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NUMERICAL ANALYSIS OF THE THERMAL – STRESSES OF A PETROL ENGINE PISTON WITH DIFFERENT MATERIALS

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ABSTRACT
In this paper a numerical analysis is used to analyze the stresses due to thermal cycle with different aluminum alloy of piston .Finite element method was used to evaluate the coupling field (thermal –stress) on the piston .ANSYS5.4 Finite element code is used to carry out the modeling process to determine the coupling stress .Two models with three dimensions are created .The first is used to evaluate the temperature distribution through the piston volume, and the second is used to evaluate the thermal stress distribution due to heat gradient and the material different.
The result show the maximum range of temperatures is 4.3 °C and increases with decreasing of material thermal conductivity .Thermal stress is concentrated on the piston edges and depends on the material types.

الخلاصه:
تم خلال هذا البحث استخدام التحليل العددي للاجهادات الناتجه من دورة الحراره التي يتعرض لها مكبس محرك بنزين مصنع من سبائك مختلفه من الالومنيوم .تم استخدام طريقه العناصر المحدده لحساب توزيع الاجهادات المرافقه للحراره على المكبس.استخدم نظام التحليل ANSYS5.4 لتنفيذ عملية النمذجه .تم بناء نموذجين ثلاثية الابعاد الاول لحساب توزيع درجة الحرارة خلال المكبس اما الثاني فيستخدم لحساب توزيع الاجهادات الحراريه الناتجه من الانحدار الحراري واختلاف مادة المكبس .
اوضحت النتائج ان اقصى مدى للحراره هو (4.3 °C) ويزداد مع نقصان التوصليه الحراريه للماده . الاجهاد الحراري يتركز على حافات المكبس ويعتمد على نوع الماده.

INTRODUCTION
High peak pressure (hpp) operation has important mechanical design. Consequences, notably increased component stresses due to the higher pressure and thermal loads [1][2]. There are many studies to the heat transfer in diesel, engines components ex, A .P. Kleeman et al. [1], in their work the magnitude and origins of local of spatial and temporal surface heat flux variations in a diesel engine have been investigated using a computational fluid dynamics (CFD) simulation code and experimental measurement, as a part of the CFD explorations two diffract wall function models of flow and thermal boundary layers have been used. The single-cylinder Hpp proto types DI diesel engine developed in their project is based on the OM500 series heaving-duty four valve truck engine with characterization[3], as shown in table(1).
Thomas Gross [4], in his paper develops engines value with improved heat transfer for large diesel engines. Finite element analysis of thermal operating characteristics of thermo value is carried out by using ANSYS FE code. 3-Dimension model of one quarter of valve with cylinder heads is created and implemented ANSYS codes. The level of efficiency is increased with increasing of pressures and temperatures, this, in turn, requires improved heat transfer from combustion chamber to the cooling medium by all cylinder head components, which must therefore also be more and more resistant to heat. In the area of gas exchange component, this problem was

solved by using new material and new combinations of materials as well as by using alternative geometry [4,5].
In present work 3-Dimensional FEM model of engine piston is created and implemented by using FE ANSYS 5.4 code to study the range of stresses distribution within one cycle of operation for petrol engine was made of different alloys .

Boundary Conditions:

Temperature and pressure calculation of fresh charge (air & fuel mixture): The temperature and pressure of fresh charge in compression, expansion and combustion strokes are calculated depending on the first law of thermodynamic [8], which consists all equations to calculate the temperature and pressure as a function of crank angle.
In this research, the compression ratio is given (8) while the temperature and the pressure at the beginning of the stroke are assumed as 25 ◦C and 1 bar respectively.
After some calculation [8], the peak pressure and temperature my be reached to 64 bar and 3600◦C

Heat transfer conditions:

Three of the hottest points are around the spark plug, the exhaust valve and port, and the face of the piston. Not only are these places exposed to the high-temperature combustion gases, but they are difficult places to cool.
The piston face is difficult to cool because it is separated from the water Jacket or outer finned cooling surfaces.
During combustion peak gas temperatures on the order of (3000-4000k) occur within the cylinders, and effective heat transfer is needed to keep the cylinder walls and the piston from over heating.
The piston absorbs convective and radiation heat transfer from the high temperatures gases and losses the heat to the cylinder wall, rings and the lubricating oil such as:

