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Enhancement of Tribological Behavior for Diesel Engine Piston of Solid Skirt by an Optimal Choice of Interface Material

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Abstract**—**Shear stresses generate frictional forces thus lead to the reduction of engine performance due to the power losses. This friction can also cause damage to the piston material. Thus, the choice of an optimal material for the piston is necessary to improve the elastohydrodynamical contacts of the piston. In this study, to achieve this objective, an elastohydrodynamical lubrication model that satisfies the best tribological behavior of the piston with the optimum choice of material is developed. Several aluminum alloys composed of different components are studied in this simulation. An application is made on the piston 60 x 120 mm Diesel engine type F8L413 currently mounted on Deutz trucks TB230 by using different aluminum alloys where alloys based on aluminum-silicon have better tribological performance.

Keywords**—**EHD lubricated contacts, friction, properties of materials, tribological performance.

I. INTRODUCTION

As an element of power transmission in the cylinder of an engine, the piston has the function of transmitting mechanical energy to the crankshaft via the connecting rod. Aluminum alloys are generally used in piston manufacturing. There are many reasons for using the aluminum alloys in the piston of gasoline and diesel engines: low weight, high thermal conductivity, simplicity of production, high reliability, and very good recycling properties.

This work is a part of a research project which aims at the global study of a diesel engine with the direct injection piston. The goal is to improve the piston performance for the development of the industrial sector. In the diesel engine of direct injection type concerned with our study, a cavity formed in the piston promotes turbulence and increases the volume of the combustion chamber.

An analysis by the Finite Element investigates the influence of the material of the piston of a diesel engine with the direct injection by their thermo-mechanical effect which plays an essential role in the development process of an automobile engine. The thermo-mechanical analysis results by the finite element method aims at the determination of the exact concentration stresses and deformation. Thus, many researchers have focused on studying the mechanical and thermal stresses by sophisticated numerical methods, e.g. Li [2], Brun [3], and Hugues [4]. Interesting works were marked during these last years on the analysis of the diesel engines of development of light weight piston [5], high speed of diesel engines with the direct injection (HSDI) [6], and high pressure piston diesel engine with the direct injection (HDI) [7].

The steady increase in the specific power of the engines requires the implementation of predictive techniques for assessing the reliability of mechanical parts. The present work contributes to improving the tribological behavior for Diesel Engine Piston Solid Skirt by an optimal choice of interface materials.

The method of calculation of stress was Finite Element Method whose solution was obtained by using ANSYS software designed for structural analysis. The piston model is created in the SolidWorks software, then translated into the second part for the calculation of thermo-mechanical stress in ANSYS.

II. MATERIALS AND METHODS

A. Piston Design

The piston is designed as a real model of a diesel engine with direct injection type Deutz F8L413 brand whose characteristics are given in Table I.

TABLE I
ENGINE MECHANICAL CHARACTERISTICS

Total volume of displacement	11310 cm^3
Piston diameter	119.89 mm
Combustion principle	direct injection
Nominal max regime	2650 tr/mn
Temperature after the combustion piston bottom	573 K
Max combustion pressure (Pz)	7.5 MPa

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B. Drawings of the Piston

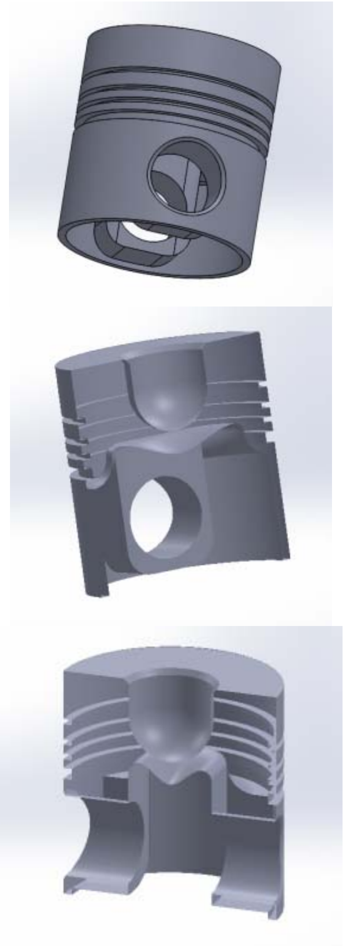

Fig. 1 Design of the model using SolidWorks

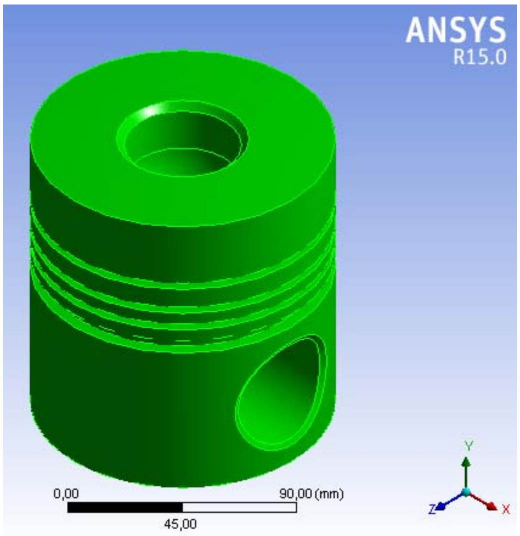

Fig. 2 Model in ANSYS

C. Material Properties

TABLE II
MATERIAL PROPERTIES

S N°	alloy	Young's modulus (Pa)	Poison's ratio	density	Thermal conductivity (W/m°C)
1	A4032	$7.9*10^{10}$	0.33	2685	154
2	AL1	$7*10^{10}$	0.32	2700	160
3	AL2	$7.1*10^{10}$	0.33	2770	174
4	AL7675T761	$7*10^{10}$	0.32	2680	134
5	ALGHS 1300	$9.8*10^{10}$	0.3	2780	120
6	AL3	$7*10^{10}$	0.35	2700	237
7	AL-Mg-Si	$7*10^{10}$	0.33	2700	200
8	Al-Si	$20*10^{10}$	0.33	2740	134
9	AL-Si1	$9*10^{10}$	0.3	2700	155
10	AL-Si2	$20*10^{10}$	0.24	2937	197

D. Analysis

Our analysis is focused on the piston assembly, which is subjected to thermal stresses created by the thermal exchange of convection h (T_{wall}-T_{∞}) where the T_{wall}, T_{∞} are the temperature of the wall and the surrounding temperature in the heat exchange surface, respectively. This exchange is caused by a heat flow emanating from the gas combustion, then transferred by convection on the bottom of the piston while passing through the part where the heat flux increases the temperature of conduction by piston. The other part is transferred to the surroundings by convection through the segments, the skirt, and the internal bosses.

