COUPLED FIELD ANALYSIS OF CYLINDER SLEEVE (COATED/UNCOATED) WITH RESPECT TO PISTON USING MATLAB & FEA

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Abstract:- *Now a days various methods are in use on cylinder piston group for improving service life and performance of I.C Engine .In this study is to design and coupled field analysis of a dry cylinder liner with respect to piston, piston rings for Diesel engine . As the performance of cylinder liner mainly depends on the design and material selected for manufacturing it. Developed a MATLAB code for design calculations to piston, piston rings, cylinder liner (coated/uncoated) by taking input parameters like Atmospheric and working pressures, Brake power, Engine speed, Thermal conductivity of different materials Greycastiron, Carbon steel and NiCrAl, Al_2O_3 (coating materials).To obtain output as Heatflux and Dimensions required to draw a model in CATIA V_5 software. Coupled field analysis done in FEA to obtain Heat flux, Temperature gradient, Equivalent stress, Deformation for the materials. Comparing the results will be recommend the best optimized material for the cylinder liner and also best coated material to be applied on the cylinder liner.*

Keywords: *Improving service life of I.C engine, Heat Flux, Thermal Conductivity, Equivalent stress, Cylinder liner coating.*

INRODUCTION

A cylinder liner is a cylindrical part to be fitted into an engine block to form a cylinder. It
is one of the most important functional parts to make up the interior of an engine[1]. This is called Cylinder liner in Japan, but some countries (or companies) call it as Cylinder sleeve. Cylinder liner being a part of engine is exposed to high temperatures ranging between 1800K and 2400K and is directly related to the overall performance and it gives a wear protective surface for piston and piston rings, and also must permit the piston and its sealing rings to move with a minimum of friction[2] . When excessive wear occurs in a block the cylinder must be re-bored or honed. Reconditioning the liner is the inconvenience, especially in large engines, of having to remove the entire cylinder block from a engine in order to replace the cylinder liner. Currently dry liners are coated so they provide longer service life. Because the ability of dry liners to transfer heat depends on having the best surface contact area in the cylinder block bore, they are designed to expand slightly more than uncoated cylinder liner when they heat to operating temperature[3].In this Thesis further study the effects and importance of cylinder liners, and possible ways to optimize the material of cylinder liner to meet engine life and performance and also coating is used on the cylinder liner material in order to increase the life of the cylinder liner[4,5].

Engine Specifications
Engine Type: 4-stroke Diesel engine
Bore : 170mm
Stroke: 350mm
Brake power: 30kw
Engine speed: 1440rpm
Working pressure: 20bar
Compression ratio: 19:1

Table 1: Properties of Cylinder liner Materials

S.no	Material name	Young modules (mpa)	Density (g/cc)	Passion ratio	Thermal conductivity k/	Thermal expansion
1	Grey cast iron (Cylinder linear)	110000	7.34	0.23	51.5	1.05×10^{-6}
2	Carbon steel (Cylinder linear)	96000	7.87	0.29	78	9.4×10^{-6}
3	Aluminium alloy	71000	2.79	0.3	155	2.3×10^{-6}

	(piston)					
4.	CAZR0_3 (piston coating material)	23300	4.47	0.28	3.4	1.1×10^{-6}
5.	NICR al (cylinder linear)	90000	2.5	0.27	16.4	1.85×10^{-6}
6.	AL$_2$0$_3$ (cylinder linear)	300000	3.72	0.21	25	1.5×10^{-5}