Convective and radiation heat transfer from the high temperature gases to the piston face:

convective heat transfer on the piston face from the combustion gases:

The mathematical formulas of the convection heat transfer in the IC engine are:

$$q = h_g A_{pf} (T_g - T_{pf})$$

Where: h_g = heat transfer coefficient by convection
A_{pf} = cross sectional area of the piston face
T_g = gas temperature at the peak combustion
T_{pf} = initial temperature of the piston face

The average value of the convection heat transfer coefficient can be calculated from the knowledge of a Nusselt number value.
The Nusselt number for the inside of the combustion chamber can be defined using the following relation (Dittus - Boelter equation)[8].

$$Nu = h_g B / k_g = 0.023 \, Re^{0.8} \, Pr^{0.3}$$

Where: B = bore of cylinder
K_g = thermal conductivity of cylinder gas
Pr = Prandtl number
Re = Reynolds number

$Re = [(m_a + m_f)B] / A_{pf}\ \mu_g$

Where: m_a = mass flow rate of air into the cylinder
m_f = mass flow rate of fuel into the cylinder
A_{pf} = area of piston face
μ_g = dynamic viscosity of gas in the cylinder

Radiation heat transfer between combustion gases and cylinder walls and piston face

The mathematical formulas of the radiation heat transfer in the IC engine are:

$$q = Q/A = [\sigma\ (T_g^4 - T_{pf}^4)] / [[(1-\varepsilon_g) / \varepsilon_g]+[1/F_{1-2}]+[(1-\varepsilon_{pf}) / \varepsilon_{pf}]]$$

Where: T_g = gas temperature
T_{pf} = piston face temperature
σ = Stefan – Boltzmann constant
ε_g = emissivity of gas
ε_{pf} = emissivity of piston face material
F_{1-2} = view factor between gas and piston face

Even though gas temperature are very high, radiation to the walls only amounts to about 10% of the total heat transfer in SI engines. This is due to the poor emitting properties of gases, which emit only at specific wavelengths. N_2 and O_2, which make up the majority of the gases before combustion, radiate very little, while the CO_2 and H_2O of the products do contribute more to radiation heat transfer.

Heat transfer from the piston to the rings:

Heat is transferred from the piston to the rings by the conductive heat transfer because of the temperature gradient between the piston and the rings such as

$Q_{ring} = (T_{pc} – T_i)\ k_{ring} / \Delta x_{ring}$

Where: T_{pc} = Temperature of contact area between the piston and the rings
T_i= Temperature of lubricating oil sprays above the rings
K_{ring} = Thermal conductivity of the rings
Δx_{ring} = thickness of the ring

Heat transfer from the piston to the cylinder walls:

There are droplets of lubricating oil between the piston and the cylinder wall with small thickness (ΔS) which causes a conductive heat transfer from the piston to the inner walls of combustion chamber through the lubricating oil layer as follow:

$Q_b = (T_{wp} – T_w)\ k_{oil} / \Delta S$

Where: Q_b = Conductive heat transfer between the piston and the cylinder walls directly
T_{wp} = Temperature at the outer surface of the piston
T_w = Temperature of the cylinder walls
K_{oil} = Thermal conductivity of the lubricating oil
ΔS = Clearance between the piston and the cylinder walls (equal to the lubricating oil layer thickness)

Heat transfer from the piston to the lubricating oil:
Convective heat transfer is occurred from the inner face of the piston to the lubricating oil as the following relation.

$$Q_{oil} = h_{oil} (T_{ip} - T_{oil})$$

Where: h_{oil} = heat transfer coefficient by convection
T_{ip} = Temperature of inner face of the piston
T_{oil} = Lubricating oil temperature

$$Nu_{oil} = h_{oil} D_i / k_{oil} = 0.0118 Re^{0.9} Pr^{0.3}$$

$$Re = \rho_{oil} u D_i / \mu_{oil}$$

Where: ρ_{oil} = density of the lubricating oil
μ_{oil} = dynamic viscosity of the lubricating oil
$u = SN/30$
S = length of the cylinder stroke
N = rpm