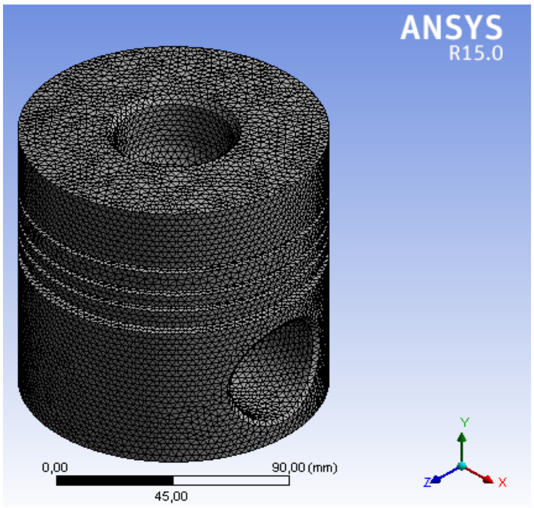

Fig. 3 Meshed of 3D model

The steady state temperature distribution is obtained by the solution of the elliptical equation in cylindrical coordinates (r, z).

$$\frac{-\partial}{\partial r}(K.r\frac{\partial T}{\partial r})-\frac{\partial}{\partial z}(K.r\frac{\partial T}{\partial z})=0 \qquad (1)$$

where, *K* is the thermal conductivity of material which is W/m°C.

Heat exchange between the piston and its surroundings are regarded as purely convective. They are expressed by using the Neumann boundary condition on the boundary surfaces of the piston.

$$n.(K.r\vec{\nabla}T) + h.r0(-T - T\infty) = 0 \qquad (2)$$

where h is the heat convection coefficient, and n is the normal to the boundary surfaces. The piston is also subjected to the mechanical stresses due to the action of the pressure of the combustion gas (Pz) and the reaction of the piston axis.

E. Meshing

An automatic three-dimensional mesh will be performed on half of the structure because it is considered symmetrical. The type of element used for the modeling of solid structures is tetrahedral ten nodes as shown in Fig. 5. The nodes on the axes of the pistons will be blocked and they will satisfy the boundary conditions.

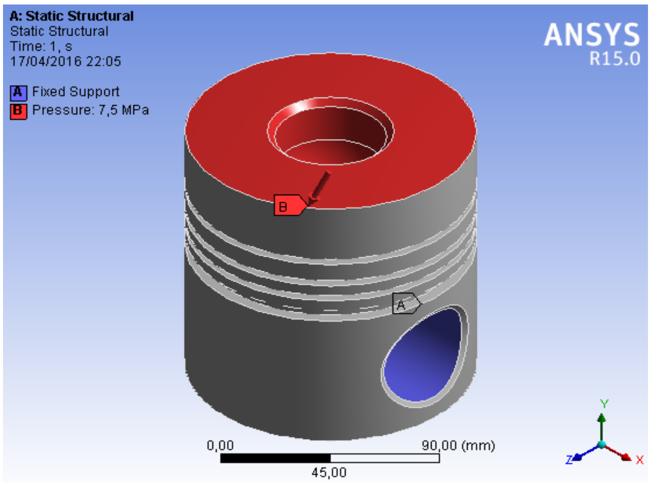

Fig. 4 Piston model under load and constraint

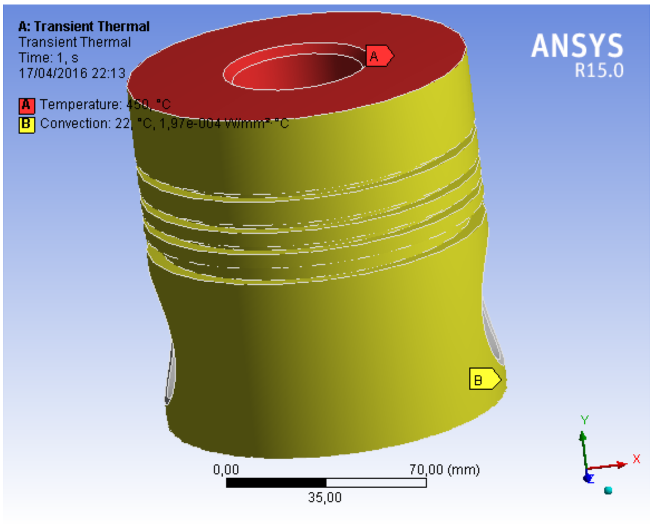

Fig. 5 Model under thermal loading

F. Boundary Condition

1- Pressure on piston head considerate 7.5 MPa.
2- Temperature on piston head T=450 °C, T_g=1000 °C [2].
3- Convection on piston.

Static analysis is used to determine displacements, stress, etc. under static loading conditions. Thermal analysis calculates the temperature distribution and the heat flux under thermal loading conditions. The numerical values of convection and thermal conductivity coefficients are taken from [1], [2].

