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Static Load Analysis of Carbon Fiber Connecting Rod

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Abstract–The connecting rod is the intermediate member between the piston and the Crankshaft. Its primary function is to transmit the push and pull from the piston pin to the crank pin, thus converting the reciprocating motion of the piston into rotary motion of the crank. This paper describes designing and Analysis of connecting rod. Thus, this study aims to carry out for the load, strain and stress analysis of the connecting rod of different materials. Based on which the Std. Unidirectional Carbon Fiber connecting rod will be compared with connecting rod made up of Stainless Steel and Aluminum Alloy. In this, drawing is drafted from the calculations. A parametric model of Connecting rod is modeled using **inventor software** and, analysis is carried out by using **ANSYS 15.0 Software.** The best combination of parameters like Von misses Stress and strain, Deformation, Safety Factor and weight reduction can be used to identify the section where chances of failure are high due to stress induced and for design modification of the connecting rod.

Keywords: Connecting Rod, Inventor, FEA, ANSYS, Crank, Crankshaft, Piston, Carbon Fiber, Aluminum Alloy.

1. INTRODUCTION

Connecting Rods are used practically generally used in all varieties of automobile engines. Acting as an intermediate link between the piston and the crankshaft of an engine of an automobile. It is responsible for transmission the up and down motion of the piston to the crankshaft of the engine, by converting the reciprocating motion of the piston to the rotary motion of crankshaft. While the one end, small end the connecting rod is connecting to the piston of the engine by the means of piston pin,the other end, the bigger end being connected to the crankshaft with lower end big end bearing by generally two bolts.

Generally connecting rods are being made up of stainless steel and aluminium alloy through the forging process, as this method provides high productivity and that too with a lower production cost. Forces generated on the connected rod are generally by weight and combustion of fuel inside cylinder acts upon piston and then on the connecting rod, which results in both the bending and axial stresses. Therefore in order to study the strain intensity, stress concentration and deformation in the crank end of the connection rod, firstly based on the working parameter and the vehicle chosen the design parameter or dimensions of the connecting rod is calculated, then the model of the connecting rod parts is prepared and finally it is analyzed using Finite Element Method and results thus achieved will provide us the required outcome of the work done here .Also further study can also be carried out later on for the dynamic loading working conditions of the connecting rod and also improvement in design can also be made for operation condition and longer life cycle against failure.

Inventor software is used for modeling of the connecting rod model and ANSYS 15.0 is for analysis. ANSYS being an analysis system which stands for “Advanced Numerical System Simulation”.

2. SPECIFICATION OF THE PROBLEM

The objective of the present work is to design and analysis of a connecting rod based upon its material properties by using connecting rod of different materials. Here Stainless Steel, Aluminum Alloy and Std. unidirectional Carbon fiber are used to analyze the connecting rod. The material of connecting analysis result output. CAD model of connecting rod will be modeled in Inventor, and then be analyzed in ANSYS Software. After analysis a comparison will be made between existing material and alternate material which will be suggested for the connecting rod in terms of deformation, stresses and strain. and the desired output results can achieved.

3. OBJECTIVE

1. Designing of the connecting rod is based on the input parameters and then modeling of the connecting rod in the Inventor 2014 software.
2. FEM tool software ANSYS 15.0 is given model and material input based on the parameters obtained.

3. To determine the Von Misses stresses, Strain Intensity, Total Deformation and to optimize in the existing Connecting rod design.
4. To calculate stresses in critical areas and to identify the spots in the connecting rod where there are more chances of failure.
5. To reduce weight of the existing connecting rod based on the magnitude of the output of analysis.

The main aim of the project is to determine the Von-Misses Stresses, Strain Intensity output and optimize the new material used for connecting rod. Based on which the new material can be compared with the existing materials used for Connecting Rod.

4. DESIGN OF CONNECTING ROD

A connecting rod is a machine member which is subjected to alternating direct compressive and tensile forces. Since the compressive forces are much higher than the tensile force, therefore the cross-section of the connecting rod is designed as a strut and the rankine formula is used. A connecting rod subjected to an axial load W may buckle with x-axis as neutral axis in the plane of motion of the connecting rod,{or} y-axis is a neutral axis. The connecting rod is considered like both ends hinged for buckling about x-axis and both ends fixed for buckling about y-axis. A connecting rod should be equally strong in buckling about either axis.

