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STRESS DISTRIBUTION FOR A PISTON WITH AN AL_2O_3 TOP LAYER DEPOSITED ON THE PISTON HEADS WHICH ABSORBS GAS PRESSURE

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Abstract: *Thin layer deposition is considered to be a method to bring internal combustion engines one step closer to the ideal engine inside which is taking place the adiabatic process. The piston is allowed to move on a single axis and is considered to be leaning in its bearings. The only force acting was considered to be due to flue gas pressure while the piston is at TDC. Thin layer deposition has been carried out on the piston and then analyzed with the finite element method using the ANSYS 13 software in order to determine the state of stress. There were designed CAD models of the piston and of the piston with top layer which were imported in ANSYS 13 software in order to carry out the analysis.*

Keywords: *thin layer, AL_2O_3, ICE piston, finite element analysis*

1. INTRODUCTION

The effects of the thin layers as thermal barrier have been studied in both naturally aspired and turbocharged Diesel engines in order to observe what improvement the deposited layer brings. The usual thickness of the deposited layer varies between 100 and 500 μm, consisting out of a intermediate layer with a thickness of 0.15mm and the ceramic layer with an 0.35mm thickness. [1-4]

The increased harshness of the obtained surface has a positive effect over the contact wear resistance thus the engine can operate with a higher compression ratio. One advantage the deposition brings is that after the thermal deposition the obtained layer no longer needs subsequent machining. [5]

Practical and mathematical studies over the thermal behavior of the piston with deposited top layer have shown that the temperature inside the base material is lower compared with the temperature the piston without deposited layer have. Also is concluded that the top layer may have a high potential to increase performance and reduce unwanted emissions. [6]

Another study is carried out by H. Mindivan and provides a review on the wear behavior of a layer of Al2O3 formed in situ in a matrix of a hypereutectic Al18Si with the purpose to improve the wear resistance of the piston. The study highlighted the effect it has the spraying distance and the characteristics of molten particles on wear behavior of the layer. The number of Al2O3 particles formed in situ by plasma deposition raises by increasing the spraying distance and decreases the speed and temperature of the molten particle. This led to improved hardness increased wear resistance. [7]

2. FINITE ELEMENT ANALYSES RESULTS

For the piston with an Al_2O_3 ceramic coating it was used the coordinate system presented in Fig. 1. – a. in order to present the stress distribution. Based on this coordinate system there are presented normal and tangential stress distributions. Fig.1. b) shows a section through the mesh network carried out in the analysis.

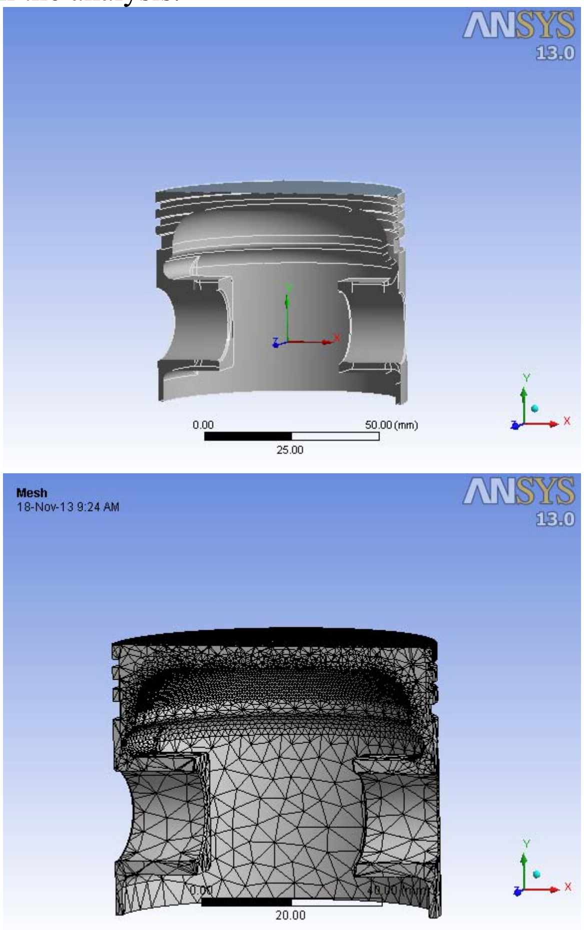

Fig.1. Section through CAD model used in the analysis of Al_2O_3 coated piston: a) coordinate system used in the analysis and b) mesh network

In the following there are presented the obtained results for the structural analysis made on the piston with an Al_2O_3 thin layer on the working surface.