III. RESULTS AND DISCUSSION

G. Results of Structural (Pressure) Analysis of Piston

1. Total Deformation

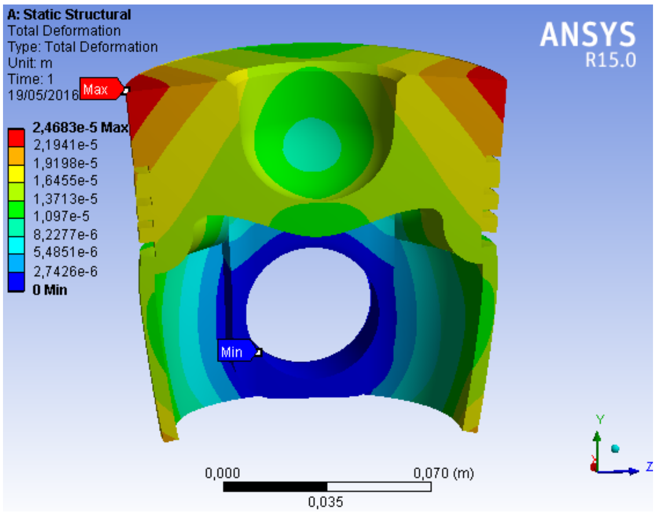

Fig. 6 Total deformation for AL4032

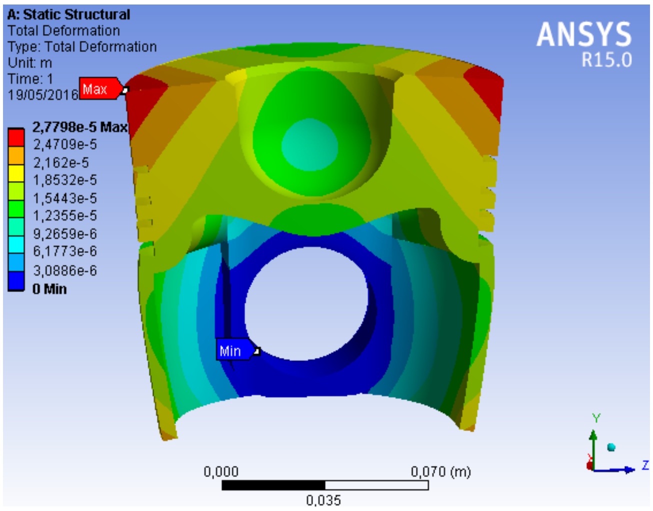

Fig. 7 Total deformation for AL1

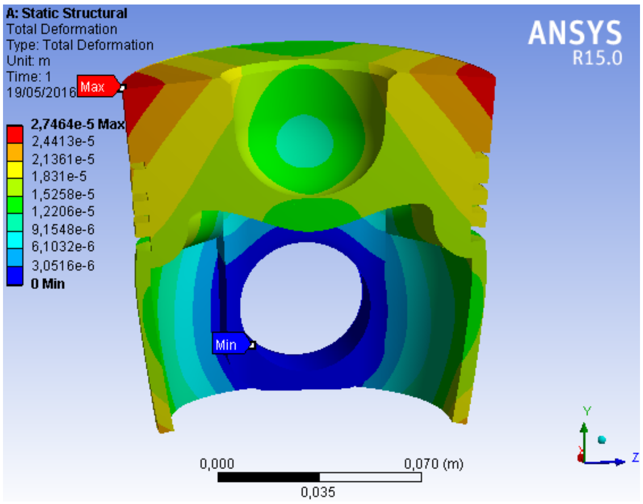

Fig. 8 Total deformation for AL2

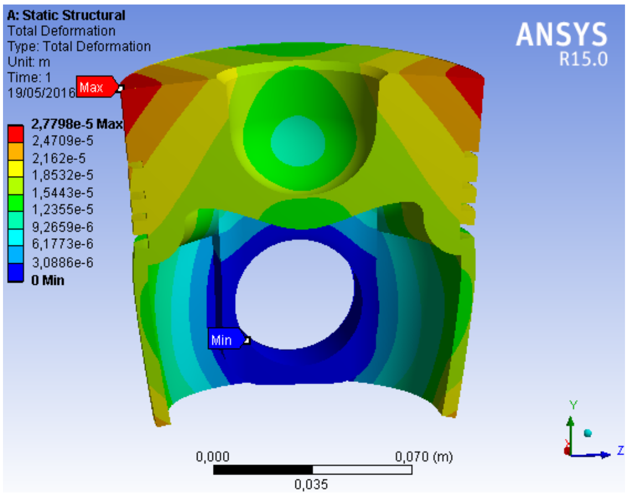

Fig. 9 Total deformation for AL765T761

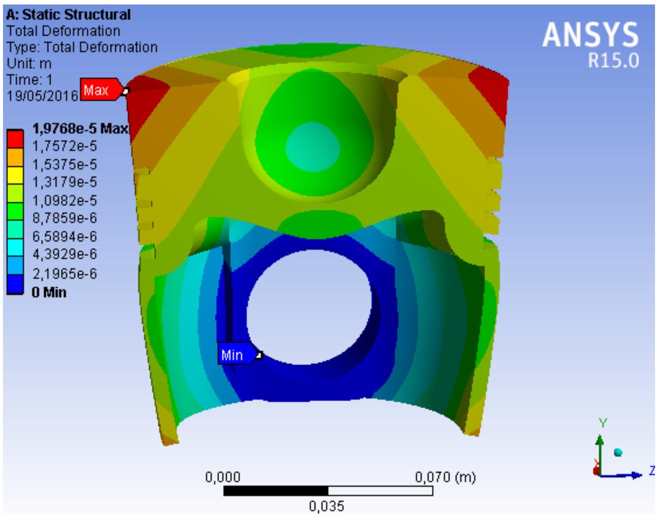

Fig. 10 Total deformation for ALGHS1300

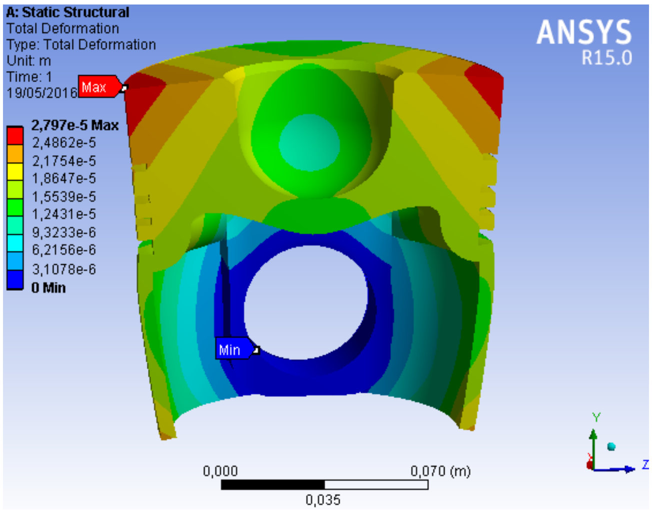