According to rankine formulae
Wcr about x-axis

$$= \frac{[\sigma c \times A]}{1+a[\frac{L}{Kxx}]^2} = \frac{[\sigma c \times A]}{1+a[\frac{L}{Kxx}]^2}$$

$$[\therefore for\ both\ ends\ hinged\ L=l]$$

Wcr about y-axis

$$= \frac{[\sigma c \times A]}{1+a[\frac{L}{Kxx}]^2} = \frac{[\sigma c \times A]}{1+a[\frac{L}{2Kxx}]^2}$$

$$[\therefore for\ both\ ends\ fixed\ L=l/2]$$

In order to have a connecting rod equally strong in buckling about both the axis, the buckling loads must be equal. i.e.

$$= \frac{[\sigma c \times A]}{1+a[\frac{L}{Kxx}]^2} = \frac{[\sigma c \times A]}{1+a[\frac{L}{2Kxx}]^2}$$

$$= [\frac{l}{Kxx}]^2 = [\frac{l}{2Kxx}]^2$$

$K^2xx = 4K^2yy$ [or] I xx = 4Iyy $[\therefore I=A\times K^2]$

This shows that the connecting rod is four times strong in buckling about y-axis than about-axis. If I xx > 4Iyy, Then buckling will occur about y-axis and if I xx < 4Iyy, then buckling will occur about x-axis .In Actual practice I xx is kept slightly less than 4Iyy. It is usually taken between 3 and 3.5 and the Connecting rod is designed for buckling about x-axis. The design will always be satisfactory for buckling about y-axis. The most suitable section for the connecting rod is I-section with the proportions shown mfg.

Area of the cross section = 2[4t x t] + 3t x t = $11t^2$

Moment of inertia about x-axis = 2[4txt]+3txt=$11t^2$

Moment of inertia about x-axis

I xx = 112 $[4t\ \{5t\}^3 - 3t\ \{3t\}^3] = 41912[t^4]$

And moment of inertia about y-axis

I yy = $2\times112\times t\times\{4t\}^3+112\{3t\}t^3 = 13112[t^4]$

I xx

I yy = [419/12]x[12/131]=3.2

Since the value of I xx/I yy lies between 3 and 3.5 m therefore I-section chosen is quite satisfactory.

4.1 Pressure Calculation.

Maruti Suzuki SX4 Specifications

(based on homologation Document)

Engine type water cooled 4-stroke
Bore x Stroke (mm) = 78×83
Displacement = 1586 CC
Maximum Power = 104.7 PS @ 5600 rpm

Force Acting on piston

$$Fp = \frac{\pi}{4}\ d^2\ \text{X Gas Pressure}$$

Gas pressure

Density of Petrol C8H18 = 737.22 kg/m^3
= 737.22E-9 kg/mm^3
Flash point for petrol (Gasoline)

Flash point = -43°c (-45°F)
Auto ignition temp. = 280°c (536°F) = 288°k

Mass = Density x volume
= 737.22E-9 x 396.5E3
= 0.29kg

Molecular weight of petrol = 114.228g/mole
= 0.11423 kg/mole

From gas equation,
PV=m * Rspecific * T

Where, P = Pressure, MPa
V = Volume
Rspecific = 8.3143/0.29
Rspecific = 28.67 Nm/kg K

P = m.Rspecific.T/V

$$P = \frac{(0.29*28.67*288.85)}{396\ X\ 10^3}$$

P = 6.06 MPa

P = 6.10 MPa

Force acting on Piston

$$Fp = \frac{\pi}{4}\, d^2\ X\ \text{Gas Pressure}$$

$$Fp = \frac{\pi}{4}\, 78^2\ X\ 6.1$$

Fp = 29148.01

Total Force acting F = Fp - Fi
Where Fp = force acting on the piston
Fi = force of inertia

$$Fi = \frac{1000\ wrv^2}{gv} \times \cos\theta \pm \frac{\cos 2\theta}{n'}$$

wr = weight of the reciprocating parts
wr = 0.673 x 9.81 = 6.24 N
r = crank radius, r = 41.5
Also, θ = Crank angle from dead center = 0
considering connecting rod is at TDC position
n'= length of connecting rod / crank radius

Angular velocity,w= $\frac{2\pi N}{60} = \frac{2\pi\ 5600}{60}$ = 586.43
Crank velocity V= rw = 41.5E^{-3} x 586.43
= 24.33m/sec

$$Fi = \frac{1000\ X\ 6.24\ X\ 24.33^2}{9.81\ X\ 41.5} \times \cos 0 \pm \frac{\cos 2(0)}{4}$$