Fig.2 presents the primary stress vector distribution in the base material of the piston. With red there is presented maximum primary stress vector (σ_1). The green color highlights medium primary stress vector (σ_2), and the blue color highlights minimum primary stress vector (σ_3). It can be noticed that the maximum primary stress value is found on the upper surface of the deposited layer near the edge area and on the inner surface of the piston head. In these regions the maximum primary stress produces the stretching of the material. On the central area of the upper surface of the deposited layer acts the minimum primary stress, thus resulting in the compression of the thin layer. Medium primary stress is found mainly at the interface of the layer with the base material.

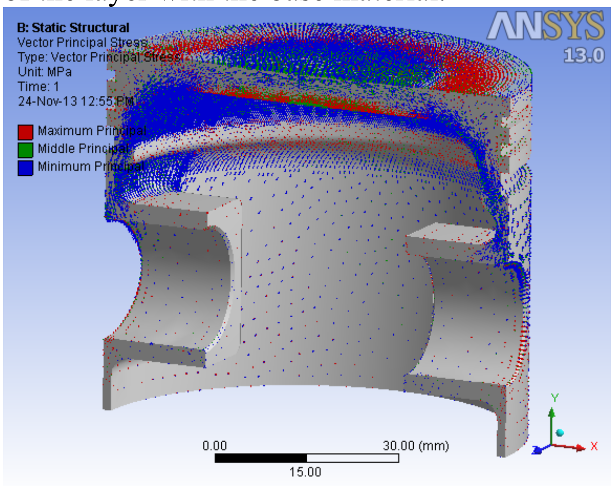

Fig.2. Primary stress distribution vectors in the piston's material with an Al_2O_3 top layer

Fig.3 shows the equivalent stress distribution for the piston with an Al_2O_3 top layer. The equivalent stress is calculated with equivalence theorem of Von Mises or the Von Mises yield criterion. The equivalent stress provides a correspondence between a complex state of stresses consisting of normal and tangential stresses and a normal stress which presents the same risk. In the case of the piston with an Al_2O_3 deposited on the piston head, the maximum equivalent stress occurs at the pin bosses and has a value of 68.17 MPa. In the layer area the maximum equivalent stress has a value of 53 MPa (Fig.3.a). In the base material in the piston head region is found maximum equivalent stress with a value of 45.5 MPa (Fig.3.b).

Normal and tangential stress determination was made according to the direction and characteristic plane of the pistons real load. Normal stress was determined for the x,y and z directions as shown in Fig.1.a) in coordinate system. Tangential stresses were expressed in planes parallel to the plane belonging to the trihedral respectively xy, zy and xz.

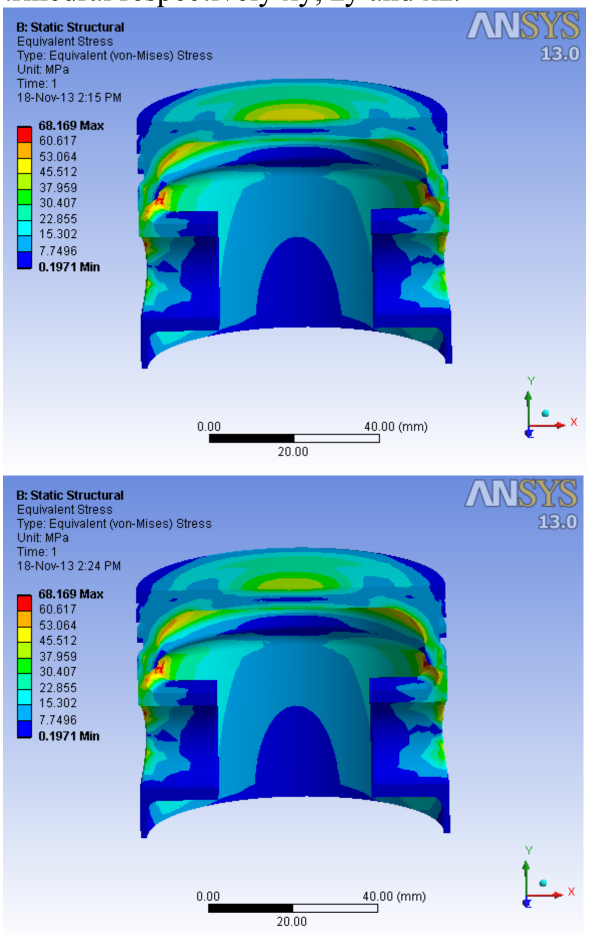

Fig.3. Equivalent stress distribution for the piston with an Al_2O_3 top layer: a) with top layer and b) with top layer removed