Finite Element Modeling
FE simulation of engine piston was performed with ANSYS 5.4 code, using widely – employed sub-models for the heat transfer, stress in elastic, plastic regions and material properties. As fallows:

1. Geometry sub-model: This sub-model includes 3-D dimensions Geometry of the engine piston with rings (mm) dimensions, as show in Fig.(1).
2. Material sub-model: this sub-model includes the material properties of the engine piston and ring in the table (2): the material properties are varying with silicon content.
3. Meshing generation: three dimensions coupling element of 3-D heat transfer (Conduction) and 3-D-stress analysis are used for modeling of heat transfer and stress analysis are (solid 70 and solid 98) with mesh size as shown in Fig. (2,a,b).
4. Parameter study: Temperature (variation) and material of piston are studied through the simulation.

Result and discussion:
Numerical analysis of petrol engine show the distribution of temperature on the piston body during one cycle of operation for the piston was made of different AL-Si alloy [7]..One of the important features of this alloy is wear resistance [7], because of the second phase of silicon in this alloy, but it suffer from decreasing the thermal conductivity and expansion with compared with AL element and that leads to increase the temperature gradient range in the piston body as shown in the figures (3,4,5 a) . The temperature gradient increases due to decrease of thermal conductivity with increasing of the silicon content in AL -alloy .Increasing of temperature gradient leads to increase the thermal stress in the piston alloy as shown in the figures (6,7,8.a) which are shown the stress contour within piston body ,also, the numerical analysis show the distribution of the temperature with piston volume . From the previous figures we note the maximum temperature is concentrated on the top face of the piston. Temperatures values decrease with increasing the distance from top face of

piston, and that means the numerical modal is active to describe the temperature distribution and temperature gradient in piston volume.
Fig.s (3.4.5,b)show temperature distribution in the rings material , also the figures (6,7,8 b) show the thermal stress in these rings. The temperature and stress distribution is differ from that in the piston material and that because of the different in the material conductivity, where the ring was made of the cast iron .From the numerical results we can conclude those models are active in analysis temperature and stress in these components .

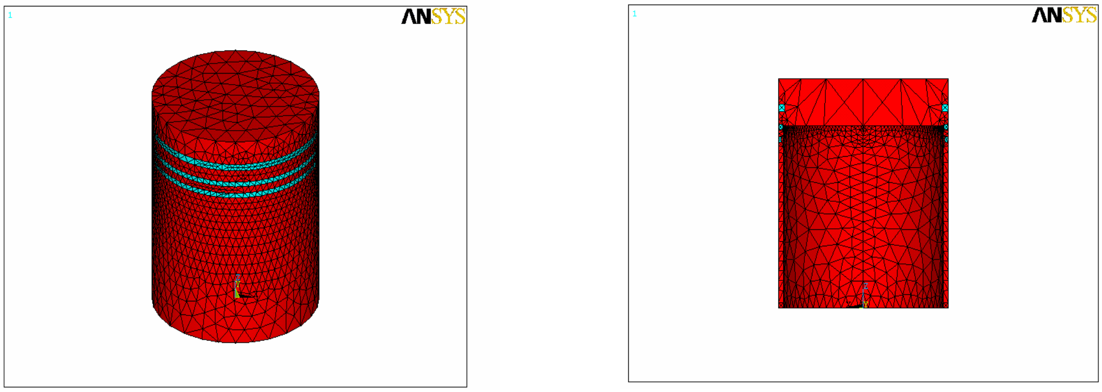
Table (1) Hpp prototype engine geometrical
information and operation conditions [3]

Bore	130mm
Stroke	150mm
Connecting rode length	273mm
Compression ratio	17.25
Boost pressure	2. 85 bar
Boost temp.	315°K(42°C)
Engine speed	1420 R.P.M

Table (2) material properties of model component

Components	Piston (alloy1) 2.5% Si	Piston (alloy1) 8% Si	Piston (alloy1) 12% Si	Rings (cast iron)
E (GPa)	60	65	70	190
K ($Wlm.k$)	229	200	180	90