Fi = 9078.39 N

Therefore, total force acting F = Fp – Fi

F = 29148.01- 9078.39
F = 20069.61 N

According to Rankin's Formulae F,

$$F = \frac{fc \times A}{1 + a[\frac{L}{Kxx}]}$$

A = c/s area of connecting rod
L = Length of connecting rod
Fc = Compressive yield strength
F = Buckling load

$$K_{xx} = \sqrt{\frac{Ixx}{A}} = 1.7t$$

$$a = \frac{\delta c}{\pi E^2} = 0.0004$$

$$F = \frac{fc \times A}{1 + a[\frac{L}{Kxx}]}$$

$$20069.61 = \frac{196 \times 11t^2}{1 + 0.0004[\frac{83}{1.78t}]^2}$$

t = 4.31 mm
t = 4.5 mm

In general,

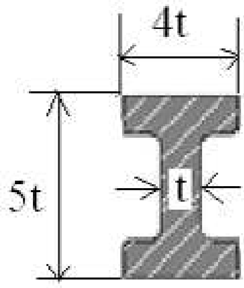

Figure 1: I Section Standard Dimensions of connecting rod

Therefore
Width B = 4t = 18 mm
Height H = 5t = 22.5 mm
Area A = $11t^2$ = 222.75 mm^2

Height at the piston end, H_1 =0.75H– 0.9H
H_1= 0.82X17.5 = 18.45mm
Height at the crank end,H_2=1.1H – 1.25H
H_2= 1.18 X 17.5 = 26.55 mm
Length of the connecting rod (L) = 166mm

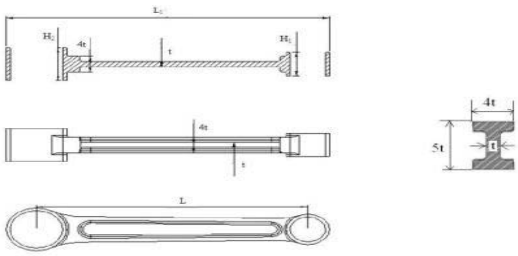

Fig 2: Cross section view of connecting rod.

Design of small end:
Load on the piston pin or the small end bearing (Fp)
= Projected area x Bearing pressure
= *dp X lp* * P_{bp}
Fp= 29148.01 N load on the piston pin,
dp = Inner dia. of the small end
P_{bp} = Bearing pressure
= 10.0 for oil engines.
= 12.7 for automotive engines.
We assume it is a 150cc engine, thus
P_{bp} = 12 MPa
lp = length of the piston pin
lp = 1.75 *dp*
Substituting,
29148.01 = 1.75 *dp X dp*.x 12
dp = 42.81 mm
dp = 43.00mm
lp = 1.75X43 = 75.00 mm
Outer diameter of small end =1.3dp
= 1.3 X 43 = 56.00mm
Od= 50mm

Design of Big end:
Load on crankpin or the big end bearing (Fp)
=Projected Area * Bearing pressure Fp = *dp X lp X* P_{bp}
Fp = 29148.01Nforce or load on piston pin
dp = Inner dia. of big end
lp = length of crankpin = 1.3 dp
P_{bp} = 9 MPa
Putting these,
29148.01 = 1.3dc X dc X 9
Dc = 55.9 =56 mm
Lp = 1.3 X 56 = 76 mm

Design of Big end Bolts:
Force on bolts $=\frac{\pi}{4} d^2 \times \delta t \times Nb$
d_{cb} = Core dia. of bolts
δt = Allowable tensile stress for material of bolts (SAE 3130 = 156.667 MPa)
n_b = Number of bolts(2 bolts are used)
Force on bolts $=\frac{\pi}{4} d^2 \times \delta t \times Nb$
$9078.39 = \frac{\pi}{4} d^2 \times 156.667t \times 2$
D= 6.20mm
Nominal Dia of Bolt Db = $dcb/0.84$
Diameter of bolt = 7.38/ 0.84
Diameter of bolt = 8mm
Use M8 bolt.

