THERMAL AND STRUCTURAL ANALYSIS OF CONNECTING ROD OF AN IC ENGINE

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Abstract*—The connecting rod is a major link inside of combustion engine. It connects the piston to the crankshaft and is responsible for transferring power from the piston to the crankshaft. It has to work on high r.p.m. because of which it has to bear severe stresses which make its design vital for internal combustion engine. In this paper, a connecting rod for two wheeler is designed by analytical method. On the basis of that design a physical model is created in CATIA V5. Structural system of connecting rod has been analysed using FEA. With the use of FEA various stresses are calculated for a particular loading conditions using FEA software ANSYS WORKBENCH 14.5. The same work is carried out for different material. Also the thermal analysis of the connecting rod is performed. The obtained results are compared on the basis of various performances with considerable reduction in weight.

***Index Terms*—Connecting rod, structural steel, Finite Element Analysis (FEA), thermal behaviour.**

I. INTRODUCTION

The internal combustion engine is basically a crank-slider mechanism, where the slider is the piston in this case. The piston is moved up and down by the rotary motion of crankshaft. The piston is encapsulated within a combustion chamber. The combustion of a fuel occurs with an oxidizer in a combustion chamber which is an integral part of the working fluid flow circuit. In an internal combustion engine, the expansion of the high-temperature and high-pressure gases produced by combustion applies direct force to piston. This force moves the component over a distance, named as connecting rod, crankshaft, which transforms chemical energy into useful mechanical energy.

The valves on top represent suction and exhaust valves necessary for the intake of an air-fuel mixture and exhaust of chamber residuals. In a petrol engines, a spark plug is required to transfer an electrical discharge to ignite the mixture. Some of the important components of the internal combustion engine are Cylinder, piston, piston rings, Connecting rod, crankshaft etc.

The connecting rod forms an integral part of an internal combustion engine. It acts as a linkage between piston and crank shaft. The small end of connecting rod attaches to the piston pin, gudgeon pin (the usual British term) or wrist pin, which is currently most often press fit into the connecting rod but can swivel in the piston. The other end, the bigger end being connected to the crankshaft.

The main function of connecting rod is to transmit the translational motion of piston to rotational motion of crank shaft. The function of the connecting rod also involves transmitting the thrust of the piston to the connecting rod.[6]

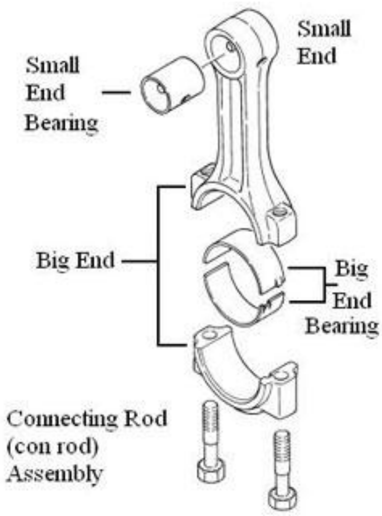


Fig 1: Connecting Rod

The connecting rods subjected to a complex state of loading. It undergoes high cyclic load of order 10^8 to10^9 cycles, that is why it comes under the influence of different types of loads in operation. Fatigue loading is one of the prime causes contributing to its failure. The maximum stress occurs in the connecting rod near the piston end due to thrust of the piston. The tensile and compressive stresses are produced due to the gas pressure, and bending stresses are produced due to centrifugal effect. Due to these factors, the connecting rod has been the topic of research for different aspects such as production technology, materials, performance simulation, fatigue parameter etc. There are different types of materials and production methods used in the creation of connecting rods. The most common materials which are being used for Connecting rods are steel and aluminium. The most common types of manufacturing processes are casting, forging and powdered metallurgy.[7]

From the viewpoint of functionality, connecting rods must have the highest possible rigidity at the lowest weight. So the connecting rods are designed generally of I-section to provide maximum rigidity with minimum weight. On the basis of that design, a physical model is modelled in CATIA V5. Structural system of connecting rod has been analysed using FEA. With the use of FEA, various stresses are calculated for a particular loading conditions using FEA software ANSYS WORKBENCH 14.5.

ANSYS being an analysis system which stands for "Advanced Numerical System Simulation". It is an CAE software, which has many capabilities, ranging from simple static analysis to complex non-linear, dynamic analysis, thermal analysis, transient state analysis, etc. By solid modeling software, the geometric shape for the model is described, and then the ANSYS program is used for meshing the geometry for nodes and elements. In order to obtain the desirable results at each and every point of the model, the fine meshing is done which also results in accurate results output.