MATLAB code for coated/uncoated cylinder liner with respect to pistonhead, pistonrings

```
clc
clear all
n=1.25; %is the ratio of specific heat
p1=input('Enter the Value of atm. Pressure=101330 N/m^2;  ');
p3=input('Enter the Value of working Pressure =2e6 N/m^2;  ');
BP=input('Enter the Value of Brake Power =30 KW;  ');
N=input('Enter the Value of Engine Speed RPM =1440 ;  ');
ts=input('Enter the Value of Tensile Stress = 60e6 N/m^2;   ');
ma=input('Enter the Value of mass of the air intake  Kg/s =0.0375 ;  ');
mf=input('Enter the Value of mass of the fuel intake  Kg/s =0.21 ;  ');  % Avg fuel consumption for diesel engine
mu=input('coefficent of friction = 0.1;  ');
k=input('thermal Conductivity of cylinder wall (W/m-K) for , Gray Cast iron =51.5,  Carbon Steel = 78;  ');
E=input('Young's Modulus in Gpa  for Gray Cast iron =140e9, Carbon Steel = 96e9;  ');
a=input('coefficient of linear thermal expansion of cylinder liner for Gray Cast iron =10.5e-6,Carbon Steel =9.4e-6;
Ylimit=input('Yield limit of the liner material in Mpa  ');
kn=input('thermal Conductivity of coated material on piston (W/m-K) for CaZrO3 3.4,  ');
Xn=input('thickness of coating on piston (m) for CaZrO3 0.001,  ');
ky=input('thermal Conductivity of coating cylinder liner (W/m-K) for NiCrAl 16.4, Al2O3 25,   ');
p2=sqrt(p1*p3);
Ra=287; % gas constant for dry air (equal to 286.9 J/kgK)
T1=297; % [K] – intake air temperature
pa=1.2e5; % [Pa] – intake air pressure
rowa= pa/(Ra*T1); % [kg/m3] – intake air density
Vd= 1.2e-3; % theoretical volume of the engine/cylinder Vd [m3]
nr=2; % number of crankshaft rotations for a complete engine cycle (for 4-stroke engine nr = 2)
VE=(ma*nr)/(rowa*Vd*N);% VE=Volumetric Efficiency
ME=0.72; % ME=Mechanical Efficiency
IP=(ME)/(BP);
WD=(IP)*60;% WD=Work Done
T1=300; % 27 deg room temperature
T2=T1*((p2/p1)^((n-1)/n));% T2=Intermediate Temperature
FAD=(ma*Ra*T2*1000)/(p2*N*60);% FAD=Free Air Delivery
Vs=FAD/VE;% Vs=Swept Volume
%D=(sqrt(IP*60*4)/(p3*0.18*pi*(N/2)));% n=N/2 for 4 stroke engines
L=0.21;
D=(sqrt((Vs*4)./(pi.*L)));% D=Diameter of Piston
fprintf('Diameter of Piston (m) %0.4g\n',D)
th1=sqrt((0.162*p3*(D^2))/ts); % th=Thickness of head by working pressure
HCV=38e3; % For Diesel 38e3 kJ/Kg  For petrol 47e3 kj/kg
C=0.005; % ratio of heat absorbed by the piston to the total heat developed by the cylinder
H=(C*HCV*mf*BP);
Pw=5;
t1=D*100*(sqrt((3*Pw)/ts));% t1=Radial Thickness of Piston
fprintf('Radial Thickness of Piston in (m) %0.4g\n',t1)
x=t1;
A=((pi/4)*D^2);
A1=L*x;
R1=(mu*pi*(D^2)*p3)/4;% R1=Maximum Side Thrust
```

```
fprintf('Maximum Side Thrust (N) %0.4g\n',R1)
Pb=0.25;% Pb=Bearing Pressure
l=Ra/(Pb*D);% l=Length of Piston skirt
tg=623; % Mean temperature of the burnd gasses 623 K
pe=65; % effective power of the engine 65 KW
pi=0.1*pe; % Heat flow in the piston
Alpha=280; % Avereage heat transfer coefficent W/m^2 K
%lamp=160; % piston thermal condictivity  W/m K
pi1=1.02;
Tcp= tg-(pi/A)*((15/Alpha)+((D/k)*pi1));
fprintf('Temperature at Piston head (K) %0.4g\n',Tcp)
% h=((z*6)+((1-z)*0.145*110))/((z*46)+((1-z)*110))  [KgH/Kgfuel]
h=18.2;  % Gravimeter composition gasolin c=0.855h=0.145
XC=((pi/A)*((15/Alpha)+(h/k)+((D/k)*pi1)));
Tep= tg-XC;
fprintf('Temperature at piston side wall (K) %0.4g\n',Tep)
% thermal resistance of NiCrAl
th2=(H/(12.56*k*(Tcp-Tep))); % % th=Thickness of head by temprature difference
if th1>th2;
    th=th1;
else th1<=th2;
    th=th2;
end
fprintf('Thickness of head (m) %0.4g\n',th)
rn1=D;
rn2=rn1+Xn;
rn=log(rn2/rn1);
Rni=rn/(2*pi*kn*Xn);
ry1=rn2;
ry2=ry1+Xy;
Ry=log(ry2/ry1);
Ryi=Ry/(2*pi*ky*Xy);
Rtotal=(Rni+Ryi);
Qc=1.1e1;
Tac=Tep-(Qc*Rtotal);
fprintf('Temprature after coating line (k) %0.4g\n',Tac)
hc=800; % convection heat transfer coefficient collent side (W/m^2 K)
hg=150; % Convection heat transfer coeffecent gass side (W/m^2 K)
Tc= 298; % collent temprature in (K)
Tg=Tac; % gas temprature in the combustion chamber
Q=(Tg-Tc)/[(1/hg)+(x/k)+(1/hc)]*A1; % Heat transfer in W
q=(Q/A1)*2.68; % Heat flux W/m^2, 2.68 is the correction factor for 2D modal to 3D modal
fprintf('Heat Flux over Cylinder (W/m^2) %0.4g\n',q)
```