Design of Big end Cap:
Maximum bending moment is taken as
$B_{max} = \frac{Fi \ x \ Lo}{6}$

Lo= distance between bolt centre
= dia of crank pin + Nominal dia of bolt+ (2x thickness of bearing liner)+ Clearance

= 50+14+(2 X(0.05*50+1))+3
Lo = 76 mm

$B_{max} = \frac{9078.39 \ x \ 74}{6}$

B_{max} = 114992.94 N.mm

Section Modulus for the cap

$Z = \frac{b \ x \ h^2}{6}$
$Z = \frac{76 \ x \ h^2}{6}$

Z = 12.66 h^2

We know that bending stress

$\delta b = \frac{Bmax}{Z}$ δb = 40.00MPa

$h^2 = \frac{114992.94}{40.00 \, x \, 12.66}$

h^2=227.07
H = 15.06 mm
h = 15.00 mm

Sr.No	Parameters (mm)
01	Thickness of the connecting rod (t) = 4.5mm
02	Width of the section (B = 4t) = 18 mm
03	Height of the section(H = 5t) = 22.5 mm
04	Height at the big end =(1.1 to 1.125H) = 26.55 mm
05	Height at the small end =(0.9Hto0.75H)= 18.45mm
06	Inner diameter of the small end = 43mm
07	Outer diameter of the small end = 56mm
08	Inner diameter of the big end = 58mm
09	Outer diameter of the big end = 88mm
10	Centre distance of bolt = 76mm
11	Length of connecting rod =166mm.

Table 1: Dimensional Specification of connecting rod

5. MODELING OF THE CONNECTING ROD USING Inventor

Inventor software is used to create a complete 3D digital model of connecting rod. The models consist of 2D and 3D solid model data which can also be used downstream in finite element analysis, rapid prototyping, tooling design, and CNC manufacturing. The dimensions are calculated based on the design and working parameters. According the dimensions obtained the model of the connecting rod is developed in the Inventor.

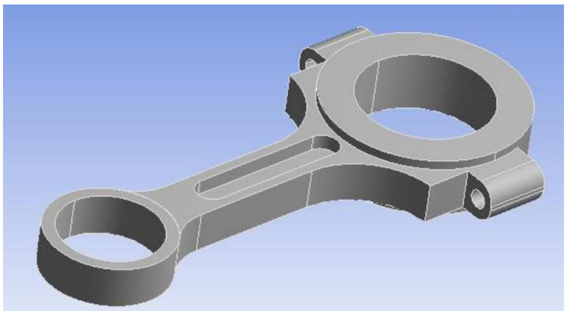

Fig 3: Model of connecting rod in Inventor

6. STATIC FORCE ANALYSIS OF CONNECTING ROD

6.1 Carbon Fiber
6.2 Aluminum Alloy

	Carbon Fiber	Aluminum Alloy 7075
Young modulus	133.9 GPa	71.7 GPa
Poisson Ratio	0.10	0.33
Density	0.155 g/cc	2.81 g/cc
Shear modulus	30 GPa	26.9 GPa
Tensile Strength, Yeild	1050MPa	572MPa
Shear Strength	600 MPa	331MPa

Table 2: Mechanical Properties used for Analysis.

6.1.a Static Force Analysis of connecting rod using magnitude of force of 30KN (taking inertia load into account)