In Fig.4 there is presented the tangential stress distribution for the planes parallel with the XY plane for the piston with an Al_2O_3 top layer. The maximum tangential stresses in this plane have two components τ_1 and τ_2. The τ_1 component of the tangential stress has a value of 26, 285 MPa, and the τ_2 component has a value of 26,331 MPa. These are found in the radius of curvature area between the piston head and the piston rings area and in the radius of curvature of the pin bosses. They have opposite directions and at a 45° angle to the main directions.

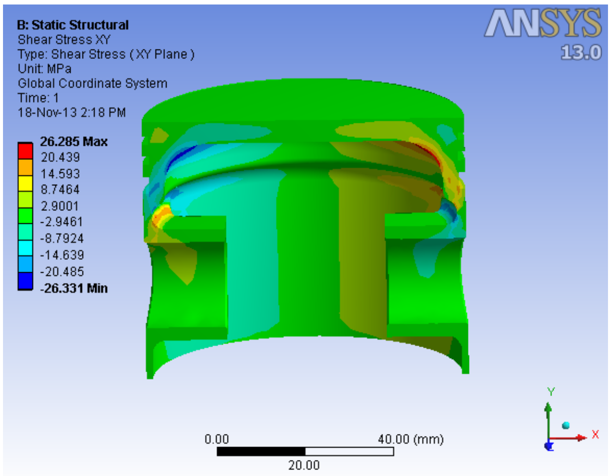

Fig.4. Tangential stress distribution for the xy plane for a piston with an Al_2O_3 top layer

Fig.5 shows the tangential stress distribution in planes parallel with the yz plan. Maximum tangential stress components for this plane are found in radius of curvature area between the pin bore and the lower part of the piston skirt ($\tau 1$ = 29,063 MPa) and in the radius of curvature area of the piston head and the port rings region ($\tau 2$ = 27,502 MPa) and are disposed at an angle of 90° to each other from which can be deduced the fact that they are expressed on the main directions with different orientation.

The tangential stress distribution components for the xy plane of the piston head with an Al_2O_3 top layer are found both inside and on the upper surface of the deposited layer and in the inner region of the piston pin bore (Fig. 6.). The τ_1 component value is 25,344 MPa and the value of the τ_2 component is 28,208 MPa. These components are located in planes found at 45° towards the primary direction σ_1.

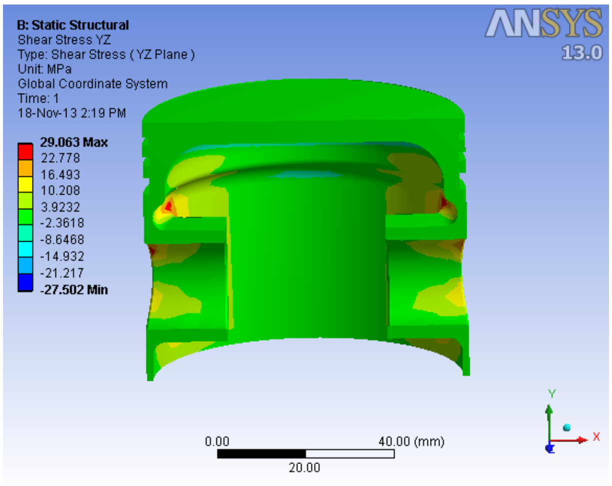

Fig.5. Tangential stress distribution for the yz plane for the piston with an Al_2O_3 top layer