PROBLEM STATEMENT

For the analysis of I.C. Engine connecting rod, the most critical area is considered. The objective of the present work is to determine the stresses in critical areas, the spots in the connecting rod where there are more chances of failure. The different dimensions of the connecting rod for Structural Steel is calculated through analytical method. Calculated loads are applied at one end and the other end kept fixed. Same process is carried out for Aluminium alloy. Finally both results are compared for performance, various stresses, weight, life cycles, fatigue life, heat flux etc. and best alternative is defined.

Connecting rod model was created in CATIA V5. After that the model is imported in ANSYS 14.5 (Workbench) for analysis.

II. DESIGN FOR PRESSURE CALCULATION

Consider 150cc Engine

Specifications

Engine type = air cooled 4-stroke
Bore x Stroke (mm) = 57 × 58.6
Displacement = 149.5 CC
Maximum Power = 13.8 bhp @ 8500 rpm
Maximum Torque = 13.4 Nm @ 6000 rpm
Compression Ratio = 9.35:1
Density of Petrol (C8H18) = 737.22 kg/m^3
= 737.22× 10^{-9} kg/mm^3
Auto ignition temp. = $60^{\circ}F$ =288.85°K
Mass = Density x volume
= 737.22× 10^{-9} × 149.5× 10^3
= 0.110214 kg
Molecular weight of petrol = 114.228 g/mole
= 0.11423 kg/mole

From gas equation,
PV=$m \times R_{specific} \times T$
Where,
P = Gas Pressure, Mpa
V = Volume
m = Mass, kg
T = Temperature, °k
$R_{specific}$ = Specific gas constant = R/M
$R_{specific}$ = 8.3144/0.114228
$R_{specific}$ = 72.788 Nm/kg K
P = $m \times R_{specific} \times T/V$
P = 0.110214 x 72.788 x (288.85 / 149.5)
= 15.49 Mpa ≅ 16 Mpa
Calculation is done for maximum Pressure of 16 Mpa.

III. PROPERTIES OF MATERIAL

Properties \ Material	Structural Steel	Al-360
Young's Modulus,(E)	2.0 × 10^5 MPa	2.1 × 10^5 MPa
Poisson's Ratio	0.30	0.33
Tensile Ultimate strength	460 MPa	317 MPa
Tensile Yield strength	250 MPa	280 MPa
Density	7850 kg/m^3	2770 kg/m^3
Behaviour	Isotropic	Isotropic

Table 1: Properties of Material

Chemical Composition of Materials

Structural Steel

C	Mn	N	P	S
0.25%	1.25%	0.012%	0.045%	0.045%

Table 2: Chemical Composition of Steel

Aluminium Alloy (Al360)

Cu	Mn	Fe	Tin	Nickel	Silicon	Zinc
0.6%	0.4%	1.3%	0.15%	0.05%	0.09%	0.035%

Table 3: Chemical Composition of Aluminium Alloy

IV. DESIGN CALCULATION FOR THE CONNECTING ROD

- Thickness of the flange & web of the section = t
- Width of the section, B = 4t
- Height of the section, H = 5t
- Area of the section, A = $11t^2$
- Moment of inertia about x-axis, Ixx = $34.91t^4$
- Moment of inertia about y-axis, Iyy =$10.91t^4$
- Therefore Ixx/Iyy = 3.2
- Length of the connecting rod (L) = 2 times stroke
L = 117.2 mm

Total Force acting F = $F_P - F_I$
Where,
F_P= force acting on the piston
F_I = force of inertia
$F_P = \left(\frac{\pi}{4}\right) D^2$ ×Gas pressure
Where,
D = Bore Diameter
$F_P = \left(\frac{\pi}{4}\right) 57^2 \times 15.49 = 38275$ N

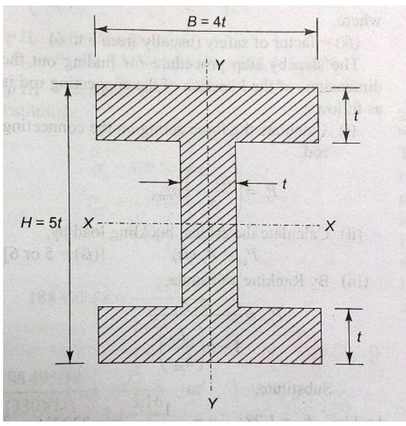


Fig 2: I Section Standard Dimensions of Connecting Rod

$F_I = m \times \omega^2 \times r\left(cos\emptyset + \frac{cos2\emptyset}{n}\right)$

