

# Design, Analysis and Optimization of Four Stroke S.I. Engine Connecting Rod using Finite Element Analysis with the help of CAE and CAD Software

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**Abstract**— The aim of this paper is to design, analysis and optimization of connecting rod which is stronger and light-weight with respect to existing connecting rod with the help of CAE and CAD Software. Static structural analysis is done to analyze stresses, strain, total deformation and factor of safety distribution in various parts of the connecting rod to know the effect due to maximum compressive loading using ANSYS 16.2. Solid parametric models of connecting rod have been made using CATIA V5R20. In this study advance materials, aluminium alloy A16T, titanium alloy Ti-6Al-4V, and carbon-fibre reinforced polymer material are used to replace the existing material of connecting rod. These materials have very high strength in compression as well as in tension and have low density 3 to 4 times less than existing forged steel material. Therefore, by replacing existing connecting rod material (forged steel) with these advance materials connecting rod weight will reduce and factor of safety will increase. Shape optimization module is used for weight optimization of the existing connecting rod. Fatigue analysis is done for aluminium alloy connecting rod. Connecting rod made of aluminium alloy A16T, titanium alloy Ti-6Al-4V and carbon-fibre reinforced polymer material has weight reduction percentage with respect to existing material (forged steel) is 59.12%, 48.59% and 77.01% respectively. Factor of safety for connecting rod made of forged steel, aluminium alloy A16T, titanium alloy Ti-6Al-4V and carbon-fibre reinforced polymer material is 1.8348, 1.1562, 2.2056 and 2.4299 respectively. Fatigue life for aluminium alloy connecting rod under the effect of extreme peak compressive gas loading is 99507 cycles and when load is half its minimum life is 108 cycles.

**Key words:** S.I. engine connecting rod; weight optimization; Static structural analysis; CAE and CAD

## I. INTRODUCTION

The connecting rod is the intermediate member between the piston and the crankshaft. It consists of a long shank, a small end, and a big end. The cross-section of the shank may be rectangular, tubular, circular, H-section or I-section. Generally, a circular section is used for low speed engines while I-section is preferred for high speed engines. Its primary function is to transmit the power from the piston pin to the crankpin and thus convert the reciprocating motion of the piston into the rotary motion of the crank.

Static structural analysis is used to determine the distribution of displacements, stresses, strains, factor of safety and forces in components of connecting rod caused by extreme peak compressive gas loading that do not induce significant inertia and damping effects.

Shape optimization is used for performing weight-reduction on existing design. The Shape Finder tries to find

areas where material can be removed without adversely affecting the strength of the overall structure.

## A. Nomenclature

$d_c$	Inner diameter of big End
$D_c$	Outer diameter of big End
$d_p$	Inner diameter of small End
$D_p$	Outer diameter of small End
$n$	Number of working stroke per minute
$P_{bp}$	Bearing pressure at big End
$P_{cp}$	Allowable bearing pressure for piston pin bearing
$T$	Thickness of I section flange
$\sigma_c$	Compressive yield strength

Table 1:

## II. LITERATURE REVIEW

R.J. Yang et al, described process of shape optimization for connecting rod upper end (pin end), in their paper they optimized upper end (pin end) of connecting rod. They clamped shank of connecting rod, and a uniformly pressure 100 MPa is applied at pin end to simulate the firing force. Critical stress used for analysis is chosen as 1000 MPa in two different models. In first model (first case) they took 5 design parameters and optimized volume from 8114 mm<sup>2</sup> with 3% stress violation (3% over critical stress) to 7183 mm<sup>2</sup> with no stress violation, in second case they took 10 design parameters and optimized volume from 6395 mm<sup>2</sup> with 41% stress violation to 7140 mm<sup>2</sup> with 2% violation. In second model design is identical as first model and velocity is updated for each iteration. They optimized volume from 8114 mm<sup>2</sup> with 3% stress violation to 7235 mm<sup>2</sup> with 2% stress violation. [1]

M. Omid et al, Calculated displacements and stresses under the Maximum compression and tension loading in the connecting rod of universal tractor (U650). In their paper they find out critical point of connecting rod of U650 is end of the shank and near piston hole in tension and compression loading. That Result is useful for modification of connecting rod. [2]