CALCULATIONS

Taking mass of air intake mass of fuel intake , atmospheric pressure , working pressure, Brake power Engine speed as input values

1) $D=\sqrt{(Vs * \frac{4}{\pi} * L)}$ diameter of piston

    VE=ma*nr/rowa*vd*n (volumetric efficiency) ,Where nr=no of crank shaft rotations ,

    rowa=pa/Ra*T1   (intake air density)

    FAD=ma*Ra*T2*1000/P2*N*60 (free air delivery)

    Vs=FAD/VE   (swept volume)

2) Radial Thickness of piston (t1)= $D*100*\sqrt{(3 * pw/ts)}$

Where , ts=Tensile stress of piston Pw=allowable radial pressure on cylinder wall

3) Thickness of piston head

Th= H/(12.56*k*(Tcp-Tep)) Where H=c*Hcv*mf*B.P , HCV=38×10^3 KJ/Kg for diesel

C =0.005 is the ratio of heat absorbed by piston to total heat developed in the cylinder

4) Temperature at piston head (Tcp) =tg - $\emptyset/A((1/\alpha) + (\frac{D}{\lambda p}) * \boldsymbol{\varphi 1})$

5) Temperature at piston side wall (Tep) =tg -$\emptyset/A((1/\alpha) + h/\lambda p + (D/\lambda p) * \boldsymbol{\varphi 2})$

λp=160 w/mk piston thermal conductivity, α = 350 w/m2k avg heat transfer coefficient

$\boldsymbol{\varphi 1}$ =1.02 ,$\boldsymbol{\varphi 2}$ =1.28 ,$\emptyset$ = 0.1pe , Pe= 65 effective power of engine

6) Heat flux over cylinder q =Q/A2 *1.25 Where Q=Tg-TC/((1/hg)-(1/hc)) *Rtotal

Tg =gas temperature in combustion chamber ,Tc=Collent temperature

A2=X*L ,R total =Piston ring resitivity + cylinder liner resitivity.

7) Thermal stress σ = E*a* (T_g-T_c)

E= Youngs modulus in Gpa , a=Coefficient of linear thermal expansion of cylinder liner

T_c = 300k collent side (coolant side) , T_g = gas temperature in the combustion chamber

We know that T_g = Tep (Temperature at piston side wall)

Tep = t_g-X_c , t_g =623k Mean temperature of burned gasses

$X_c = (\frac{\emptyset}{A}) + ((\frac{15}{\propto}) + (\frac{h}{k1}) + (\frac{D}{K1}))* \boldsymbol{\varphi 1}$

$\frac{6.5}{0.01726} + (\frac{15}{180} + \frac{18.2}{160} + \frac{0.148}{160}) * 1.02$ = 76.046

Tep = t_g-X_c = 623 –76.046 =546.95

8) Hoop stress:

Thickness of cylinder liner =8 mm

Inner diameter of cylinder liner =154mm

We know that $t > \frac{d}{20}$ is a thick cylinder

Another reason to say thick cylinder is on the cylinder liner there exerting two pressures one is combustion pressure from in side and other is atmospheric pressure from outside

$\sigma_h = \frac{rc_1^2 P_3 - rc_2^2 P_1}{rc_2^2 - rc_1^2} + \frac{rc_1^2 rc_2^2 (P_3 - P_1)}{rc_2^2 (rc_2^2 - rc_1^2)}$