Fig. 11 Total deformation for AL3

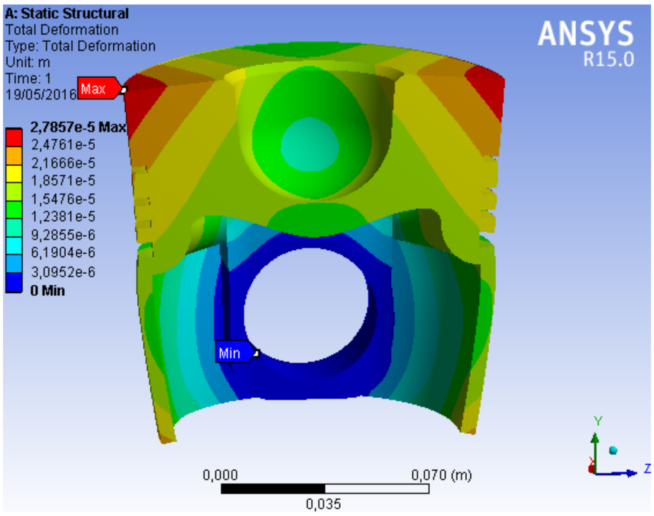

Fig. 12 Total deformation for AL-MG-SI

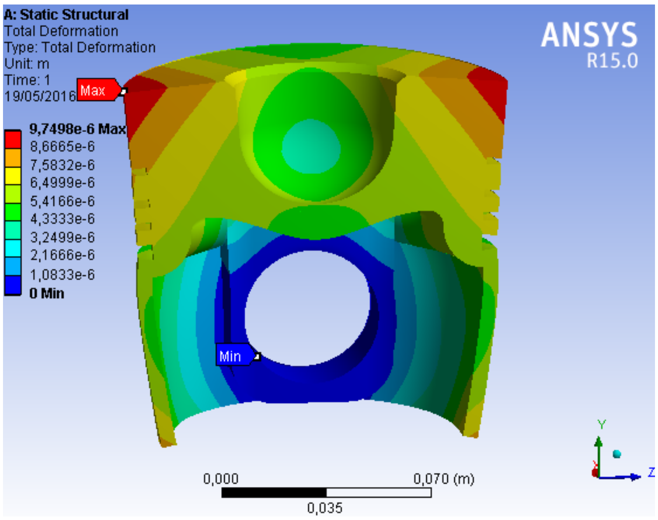

Fig. 13 Total deformation for AL-SI

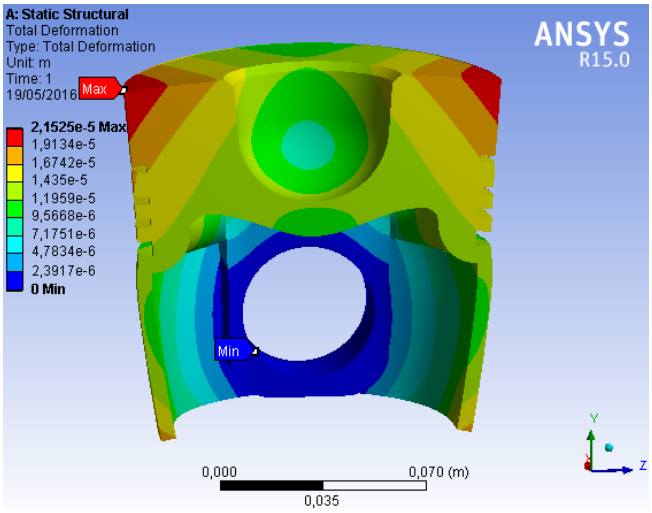

Fig. 14 Total deformation for AL-SI1

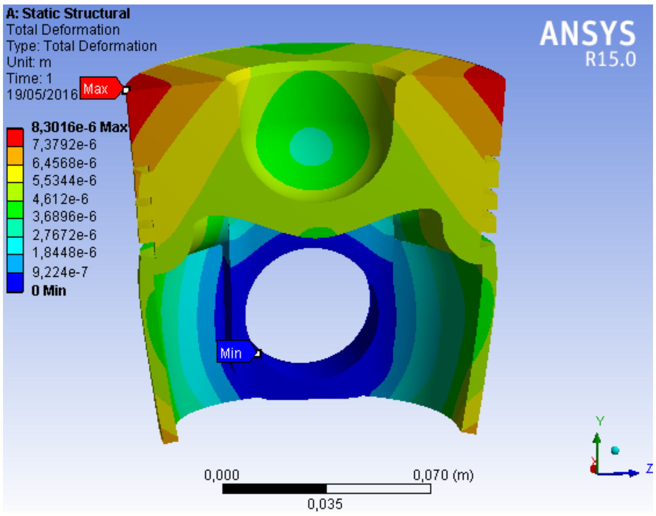

Fig. 15 Total deformation for AL-SI2

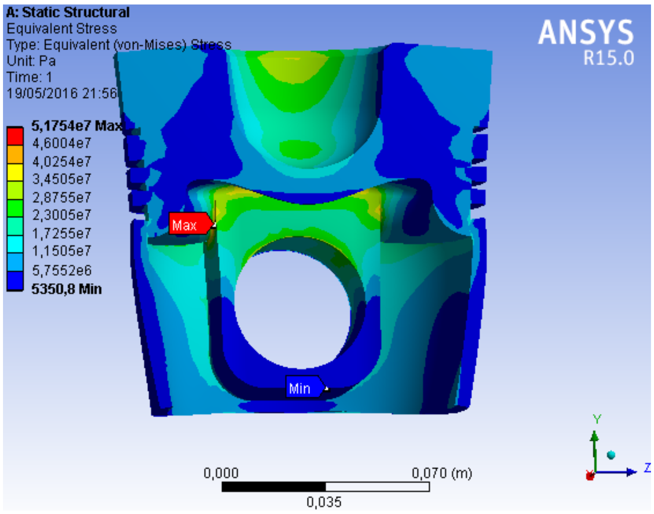

Fig. 16 Equivalent von-Mises stress for AL4032

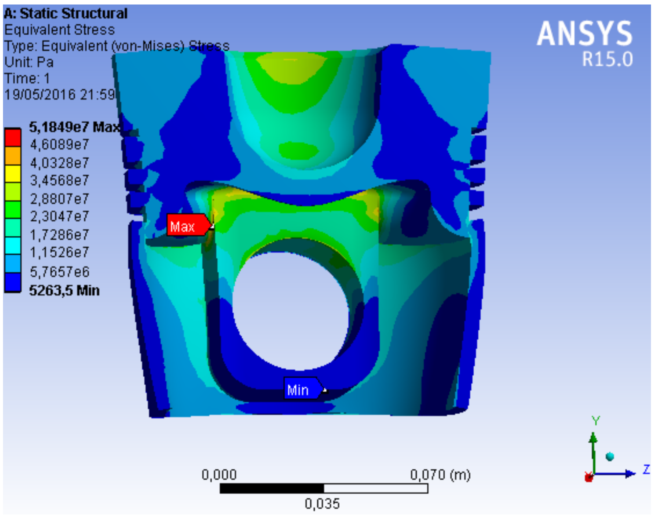

Fig. 17 Equivalent Von -Mises stress for AL1

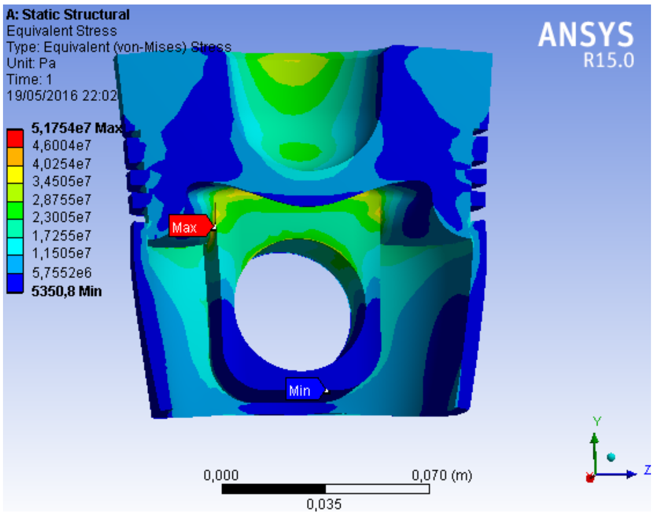