Mohammed Mohsin Ali et al, in their paper fatigue life calculated due to concentrated load and cosine type load distribution on the bigger end of connecting rod. They applied contact pressure 54 N/mm<sup>2</sup> at the piston pin end, 16 N/mm<sup>2</sup> at the crank pin end, they constrained shank of connecting rod and calculated Alternating stress =139.58 N/mm<sup>2</sup>, Cycles used/allowed = 0.1000e+07/ 0.1000e+07 and Cumulative fatigue usage = 1.00000. [3]

D.Gopinatha et al, in their paper they deal with two points, first, static load stress analysis of the connecting rod for forged steel, aluminium and titanium materials, and second, optimization for weight of forged steel connecting rod by 10.38% for the same strength. [4]

Heinz K. Junker, He directed the areas of development, design, and maintenance of engines, technology, thermodynamics, and vehicle construction, in modern gasoline and diesel engines also describe complete knowledge of S.I. engine components. In this book explained purpose and function, Boundary conditions (forces, stress, and temperature), design detail, numerical simulations and F.E. Analysis, materials, Coating and surface treatment for piston rings, piston pin and piston pin clipper, bearings, connecting rod, crankcase and cylinder linear. [5]

### III. DESIGN OF CONNECTING ROD

#### A. Configuration of Engine

In this paper single cylinder, 4 stroke, air cooled, SOHC, TVS Scooty Pep+ bike engine configuration considers for design and FE Analysis of connecting rod for three different materials. Configuration of engine is shown in Table 1. [6]

Cylinder bore, D	51mm
Stroke, L	43mm
Piston displacement	87.8cc
Compression ratio	10.1:1
Maximum power in KW, (IP)	3.68@6500 rpm
Maximum torque in Nm	5.80@4000 rpm
Maximum speed	60km/hr

Table 1: Configuration of engine

#### B. Standard Properties of I Section Connecting Rod

Standard properties of I section Connecting rod are summarized in Table 2. [7]

Depth of the section, H =	5t
Area of the section, A =	11t <sup>2</sup>
Depth of the section near the big end, H <sub>1</sub> =	1.1H to 1.25H
Depth of the section near the small end, H <sub>2</sub> =	0.75H to 0.9H
Moment of inertia about x axis, I <sub>xx</sub> =	(419/12)t <sup>4</sup>
Moment of inertia about y axis, I <sub>yy</sub> =	(131/12)t <sup>4</sup>
I <sub>xx</sub> /I <sub>yy</sub> =	3.2
Radius of gyration of the section about X-axis, K <sub>xx</sub> =	1.78t
Length of the crank pin, l <sub>c</sub> =	1.25d <sub>c</sub> to 1.5d <sub>c</sub>
Length of the piston pin, l <sub>p</sub> =	1.5d <sub>p</sub> to 2d <sub>p</sub>

Table 2: Standard properties of I section connecting rod

#### C. Dimension of Connecting Rod

Dimensions of connecting rod are calculated by shown formulas: [7]

- 1) Piston Displacement area,

$$A = \frac{\pi \times D^2}{4} \quad (1)$$

$$= 2042.8206 \text{ mm}^2$$

- 2) Mean effective pressure,

$$P_m = \frac{60 \times IP}{l \times A \times n} \quad (2)$$

$$= 0.7734 \text{ N/mm}^2$$

- 3) The Maximum gas Pressure, P<sub>max</sub> is taken as 9 to 10 times of mean effective pressure (P<sub>m</sub>),  
P<sub>MAX</sub> = 0.7734 × 9 = 6.9606 = 6 N/mm<sup>2</sup>