Fig.(1) : Geometry Sub-model



a b

Fig (2) Element Generation

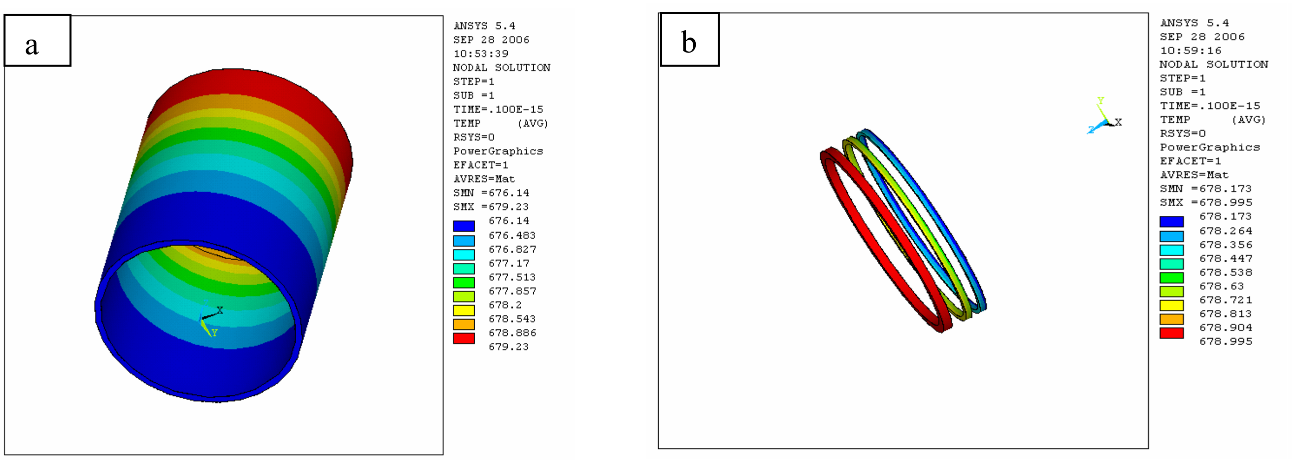


Fig (3) temperature distribution a, piston (alloy1) b-rings

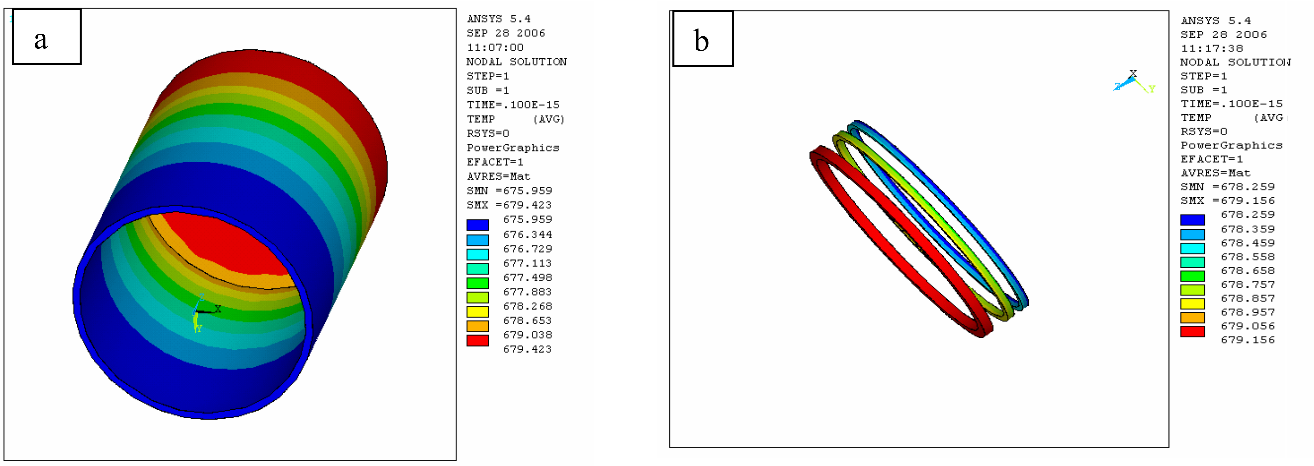