Where rc_1^2 = inner radius of cylinder liner

rc_2^2 = outer radius of cylinder liner, P_1 =atmospheric pressure, P_3 =working pressure
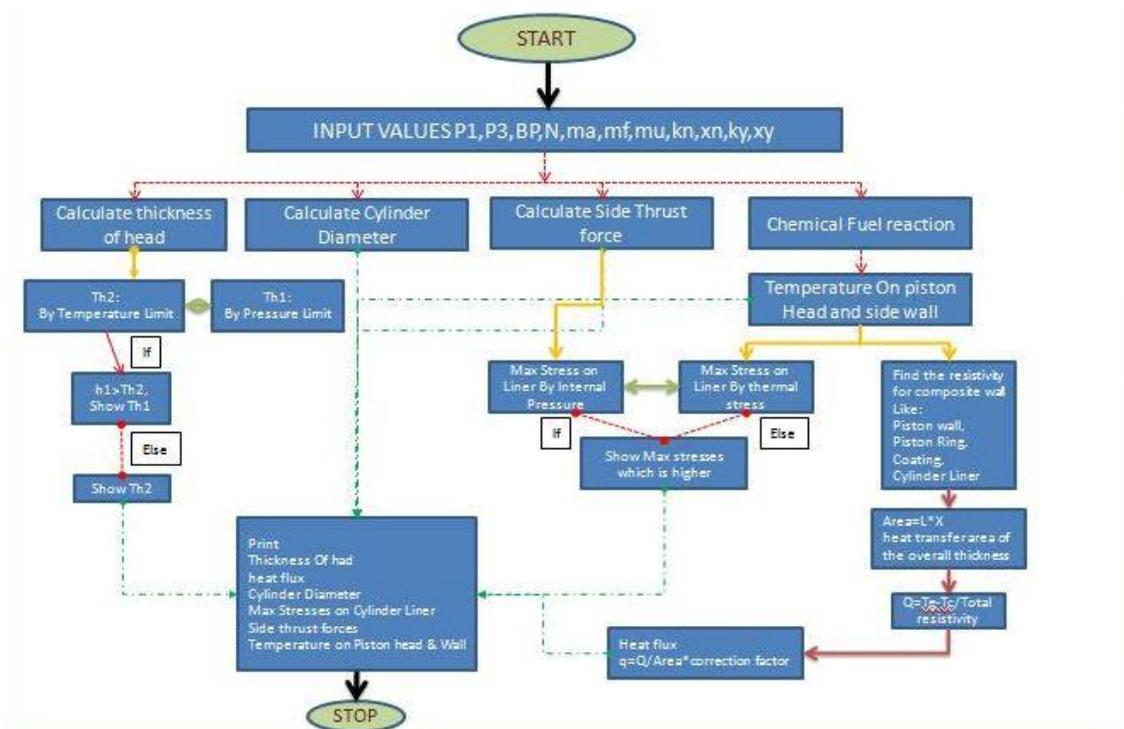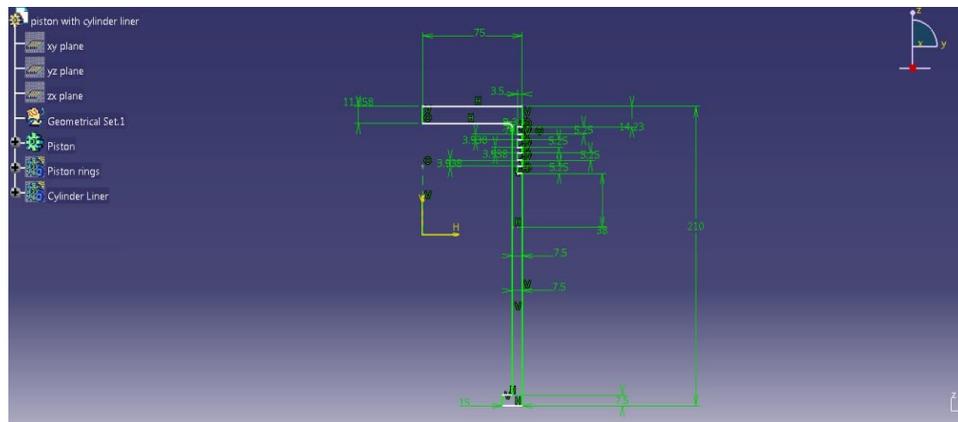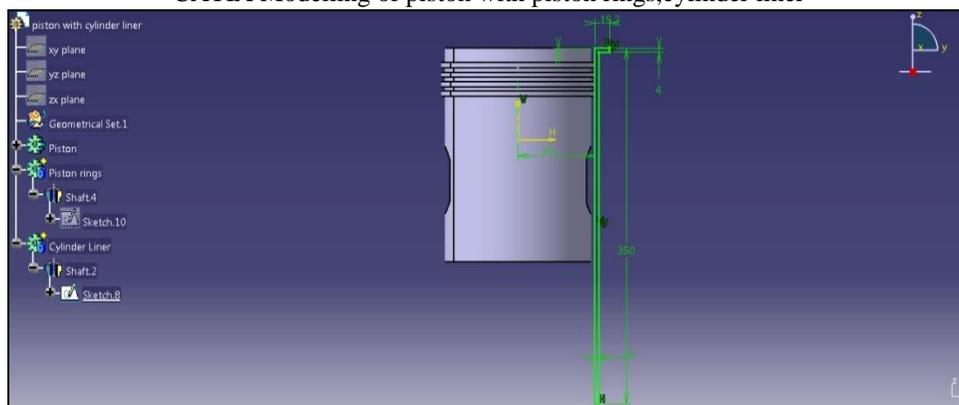
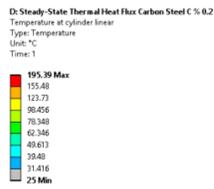**Figure 1:Flow chart for Design calculations in MATLAB**