- 4) The maximum force acting on the piston due to gas pressure,

$$F = \left( \frac{\pi \times D^2 \times P_{Max}}{4} \right) \quad (3)$$

$$= 12256.9236 \text{ N}$$

- 5) Radius of gyration of the section about X-axis,

$$K_{xx} = \sqrt{419t^4 \times \left(\frac{1}{12}\right) \times 11t^2} \quad (4)$$

$$= 1.78t$$

- 6) Length of the connecting rod,

$$l = \text{Stroke} \times 2 = 86 \text{ mm}$$

- 7) Since factor of safety is considered as, FOS = 2.8995, So Bulking load

$$W_B = 1225.9236 \times 2.8995 = 35545.085 \text{ N}$$

From Rankine's formula,

$$W_B = \frac{\sigma_c \times A}{1 + a(l/K_{xx})^2} \quad (5)$$

$$35545.085 = (415 \times 11t^2) / [1 + 0.0002(86/1.78t)^2]$$

$$t = 2.8688 \text{ mm}$$

- 8) Width of the section,

$$B = 4t = 4 \times 2.8688 = 11.4752 \text{ mm}$$

- 9) Height of the section,

$$H = 5t = 5 \times 2.8688 = 14.344 \text{ mm}$$

$$l_c = (1.25 \text{ to } 1.5) d_c \text{ and } l_p = (1.5 \text{ to } 2) d_p$$

- 10) Load on the crank pin, F<sub>L</sub> = d<sub>c</sub> × l<sub>c</sub> × P<sub>cp</sub>

$$7109.628 = d_c \times 1.5 \times d_c \times 8$$

$$d_c = 24.34 \text{ mm}$$

- 11) Outer diameter of the pin,

$$D_c = (1.25 \text{ to } 1.65) \times d_c = 40.161 \text{ mm}$$

- 12) Load on the piston pin, F<sub>L</sub> = d<sub>p</sub> × l<sub>p</sub> × P<sub>bp</sub>

- 13) 109.628 = d<sub>p</sub> × 1.5 × d<sub>bp</sub> × 8

$$d_p = 15.394 \text{ mm}$$

- 14) Outer diameter of the pin,

$$D_p = (1.25 \text{ to } 1.65) \times d_p = 19.243 \text{ mm}$$

- 15) Length of small End pin,

$$l_s = (0.3 \text{ to } 0.45) \times D$$

$$0.3 \times 51 = 15.3 \text{ mm}$$

- 16) Length of big End pin,

$$l_c = (0.45 \text{ to } 0.95) \times D$$

$$0.58 \times 24.34 = 14.1172 \text{ mm}$$

- 17) Height near the big End,

$$H_1 = (1.1 \text{ to } 1.25) \times H = 16.2 \text{ mm}$$

- 18) Height near the small End,

$$H_2 = (0.75 \text{ to } 0.9) \times H = 14.2 \text{ mm}$$

The model of connecting rod is created in CATIA as shown in figure 1, and drawing of connecting rod is created in CATIA as shown in figure 2, as per the dimensions of connecting rod.

The dimensions of the present connecting rod are taken with the help of vernier caliper from the actual TVS Scooty Pep+ connecting rod. Comparison of theoretical dimensions to the actual dimensions calculated by engine specifications are tabulates in table 3.