Fig (4) temperature distribution a, piston (alloy2) b-rings

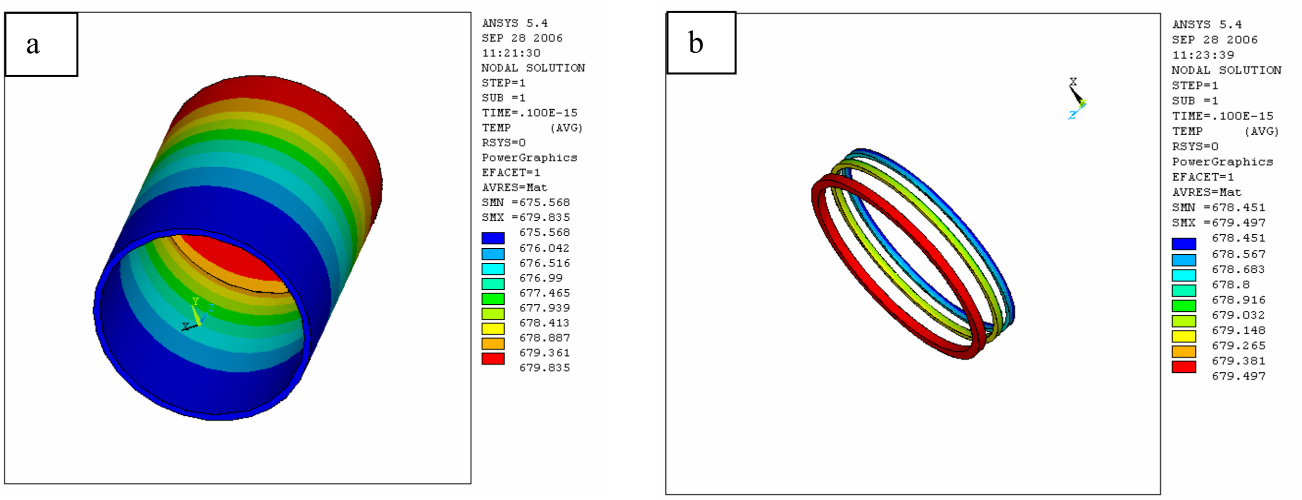


Fig (5) temperature distribution a, piston (alloy3) b-rings

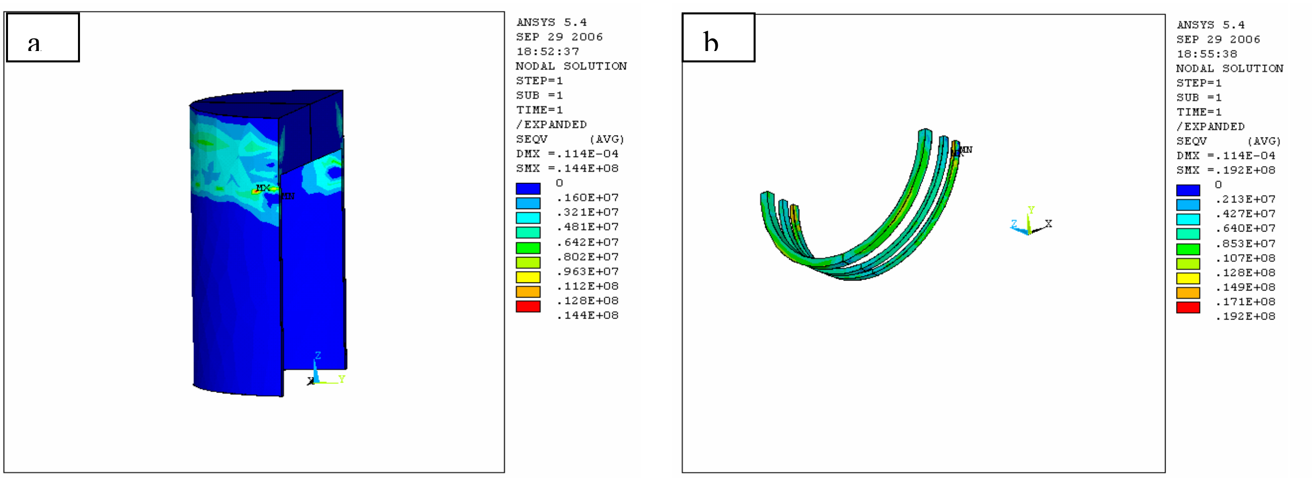


Fig (6) stress distribution a, piston (alloy1) b-rings