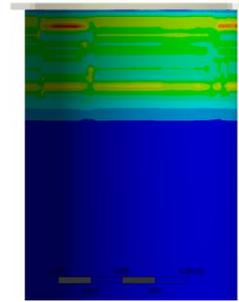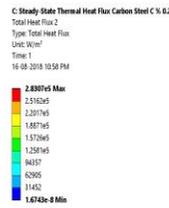Figure 1:CATIA Modelling of piston with piston rings

CATIA Modelling of piston with piston rings,cylinder liner
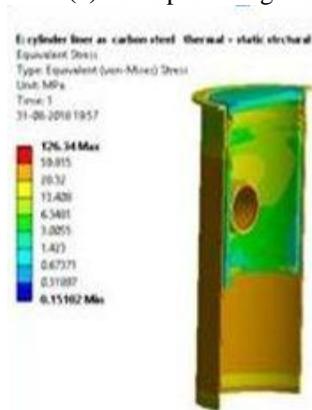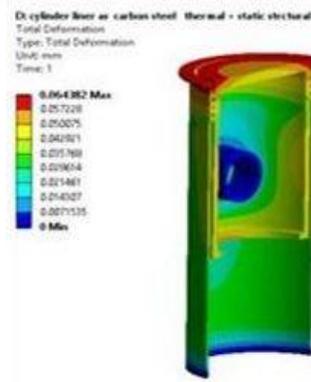
Uncoated cylinder liner
Carbon steel Thermal Analysis
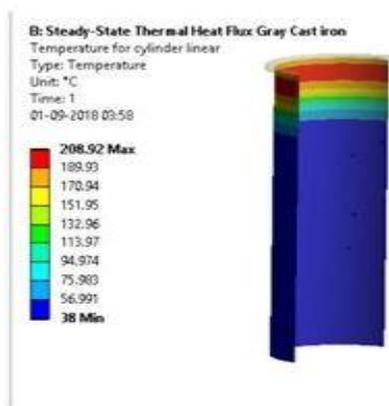

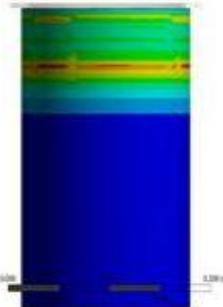| **(a)** Temperature gradient	(b) Heat flux