Where,

M = Mass

$\omega = \frac{2\pi 8500}{60} = 890.118\ rad/sec$

n = length of connecting rod(l) / crank radius(r)

=$(2 \times stroke)/(stroke/2)$

=117.2/29.3

$\therefore n = 4$

Refer fig for $\emptyset$,

The maximum gas load occurs shortly after the dead centre position at $\emptyset = 3.3^{\circ}$

$\cos(3.3) = 0.9983 \cong 1$

$\therefore F_I = 0.110214 \times 890.118^2 \times 0.0293\left(1 + \frac{1}{4}\right)$

=3200

So, F = 38275-3200 = 35075 N

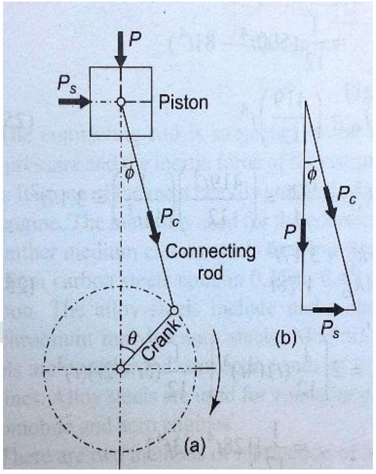


Fig 3: Dead Centre Position for Max Gas Load

According to Rankin's – Gordon formula,

$F = \frac{\delta_c A}{1+a\left(\frac{l}{Kxx}\right)^2}$

Where,

A = c/s area of connecting rod

l = Length of connecting rod

δc= Compressive yield stress

F = Buckling load

a = Constant depending upon material and end fixity coefficient

Kxx and Kyy = Radius of gyration of the section about x – x and y – y axis respectively.

On substituting to Rankin's formula

35075 = $\frac{170\times 11t^2}{1+0.002(117.2/1.78t)^2}$

By solving this,

t =5.5 mm

Therefore,

Width B = 4t = 22 mm

Height H = 5t = 27.5 mm

Area A = $11t^2$ = 332.75 mm^2

Height at the small end H1 = 0.75H to 0.9 H

H1 = 0.9× 27.5= 24.75 mm

Height at the big end H2 = 1.1H to 1.25H

H2 = 1.25× 27.5 = 34.375 mm

Design of small end:

Load on the small end (F_p) = Projected area ×Bearing pressure

= $dplp$ ×Pbp

Where,

Fp = 38275 N load on the piston pin

d_p = Inner dia. of the small end

l_p = length of the piston pin

= 1.5d_p to 2d_p

Pbp = Bearing pressure

= 10.0 for oil engines.

= 12.5 to 15.4 for automotive engines.

We assume it is a 150cc engine, thus

Pbp = 15.4 Mpa

Substituting,

38275 = $2d_p \times d_p \times 15.4$

$\therefore d_p = 35$ mm

l_p =2d_p= 70 mm

Outer diameter of small end = $d_p + 2t_b + 2t_m$

= 35 + [2×2] + [2×5]

= 49 mm

Where,

Thickness of bush (t_b) = 2 to 5 mm

Marginal thickness (t_m) = 5 to 10 mm

Design of Big end:

Load on the big end (F_c) = Projected Area ×Bearing pressure

= $dclc$ ×Pbc

Where,

Fc = 38275 N load on the crankpin

d_c = Inner dia. of the big end

l_c = length of the crank pin

= 1.25d_c to 1.5d_c

Pbc = 5 to 12.6 Mpa

Substituting,

38275 = 1.5$d_c \times d_c \times 12.6$ $\therefore d_c = 45$ mm

l_c = 1.5d_c= 67.5 mm

Outer diameter of big end = $d_c + 2t_b + 2t_m + 2d_b$

= 45 + [2×2] + [2×5] + [2×2]