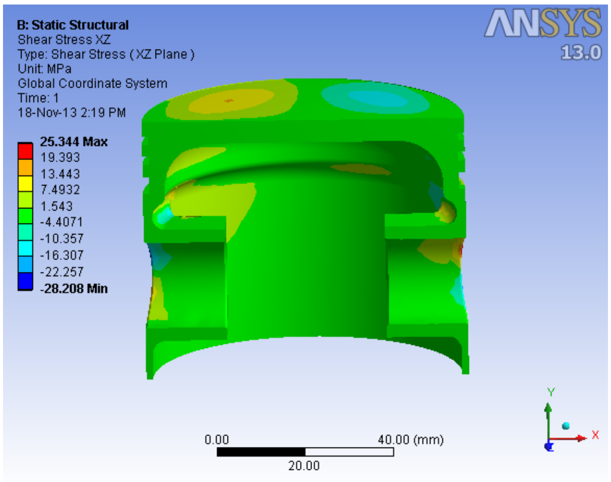

Fig.6. Tangential stress distribution for the xz plane for the piston with an Al_2O_3 top layer

Fig.7 shows the normal stress distribution for the x axis direction in the case of the piston with an Al_2O_3 top layer. The compression component of the normal stress after this direction has a maximum value of 42.351 MPa, value found on the upper surface of the piston head respectively in the deposited layer. The stretching component of the normal stress is found on the inner surface of the piston head and on the upper surface of the deposited layer in the edge area and has a maximum value of 60.043 MPa. The compression component that occurs in the x axis direction is due to minimal primary stress σ_3, and the stretching component is due to maximum primary stress σ_1.

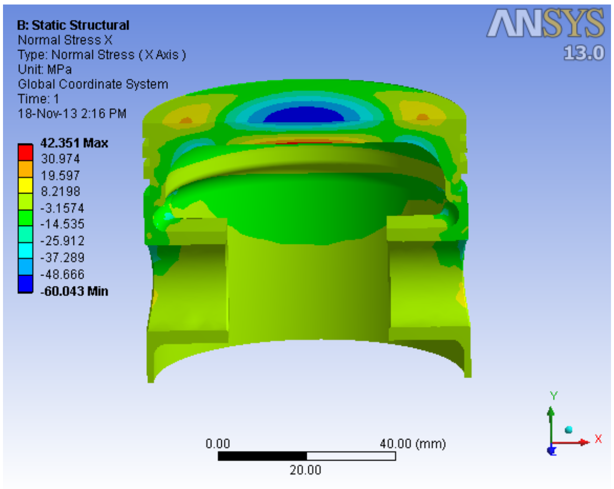

Fig.7. Normal stress distribution for the x axis direction for the piston with an Al_2O_3 top layer

For the y axis direction the normal stress distribution is presented in Fig. 8. For this direction the normal stress acts mainly in the radius of curvature area between the pin bolt and the piston's skirt where the maximum value of the compression component is 74,869 MPa and in the lower part of the pin bore and the port rings area where the stretching component has a maximum value of 41,848 MPa. Normal stress after this direction is produced mainly by the primary stresses σ_1 and σ_3.

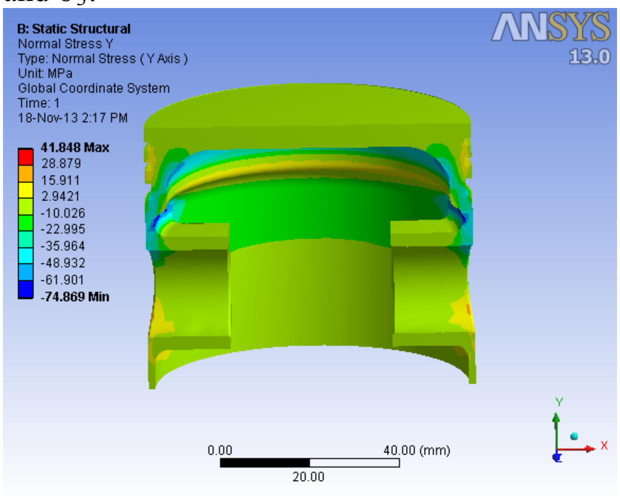

Fig.8. Normal stress distribution for the y axis direction for the piston with an Al_2O_3 thin layer

Normal stress distribution for the z axis direction is shown in Fig. 9. The maximum value of the compression component for this direction is 60.069 MPa, and the maximum value of the stretching component is 86.424 MPa. The compression on the upper surface of

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the deposited top layer and the stretching in the pin bore region are produced by the primary stress σ_3. The stretching that appears on the inner surface of the piston head is produced by the primary stress σ_2.

