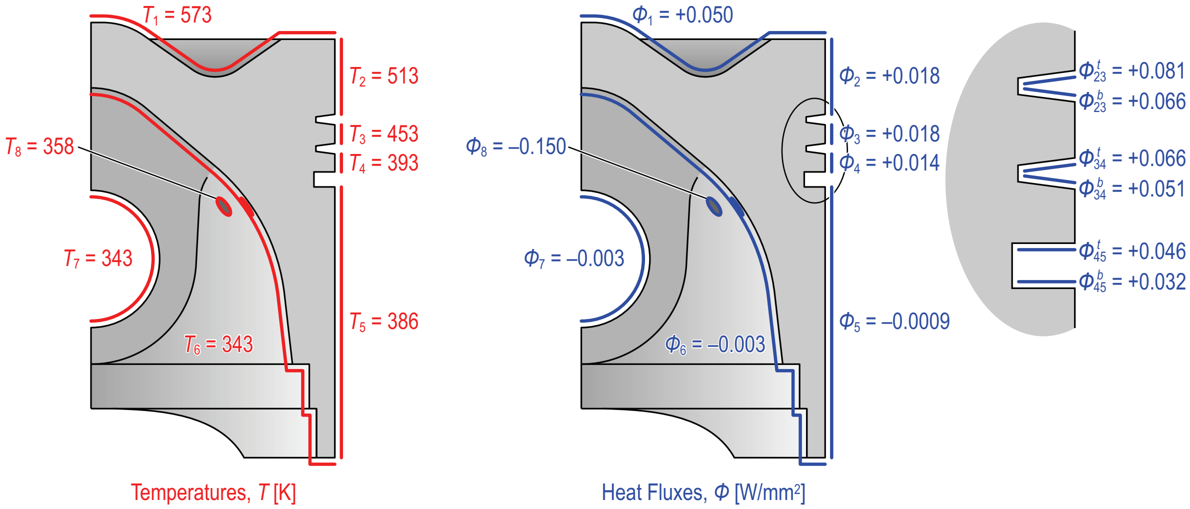

Fig. 6. Average values of the thermal boundary conditions for the S12U engine piston, according to [1–3]

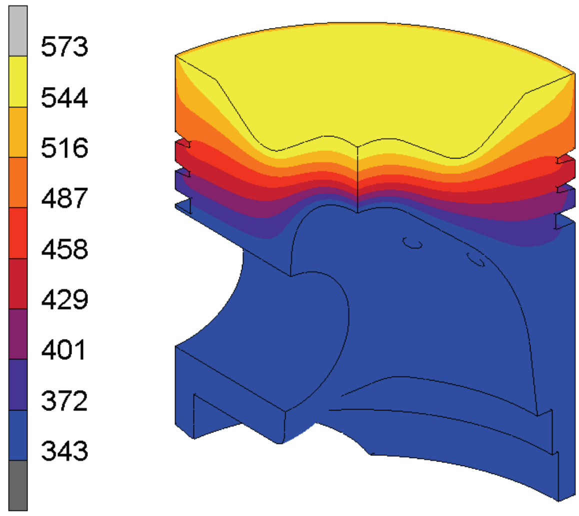

Fig. 7. The temperature contour bands [K] for the piston under thermal load

Selected results of the thermomechanical FE analysis in the form of contour band are presented in Fig. 8.

7. Conclusions

The preliminary thermomechanical FE analysis was presented in the paper. Its main purpose was to compare behaviour of the piston made of different type of materials under thermal load. The new composite material was primarily considered due to low hysteresis of the coefficient of thermal expansion for heating and cooling. The obtained results shows that the new composite piston has around 4 times lower radial displacements than the actual one. Therefore, a dimensional stability of the piston is strongly improved. The radial component of the stress is also much lower for the new composite piston as well.