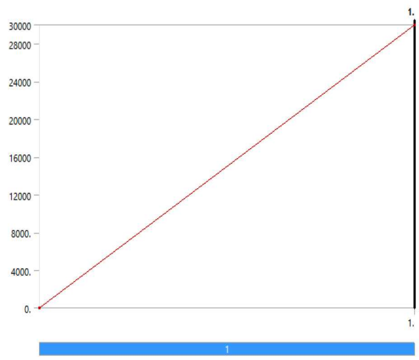

Fig 4: Force Vs Time

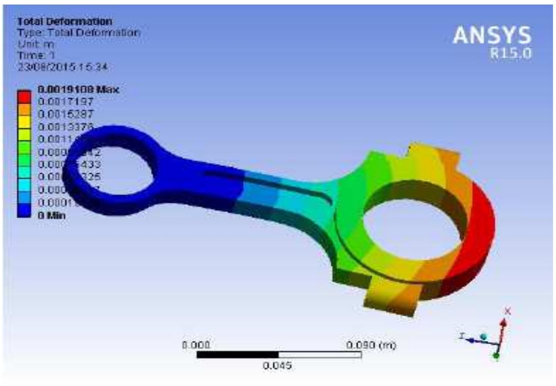

Fig 5: Total deformation of CF Connecting Rod @ 30000N

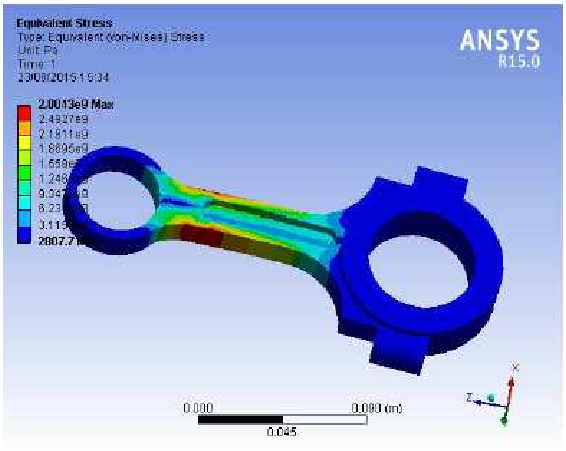

Fig 6: Von-Mises Stress of CF Connecting Rod @30000N

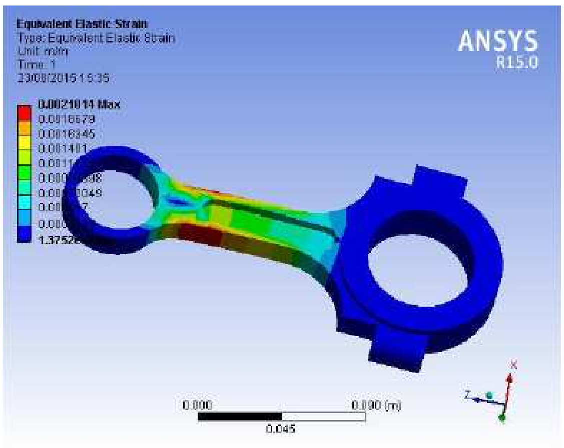

Fig 7: Elastic Strain of CF Connecting Rod @30000N

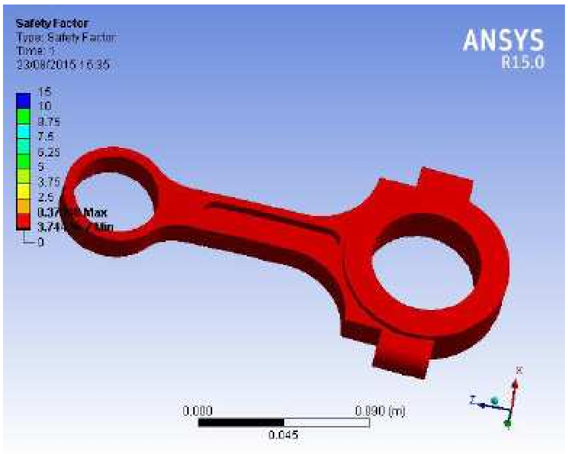

Fig 8: Safety Factor of CF Connecting Rod @30000N

6.1.(b) Static Force Analysis of connecting rod using magnitude of force of 20KN (Neglecting inertia load)