= 63 mm

Where,

Thickness of bush (t_b) = 2 to 5 mm

Marginal thickness (t_m) = 5 to 10 mm

Marginal thickness of bolt (d_b)= 2 to 5 mm

Final Dimensions of connecting rod

Parameters	Size (mm)
Thickness (t)	5.5
Width (4t)	22
Height (5t)	27.5
Height at the small end (H1)	24.75
Height at the big end (H2)	34.375
Inner dia. of the small end	35
Outer diameter of small end	49
Inner dia. of the big end	45
Outer diameter of big end	63

Table 4: Parameters of connecting Rod

V. FEA OF CONNECTING ROD

Modelling

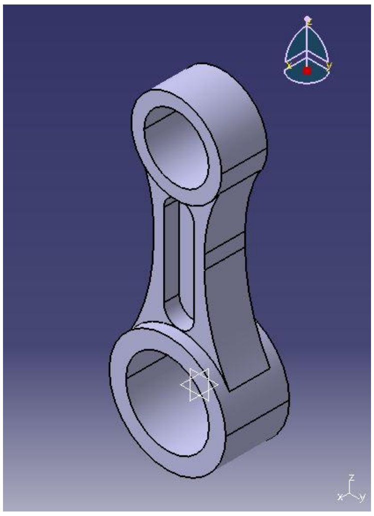
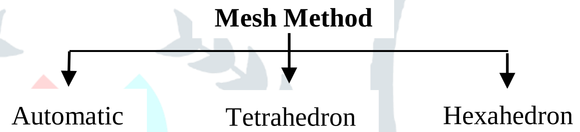


Fig 4: 3D Model

Mesh

Any continuous object has infinite degrees of freedom and it's just not possible to solve the problem in this format. Finite Element Method reduces the degrees of freedom from infinite to finite with the help of discretization or meshing (nodes and elements). So, in ANSYS, following are the basic methods being used for meshing

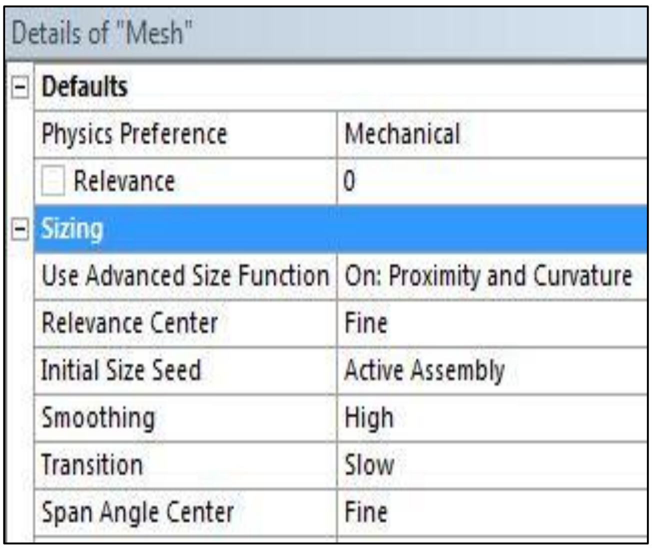


Mesh Method	Nodes	Elements
Automatic	2490	1234
Tetrahedron	2523	1257
Hexahedron	3163	1009

Table 5: Mesh Methods

As we see the above table, Automatic mesh method gives poor number of nodes and elements. With the help of Hexahedron mesh method, it gives more number of nodes but less number of elements, due to this, the complications to solve the problem will rise. Tetrahedron mesh method gave appropriate mesh results.

Selecting Tetrahedron method with choosing improved sizing of mesh as shown in fig, We got maximum number of Nodes: 184770 and Elements: 124599



Details of "Mesh"

Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	On: Proximity and Curvature
Relevance Center	Fine
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Slow
Span Angle Center	Fine