Fig. 18 Equivalent Von-Mises for AL2

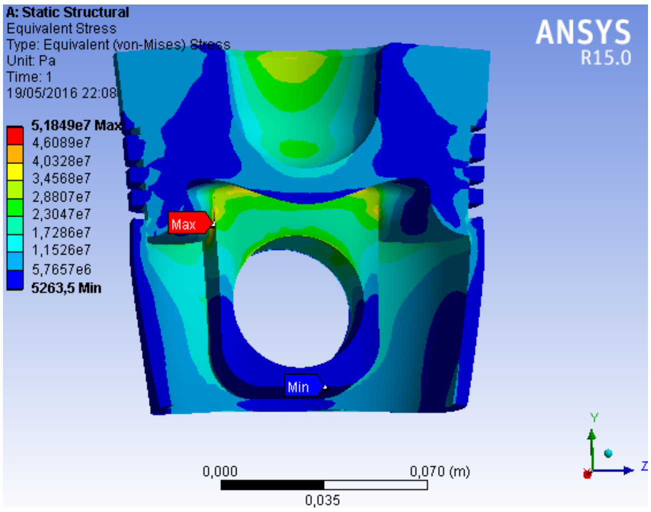

Fig. 19 Equivalent von-Mises stress for AL765T761

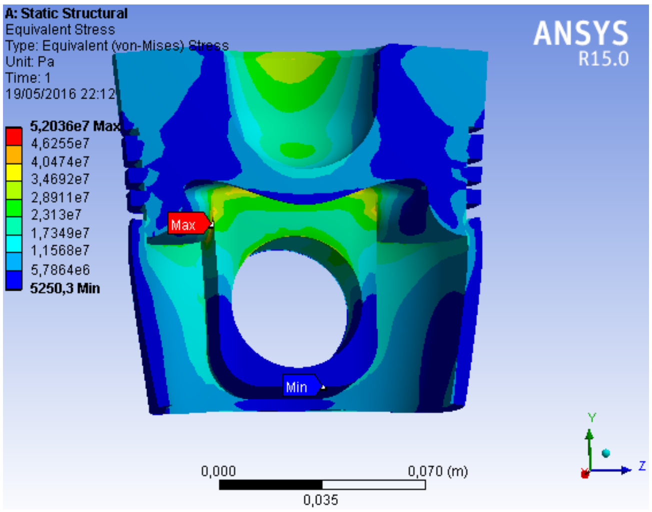

Fig. 20 Equivalent von -Mises stress for ALGHS1300

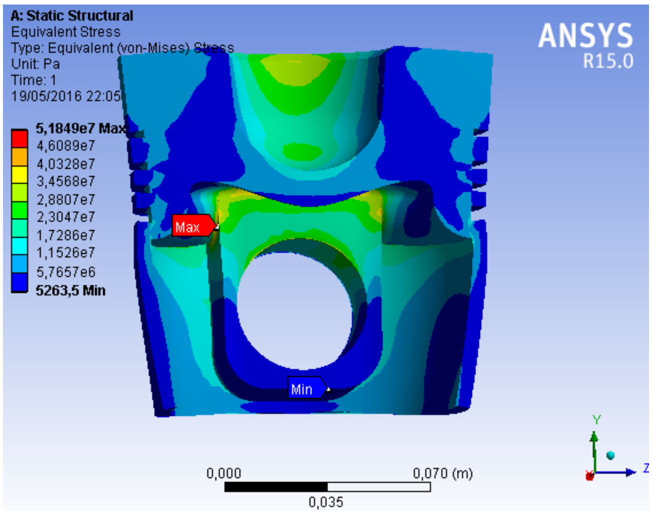

Fig. 21 Equivalent von-Mises stress for AL3

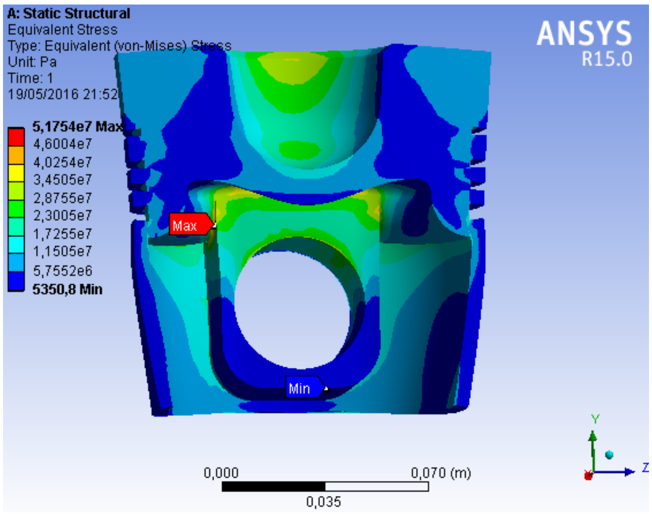

Fig. 22 Equivalent von-Mises stress for AL-MG-SI

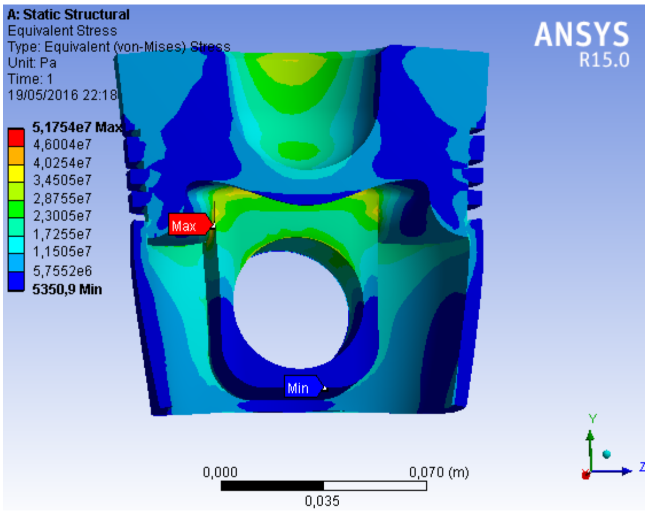

Fig. 23 Equivalent von-Mises stress for AL-SI

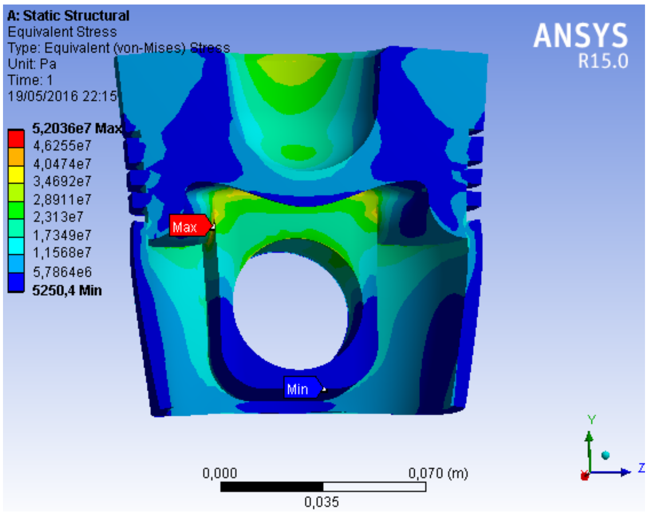