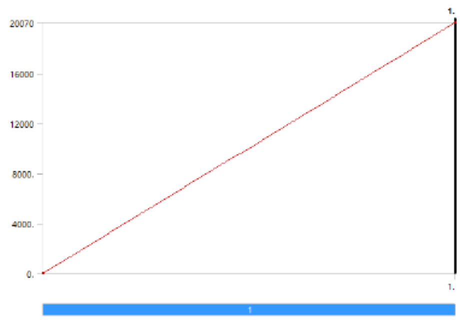

Fig 9: Force Vs Time

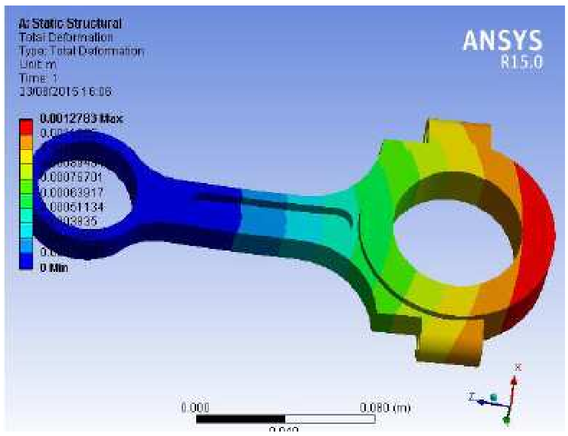

Fig 10:Total deformation of CF Connecting Rod @ 20070N

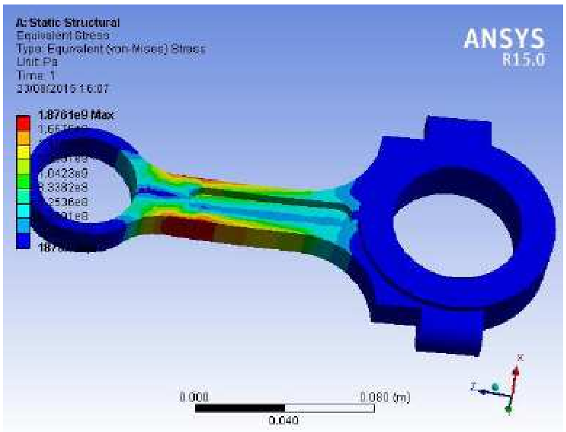

Fig 11: Von-Mises Stress of CF Connecting Rod @20070N

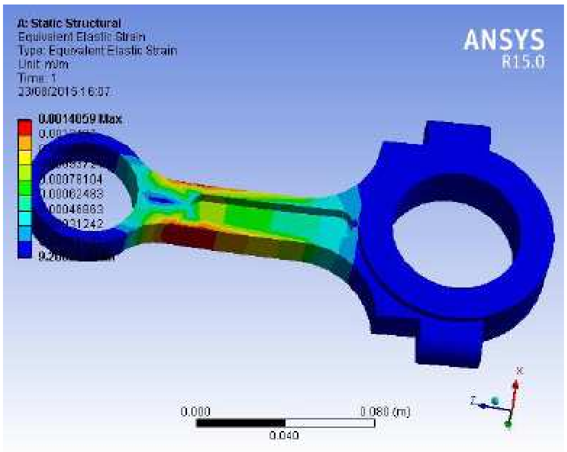

Fig 12 : Elastic Strain of CF Connecting Rod @20070N

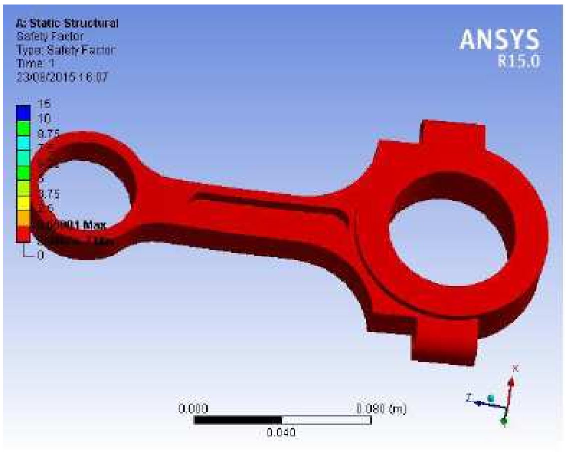

Fig 13: Safety Factor of CF Connecting Rod @20070N

(2) Aluminum Alloy

6.2. (a) Static Force Analysis of connecting rod using magnitude of force of 30KN (taking inertia load into account)