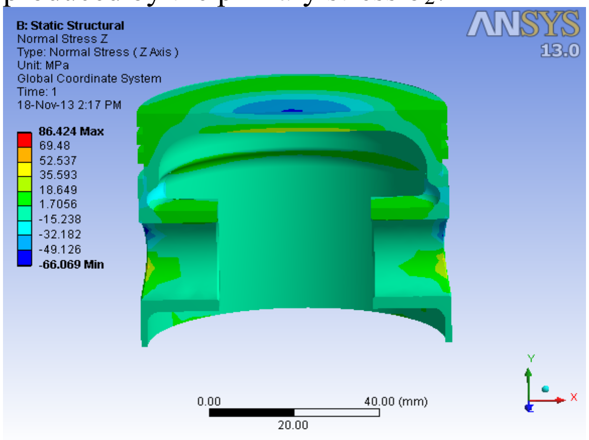

Fig.9. Normal stress distribution for the z axis direction for the piston with an Al_2O_3 top layer

Fig.10 presents the deformation that appears inside the piston following the loads that have been applied.

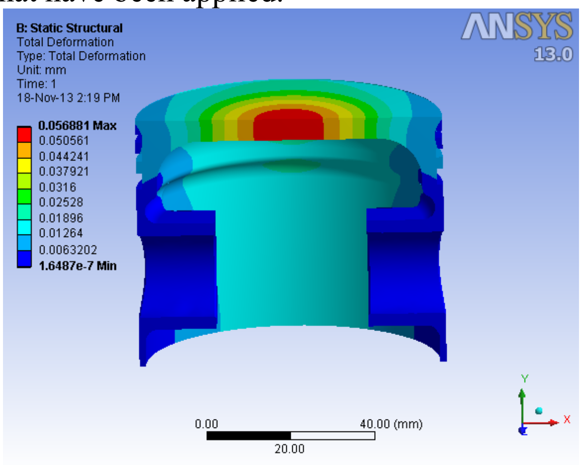

Fig.10. Present deformation in case of the piston with an Al_2O_3 top layer

The maximum value of the deformation is found in the piston head region and has a value of 0.57 mm.

Fig.11 presents the elastic deformation that appears in this piston, reording a maximum value of 9.6013 x 10^{-4} mm/mm in the radius of curvature area between the pin bore and the skirt. The elastic deformation that is found in the deposited layer has a maximum value of 7.4739 x10^{-4} mm/mm.

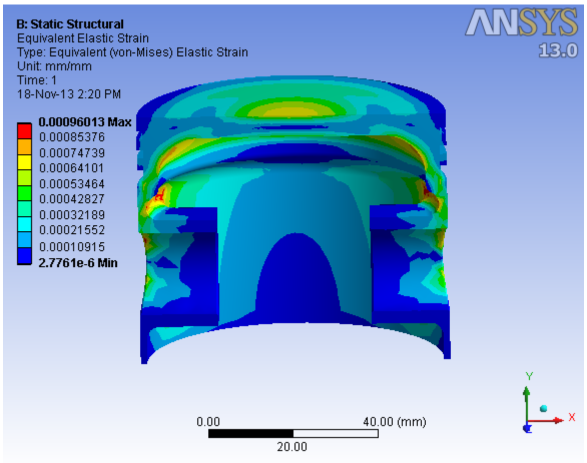

Fig.11. Elastic deformation that is found in the piston with an Al_2O_3 top layer

3. CONCLUSIONS & ACKNOWLEDGMENT

The finite element analysis strated with the CAD models of the piston and of the piston with top layer. These models were designed in SOLIDWORKS and then imported in the ANSYS 13 software. The first module, in which the data were inserted in, was the Data Engineering module. In this module, properties of the piston and of the deposited layer such as: material properties, young's module, tensile strength, density and Poisson's constant were defined. The Mechanical module was used to develop the mesh models for each individual model.

From the finite analysis we can conclude that the Al_2O_3 layer has a good mechanical behavior, which recommends it for this kind of thin layers. By applying this kind of thin layer, the base material is less stressed conducing to a better wear resistance due to flue gas pressure and thermal stress.

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