Fig. 24 Equivalent von-Mises stress for AL-SI1

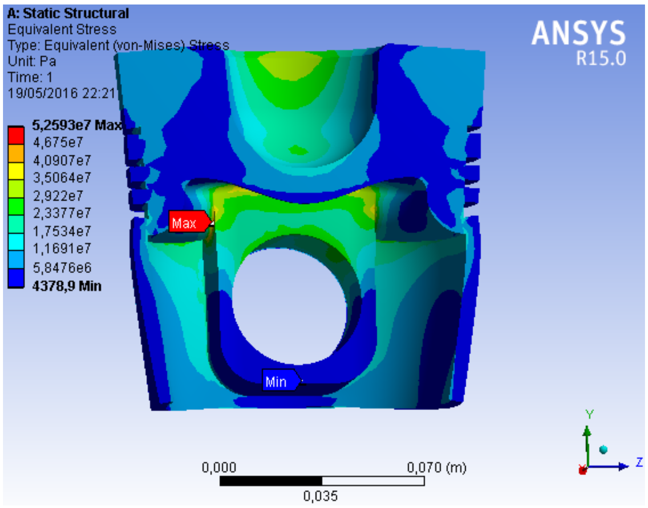

Fig. 25 Equivalent von-Mises stress for AL-SI2

When the piston is subjected to a mechanical loading (a pressure due to the gases flaring at the bottom of the piston), the behavior of material of this piston is illustrated in Figs. 6-15, which show us that the maximum stress is found at the bottom of piston, and the minimum stress is on the level of the axis of piston. Figs. 17-25 show the concentration of the mechanical constraints due to the pressure of the gases.