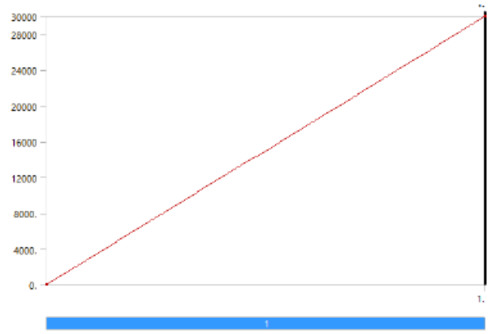

Fig 14: Force Vs Time

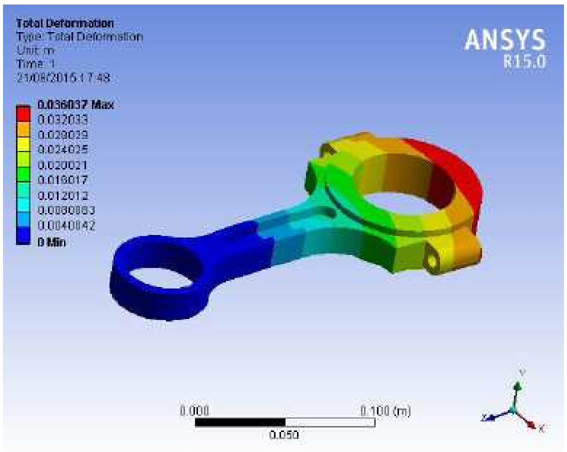

Fig 15: Total deformation of AL Connecting Rod @ 30KN

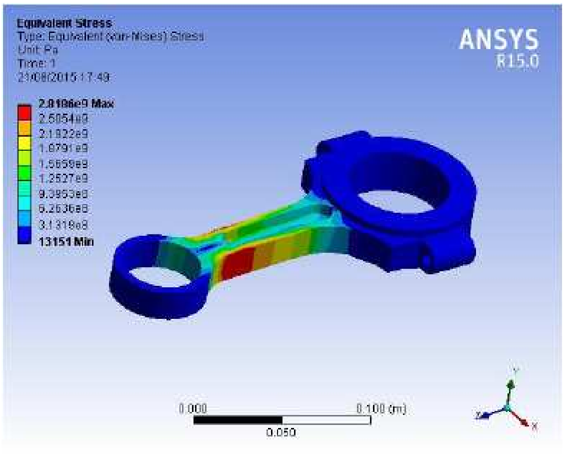

Fig 16 : Von-Mises Stress of AL Connecting Rod @30KN

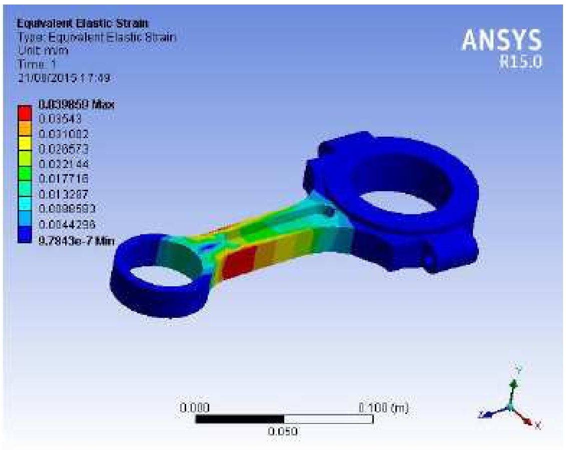

Fig 17: Elastic Strain of AL Connecting Rod @30KN

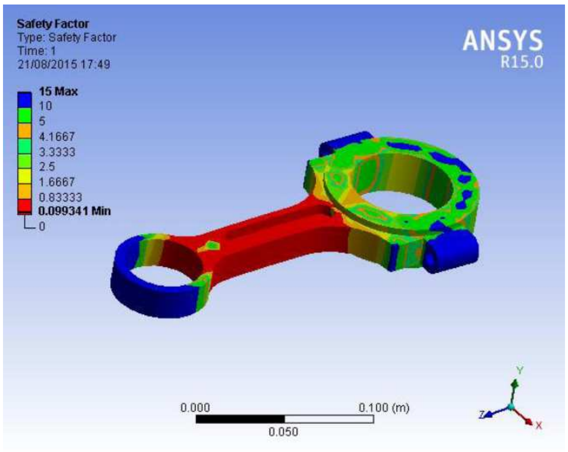

Fig 18: Safety Factor of AL Connecting Rod @30KN

6.2. (b) Static Force Analysis of connecting rod using magnitude of force of 20KN (Neglecting inertia load)