Fig 5: Details of Mesh

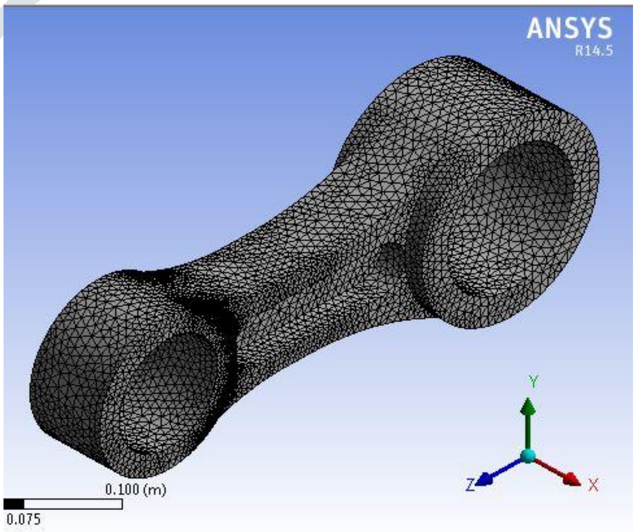


Fig 6: Meshing of Connecting Rod

Loading Conditions

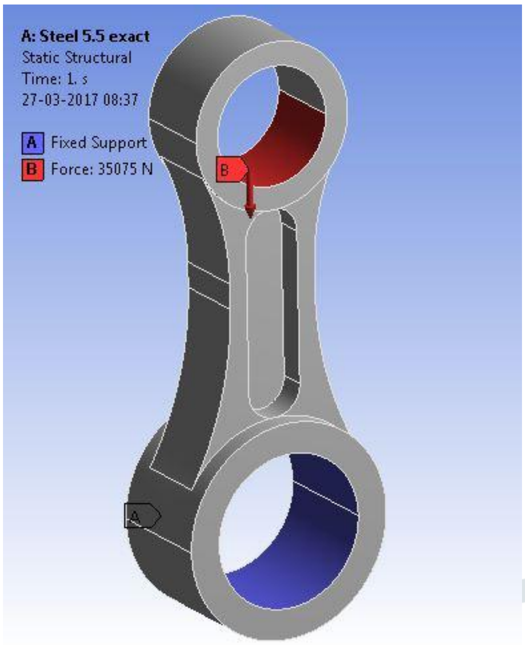


Fig 7: Small End Loaded

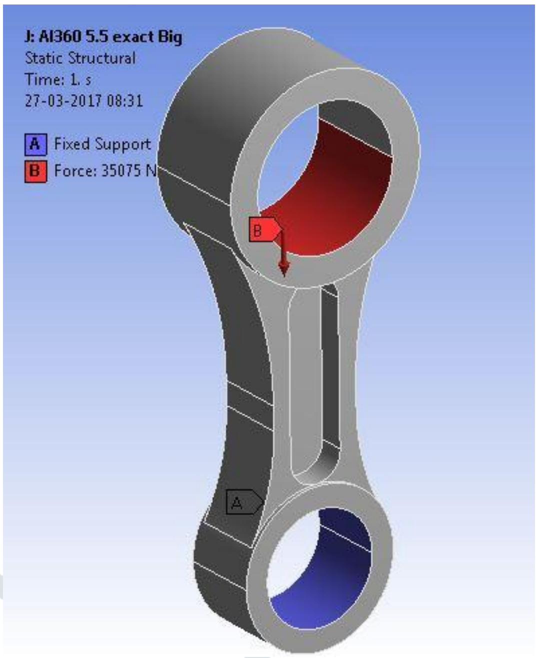


Fig 8: Big End Loaded

Analysis of Structural Steel connecting rod
Small End Loaded

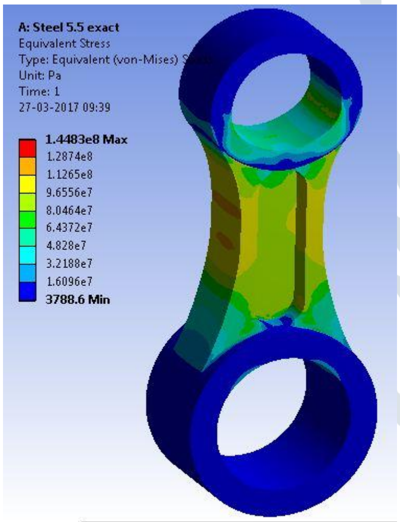


Fig 9: Equivalent Stress

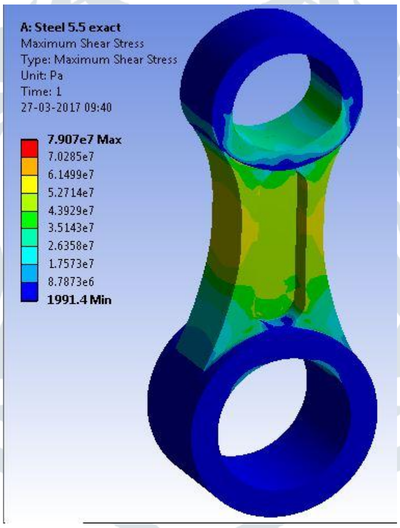


Fig10: Max Shear Stress

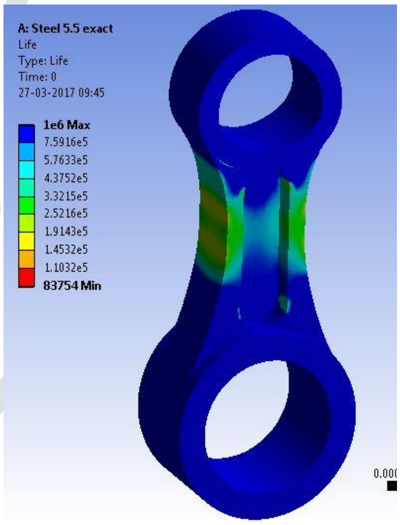


Fig11: Fatigue Life

Big End Loaded

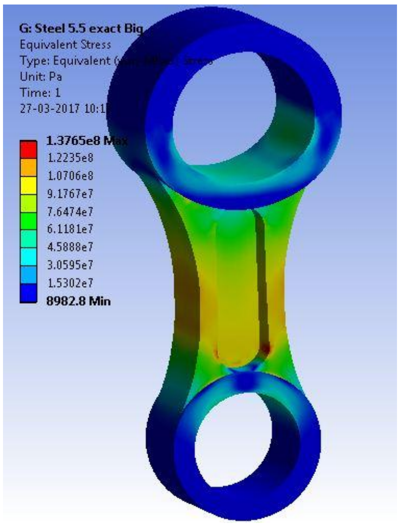


Fig12: Equivalent Stress

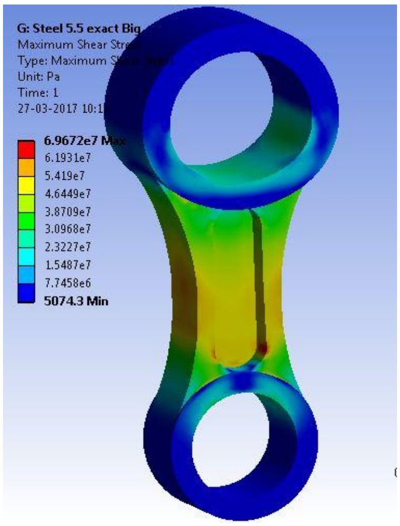


Fig13: Max Shear Stress

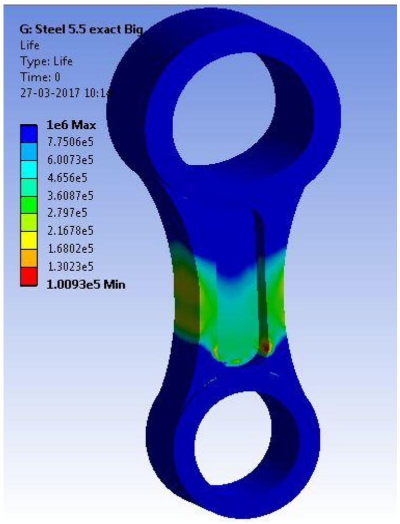


Fig14: Fatigue Life

Analysis of Aluminum Alloy (Al 360)
Small End Loaded

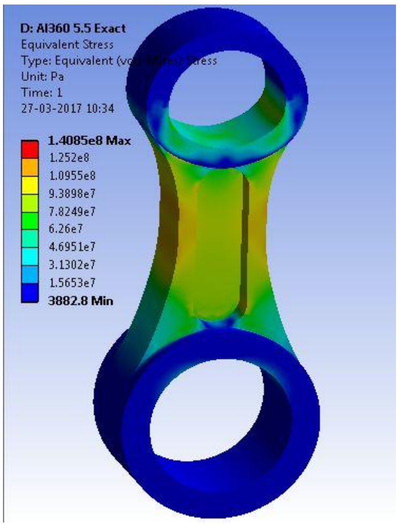


Fig15: Equivalent Stress