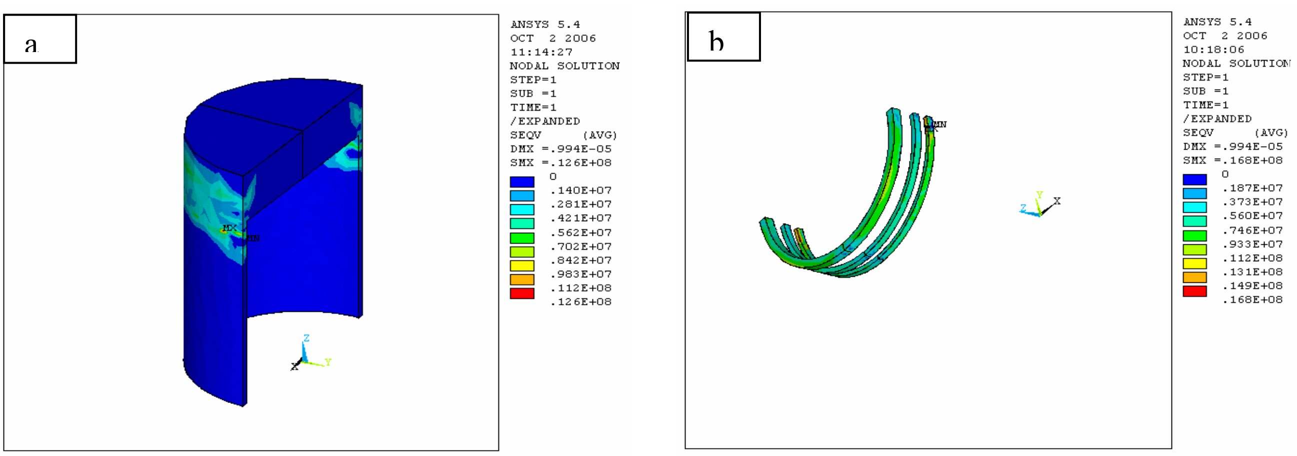
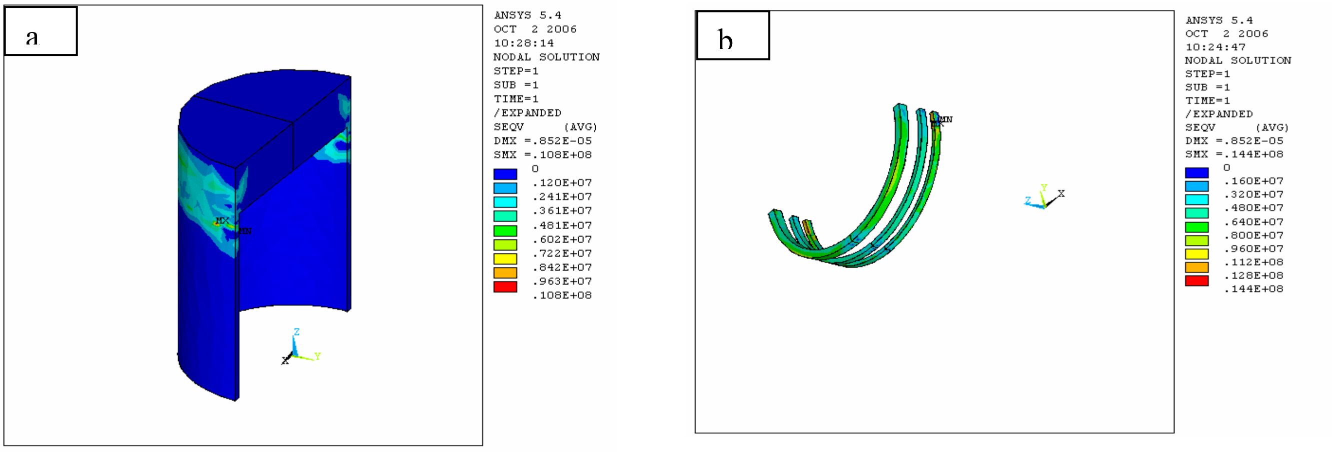


Fig (7) stress distribution a, piston (alloy2) b-rings



Fig(8) stress distribution a, piston (alloy3) b-rings

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