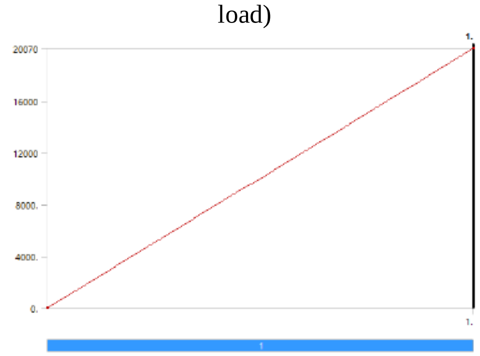

Fig 19: Force Vs Time

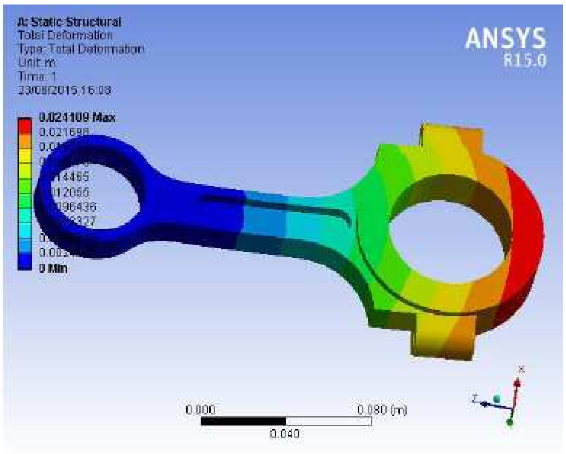

Fig 20: Total deformation of AL Connecting Rod @ 20KN

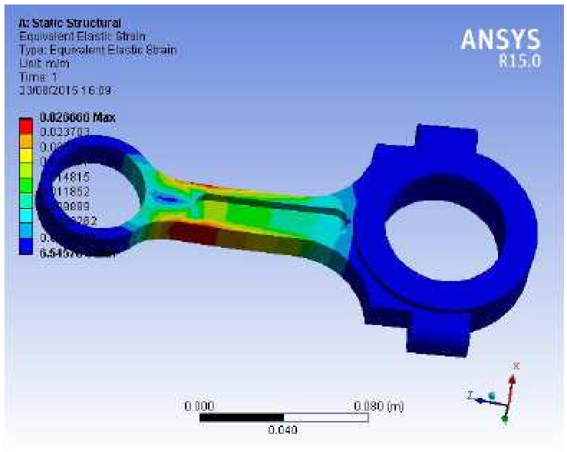

Fig 22: Elastic Strain of AL Connecting Rod @20KN.

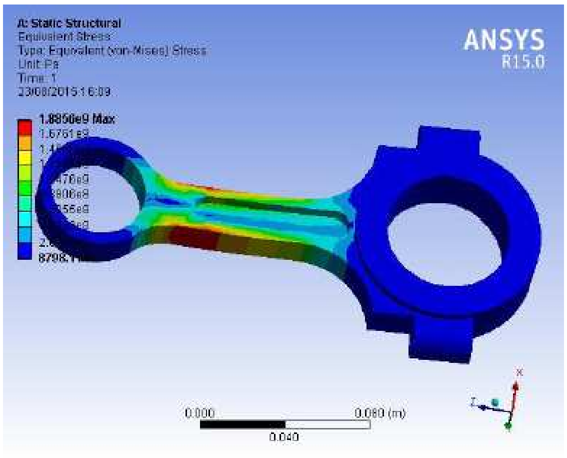

Fig 21: Von-Mises Stress of AL Connecting Rod @20KN

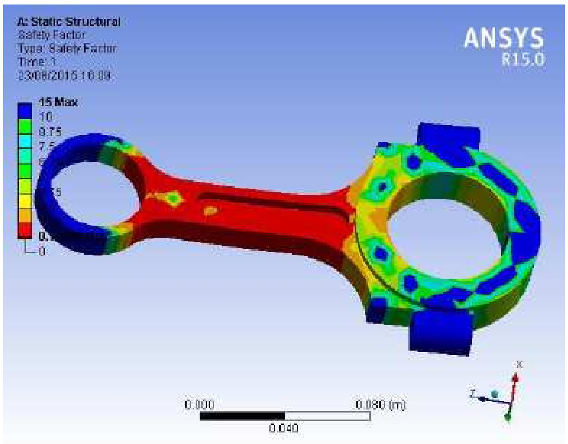

Fig 23: Safety Factor of AL Connecting Rod @20KN

Material	Results			
	Displace -ment, m	Stress, Pa	Strain	Mass of Con.Rod
Carbon Fiber	0.0019	2.804e9	0.00210	0.253 Kg
Aluminium Alloy 7075	0.036	2.81e9	0.30	0.438

Table 3: Results For Static load Analysis of Connecting Rod @30KN

Material	Results			
	Displace -ment, m	Stress, Pa	Strain	Mass of Con.Rod
Carbon Fiber	0.0012	1.87e9	0.0014	0.253 Kg
Aluminium Alloy 7075	0.024	1.88e9	0.20	0.438

Table 4: Results For Static Load Analysis of Connecting Rod @20KN

7. CONCLUSION

A connecting rod made of Std. Unidirectional Carbon Fiber and Aluminum alloy is selected to study the force stability and weight reduction of connecting rod. The connecting rod is modeled in Inventor 2014, forces are calculated theoretically and Analysis is done with the help of Ansys 15.0 software on two load conditions.

By observing the analysis results for the Static load of 30KN,

- Carbon Fiber Von-Mises Stress found 2.804e9 Pa which are very much less than the yield strength values i.e 1050 MPa.The stresses on the connecting rod are within the limit.
- Total deformation of connecting rod made up of Carbon Fiber is 0.0019m which is very less when applied Maximun load.
- Strain of connecting rod made up of carbon fiber is also well within the limit.
- The weight of connecting rod made up of Carbon fiber is half to the weight of aluminum alloys having more strength and other mechanical properties.
- The material like carbon fiber has good strength and can be used for manufacturing connecting rod.
- Carbon fiber is very expensive material which can't be affordable for general application automobile manufacturers.

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