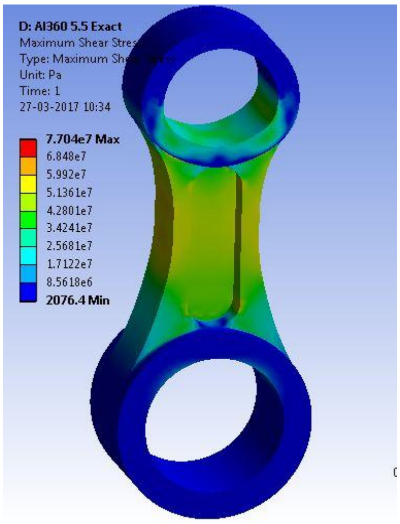


Fig16: Max Shear Stress

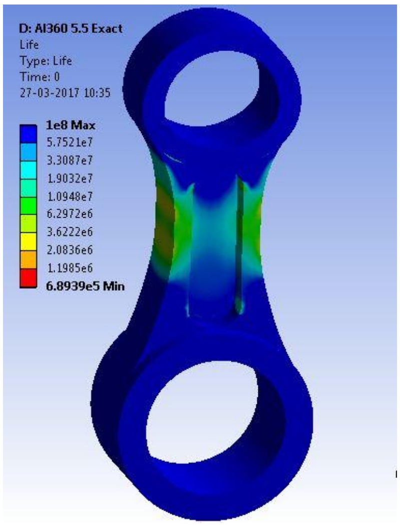


Fig17: Fatigue Life

Big End Loaded

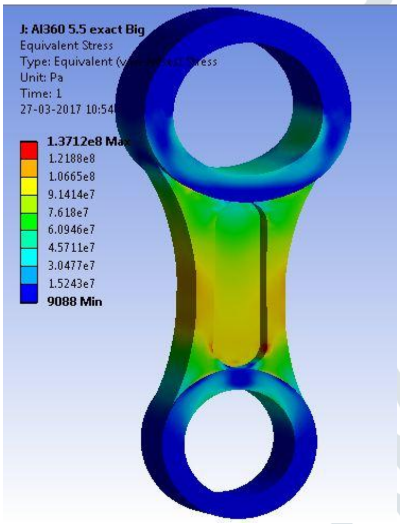


Fig18: Equivalent Stress

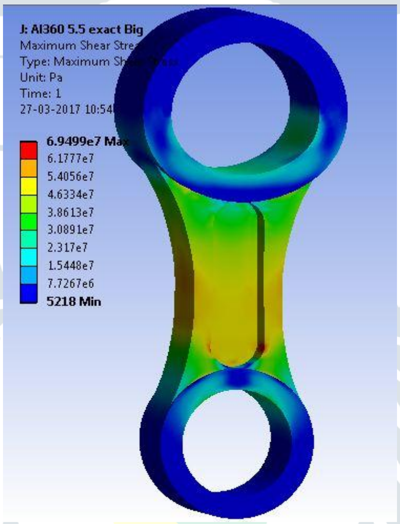


Fig19: Max Shear Stress

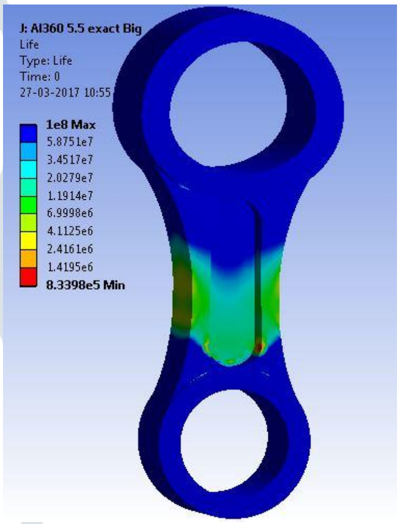


Fig20: Fatigue Life

Thermal Analysis
Thermal Analysis of Structural steel connecting rod

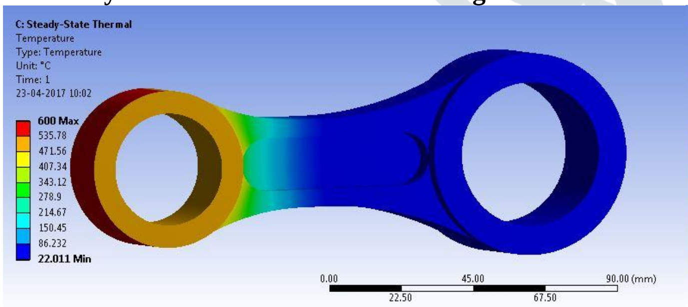


Fig21: Temperature Distribution

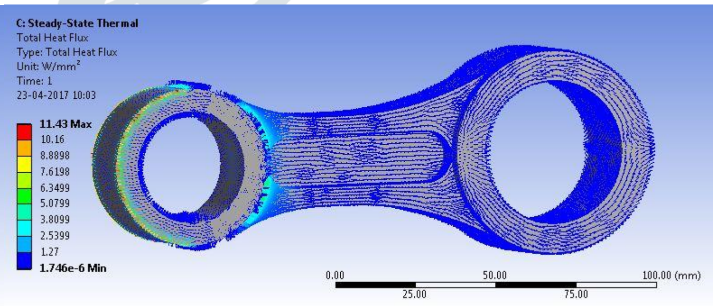


Fig22: Total Heat Flux

Thermal Analysis of Al-360 connecting rod

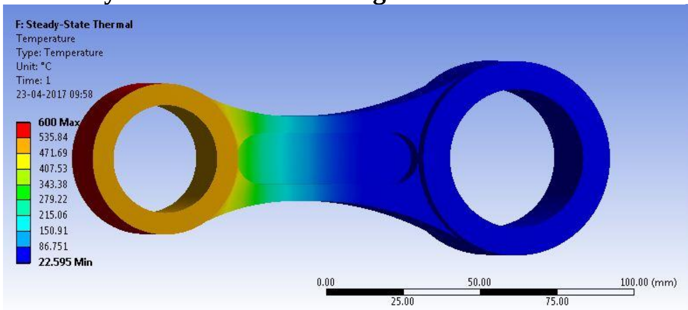


Fig23: Temperature Distribution

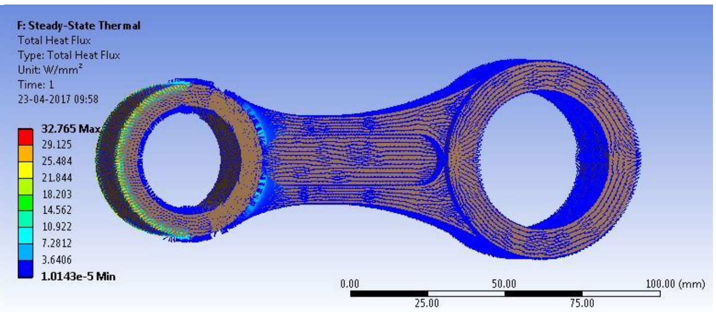


Fig24: Total Heat Flux

VI. RESULTS

Mech. Values \ Materials		Stainless Steel	Al 360
Small End Loaded	Equivalent Stress	144.83 Mpa	140.85 Mpa