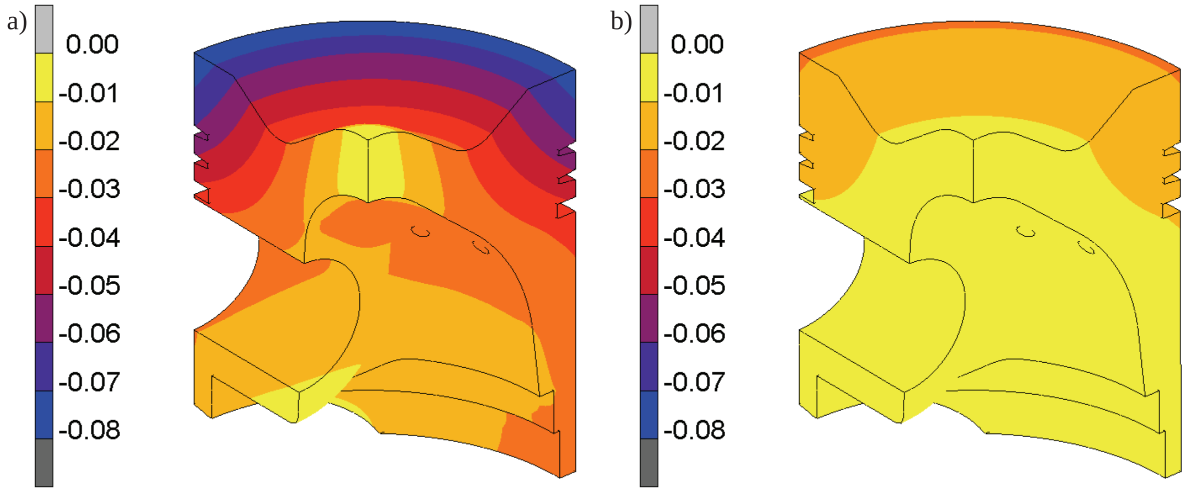

Fig. 8. Contour bands of the radial displacement [mm] for the piston made of standard material (a) and the new composite material (b) after cooling it to the temperature of 50°C

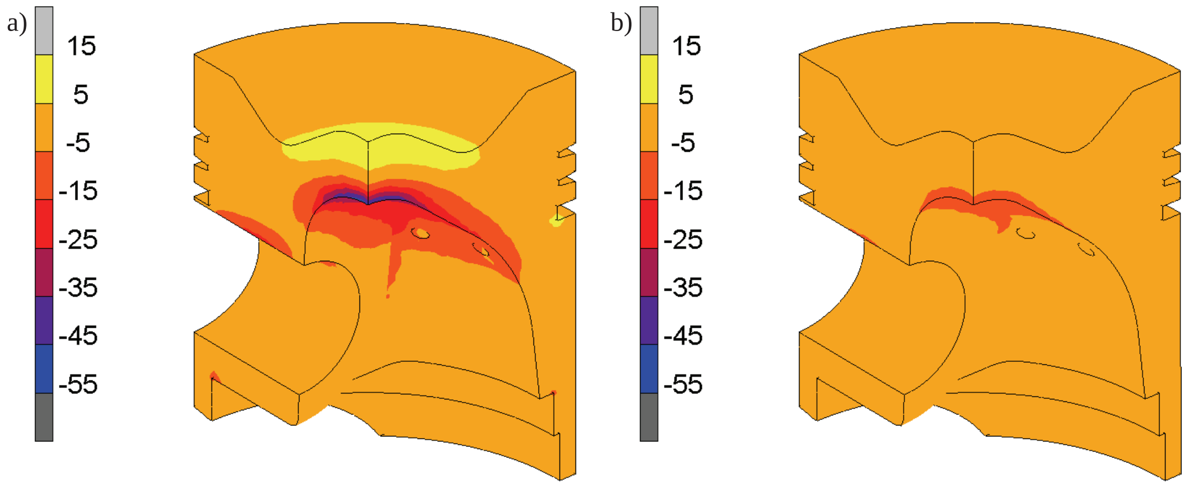

Fig. 9. Contour bands of the radial stress [MPa] for the piston made of standard material (a) and the new composite material (b) after cooling it to the temperature of 50°C

Acknowledgments

This research work is a part of Research Project No. O R00 0052 05 realized in the period 2008–2011, supported by Ministry of Science and Higher Education, Poland. This support is gratefully acknowledged.

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