H. Thermal Analysis of Piston

1. Total Heat Flux

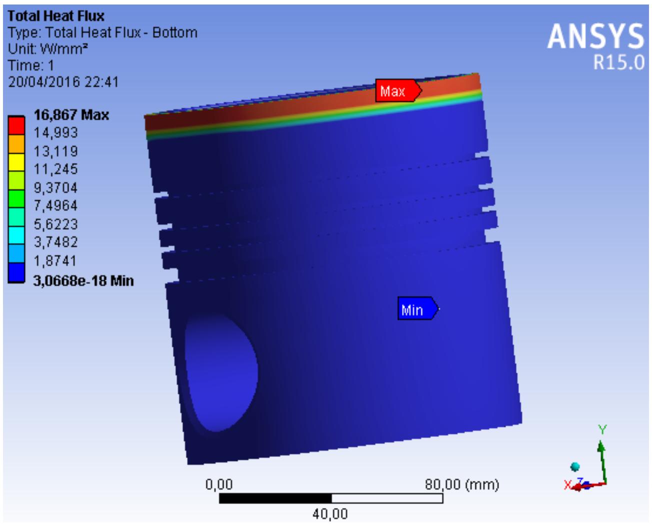

Fig. 26 Total heat flux distribution for AL4032

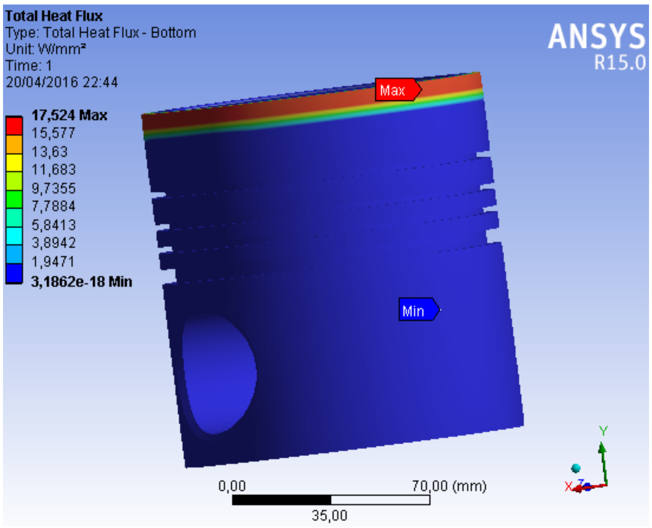

Fig. 27 Total heat flux distribution for AL1

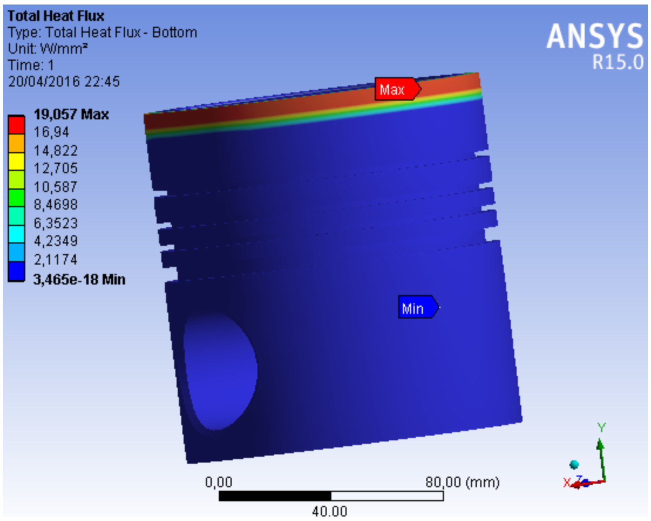

Fig. 28 Total heat flux distribution for AL2

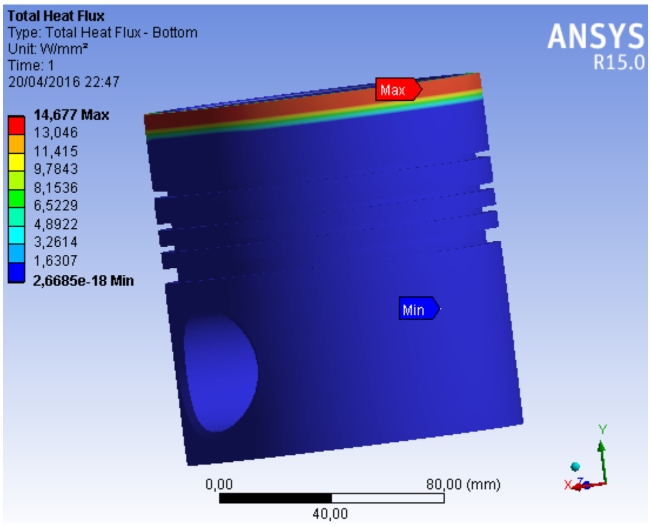

Fig. 29 Total heat flux distribution for AL765T761

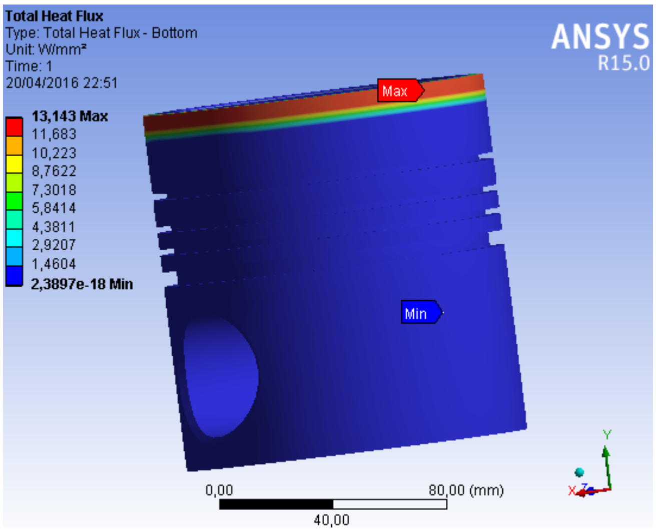

Fig. 30 Total heat flux distribution for ALGHS1300

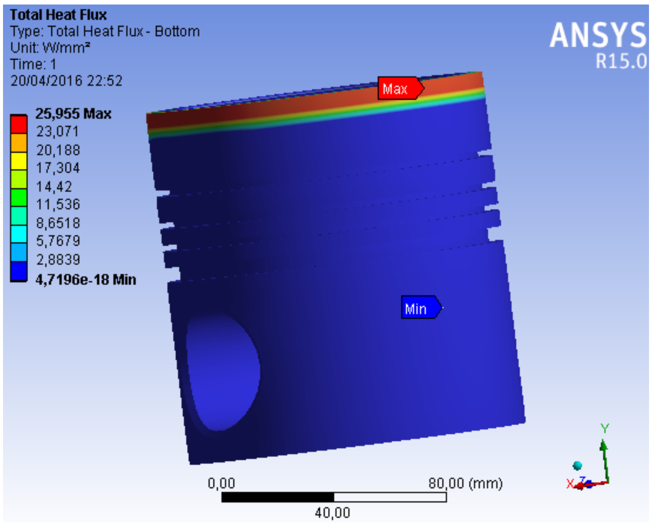

Fig. 31 Total heat flux distribution for AL3

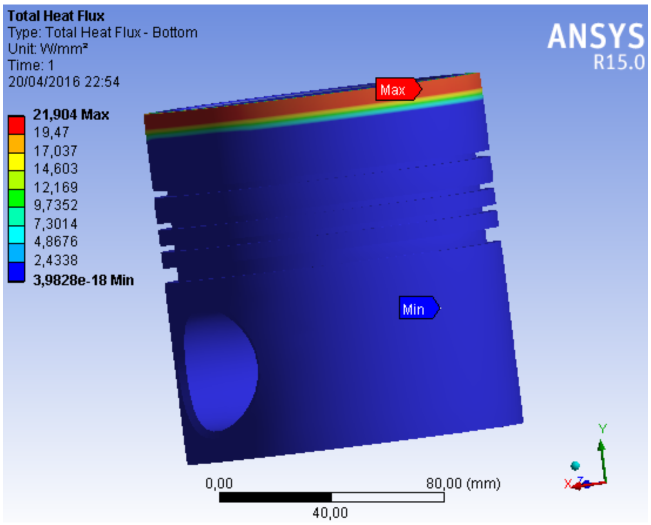

Fig. 32 Total heat flux distribution for AL-MG-SI

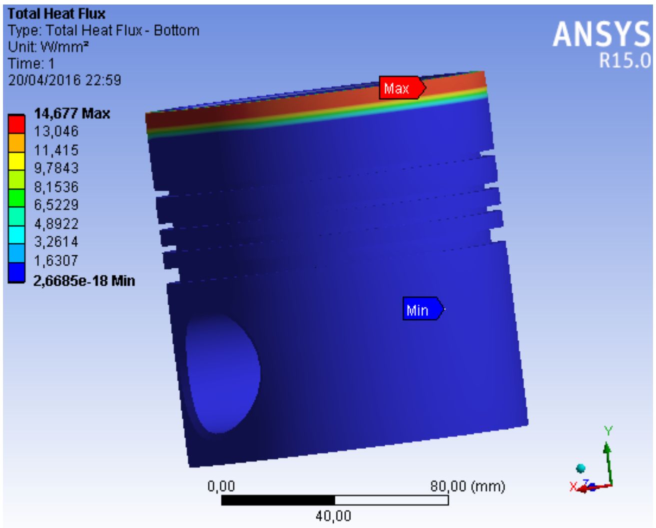

Fig. 33 Total heat flux distribution for AL-SI

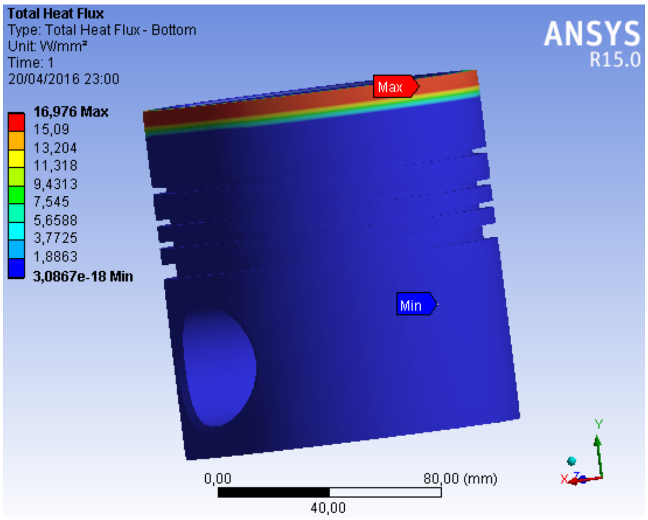

Fig. 34 Total heat flux distribution for AL-SI1

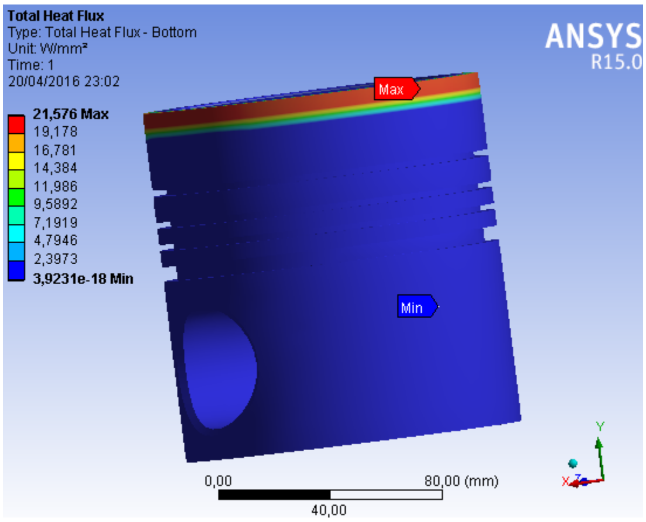

Fig. 35 Total heat flux distribution for AL-SI2

Figs. 26-35 show the total heat flux distribution in piston for different alloys.