	Max. Shear Stress	79.07 Mpa	77.07 Mpa
	Fatigue Life	10^6 Cycles	10^8 Cycles
Big End Loaded	Equivalent Stress	137.65 Mpa	137.12 Mpa
	Max. Shear Stress	69.67 Mpa	69.49 Mpa
	Fatigue Life	10^6 Cycles	10^8 Cycles
Thermal	Total heat flux	11.43 W/mm^2	32.765 W/mm^2

Table 6: Results

Weight of Connecting Rod

Structural Steel

Weight = Mass (Kg) × Gravity (m/s^2)
= 0.8255 × 9.81
= 8.098 N = 0.83 Kg

Aluminium Alloy

Weight = Mass (Kg) × Gravity (m/s^2)
= 0.2913 × 9.81
= 2.8576 N = 0.29 Kg

∴ Reduction in weight = 0.54 kg = 540 grams

VII. CONCLUSION

- Weight is reduced by 540 grams.
- There is reduction in equivalent as well as maximum shear stress for Al-360 connecting rod.
- New connecting rod has higher life cycles than steel connecting rod.
- Total heat flux for Al-360 connecting rod is 32.765 W/mm^2 which is higher than the total heat flux of structural steel.

VIII. SCOPE FOR THE FUTURE WORK

A lot has been done and still lot has to be done in this sector. This dissertation is focused only on static structural, finite element analysis. So, the further study may include dynamic loading and working conditions of the connecting rod. With the reference of thermal analysis, as oil holes are being provided on connecting rod, one can use CFD analysis to check and improve the thermal behavior of connecting rod.

Further one can investigate the behavior of connecting rod for the evaluation of performance of existing model by carrying out Experimental Stress Analysis (ESA). Now a day a lot is being said about vibration study of mechanical components which play important role in its failure. So the study may be extended to the vibration analysis of the connecting rod.

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