(c) Equivalent stress	(d) Deformation

Grey Cast Iron Thermal analysis

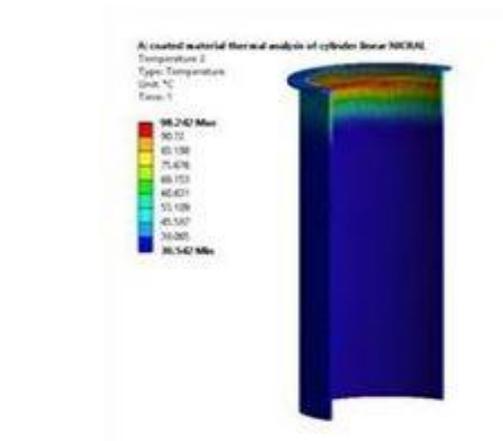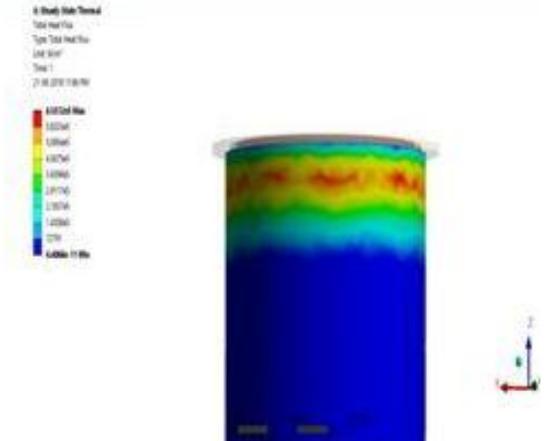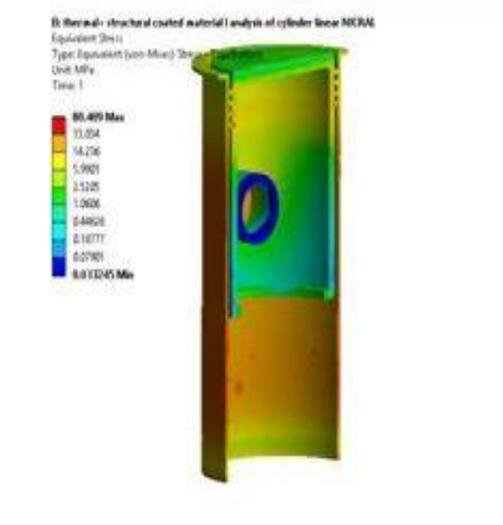| (a) Temperature gradient	(b)Heat flux
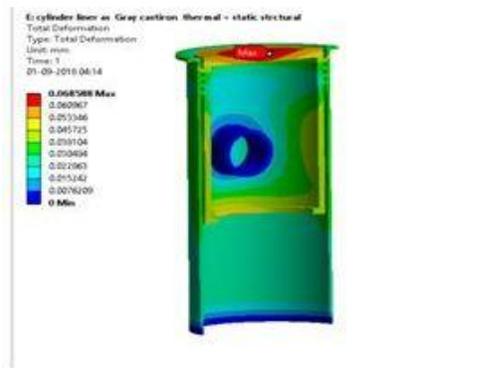
(c) Equivalent stress
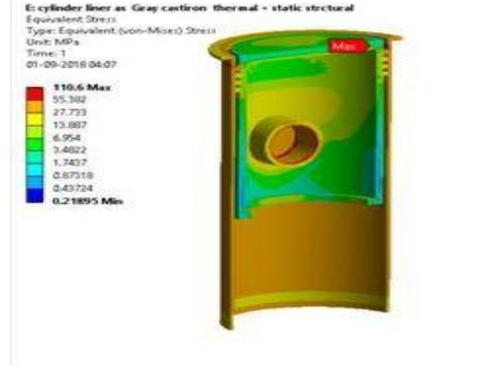
(d) Deformation

Coated Cylinder liner
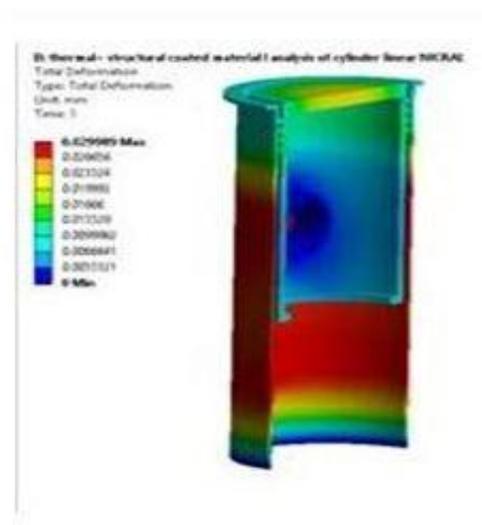Grey Cast iron + NiCrAl Thermal analysis

(a)Temperature gradient

(b) Heat flux

(c) Equivalent stress

(d) Deformation

Grey Cast iron + Al_2o_3 Thermal analysis

(a)Temperature gradient

(b) Heat flux

(c) Equivalent stress

(d)Deformation

Conclusion

After comparing the results of analysis and MATLAB (Theoretically calculated) it has been observed that Grey cast iron is the best cylinder liner material on which best coating material NiCrAl has to be coated. Therefore (Grey Cast Iron + NiCrAL) is best suggested coated material for cylinder liner than (Grey Cast Iron + Al_2O_3). Finally concluded piston with aluminium alloy , piston head coated with CaZr03 , piston ring with structural steel and cylinder liner with Grey Cast iron +NiCrAl. This combination of materials will give better results in the engine over all performance.

FUTURE SCOPE

Further, the life estimation can be carried out to check life of the cylinder liner with or without coating by Fatigue analysis.

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