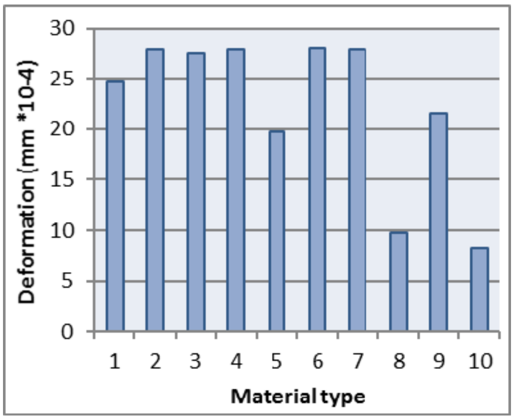

Fig. 36 Total deformation for all alloys

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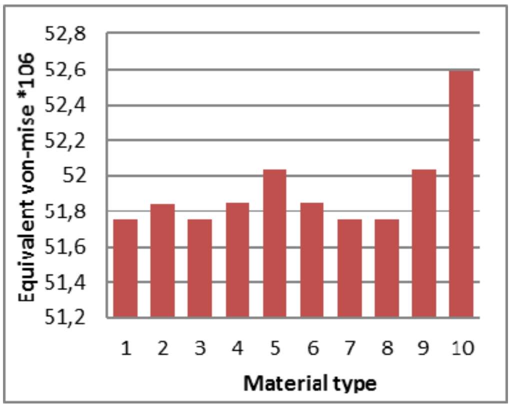

Fig. 37 Equivalent (von-Mises stress) for all alloys

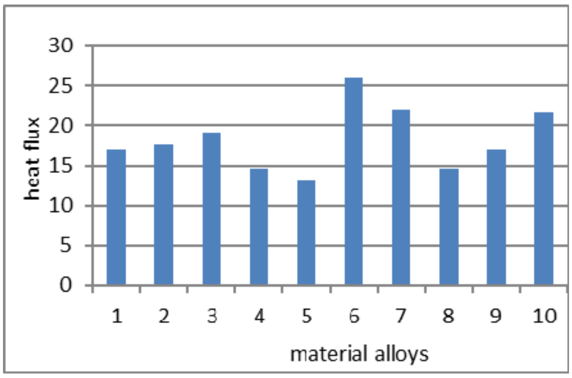

Fig. 38 Total heat flux distribution for all alloys

IV. CONCLUSION

The study of the behavior of different materials for the piston under the mechanical loading shows that the displacement in each material helps us to consider the challenge between the shirt and the piston. The comparisons of these maximum displacement values reveal that the materials 10, 8, and 5 are less deformed. Significant concentration of Von-Mises stress is found at the rib of the bottom of lower segment, and the most efficient materials are the materials 8, 7, and 1. The choice of material for a piston, which has the best performance, is based on a compromise between these results.

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