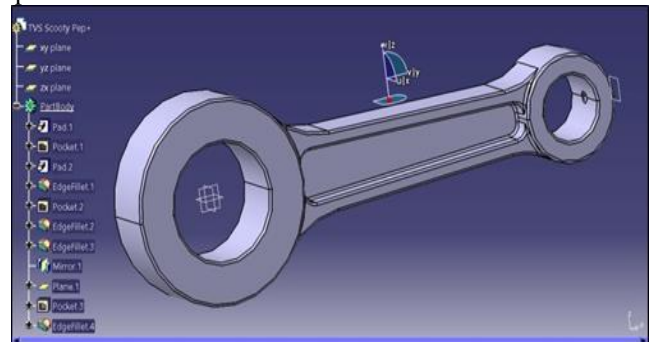


Fig. 1: Model of connecting rod in CATIA

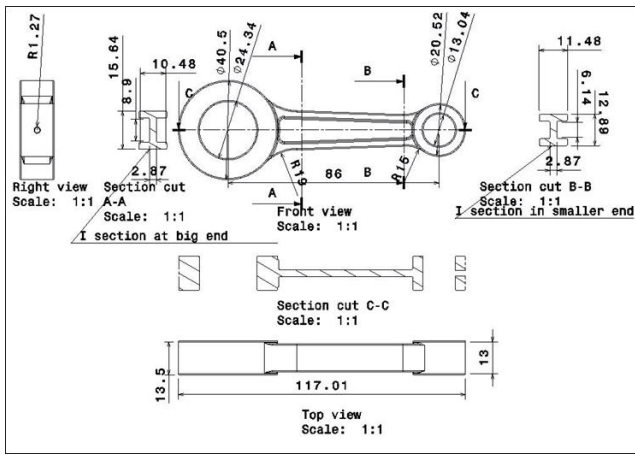


Fig. 2: The Drawing of connecting rod is created in CATIA

Dimensions	Theoretical Dimensions Values (mm)	Actual Dimensions Values (mm)
Outer diameter of big End, $D_c$	40.161	40.5
Inner diameter of big End, $d_c$	24.34	-
Outer diameter of small End, $D_p$	19.243	18.9
Inner diameter of small End, $d_p$	15.3	13.006
Thickness of the flange, $t$	2.8688	2.87
Height near the big End, $H_1$	16.2	16.2
Height near the small End, $H_2$	14.2	14.2

Table 3: Comparison of dimensions of existing connecting rod to the calculated theoretical dimensions

#### IV. FINITE ELEMENT ANALYSIS

The objective of FEA is to investigate stresses and problem area experienced by the connecting rod. Forged steel connecting rod is existing connecting rod for the FE Analysis, since this connecting rod is also used for optimization. Connecting rod is designed for long life where stresses are mainly elastic. Therefore material properties of forged steel, aluminium alloy A16T, titanium alloy Ti-6Al-4V are tabulated in table 4, [8] the mechanical properties of carbon-fibre reinforced polymer shown in table 5. [8]

Properties	Forge Steel	Aluminium Alloy A16T	Titanium Alloy Ti-6Al-4V
Ultimate tensile strength $\sigma_B$ , Mpa	625	460	$\geq 930$
Tensile yield strength $\sigma_{0.2}$ , MPa	625	300	$\geq 862$
Compressive yield strength $\sigma_{-0.2}$ , MPa	415	285	917
Modulus of Elasticity $E$ , GPa	221	71	105-115
Poisson ratio $\mu$	0.29	0.33	0.36
Density $\rho$ , g/cm <sup>3</sup>	7.7	2.8	4.43
Hardness, HBN	101	105	255-340

Table 4: Mechanical Properties of materials used for design of connecting rod

In this study advance materials, aluminium alloy A16T, titanium alloy Ti-6Al-4V, and carbon-fibre

reinforced polymer material are used, These materials have very high strength in compression as well as in tension and also have low density 3 to 4 times less than existing forged steel material.

Properties	Carbon fibreglass monolayer material
Density $\rho$ , g/cm <sup>3</sup>	2.0
Elastic Modulus in X Direction $E_x$ , GPa	125
Elastic Modulus in Y Direction $E_y$ , GPa	8.4
Poisson ration in XY plan $\mu_{xy}$	0.29
Poisson ration in X plan $\mu_{yx}$	0.29
Modulus of rigidity $G_{xy}$ , GPa	4.3
Tensile strength in X direction $\sigma_{+x}$ , Mpa	1050
Compressive strength in X direction $\sigma_{-x}$ , Mpa	950
Tensile strength in Y direction $\sigma_{+y}$ , Mpa	20
Compressive strength in Y direction $\sigma_{-y}$ , MPa	120
Shear stress in XY plane $\tau_{xy}$ , MPa	60

Table 5: Mechanical properties of carbon-fibre reinforced polymer used for design of connecting rod

#### A. Meshed Model of Connecting Rod

Figure 3, shows meshed model of connecting rod in ANSYS 16.2. Tetrahedral element ware used for the solid mesh. In table 6, shows meshing properties of existing connecting rod.

Number of nodes	Number of elements	Size of elements
22961	13405	4.5 mm

Table 6: Meshing properties of existing connecting rod

#### B. Boundary Conditions for Analysis of Connecting Rod Using ANSYS

Figure 4, shows loads applied to model of connecting rod, Pressure of 14 MPa is applied at small end and 8 MPa is applied at big end. Thus in general practice connecting rod is designed by assuming the force in the connecting equal to the maximum force due to pressure, neglecting piston inertia effect. The compressive force of 12256.9236 N was applied at small end of the connecting rod.

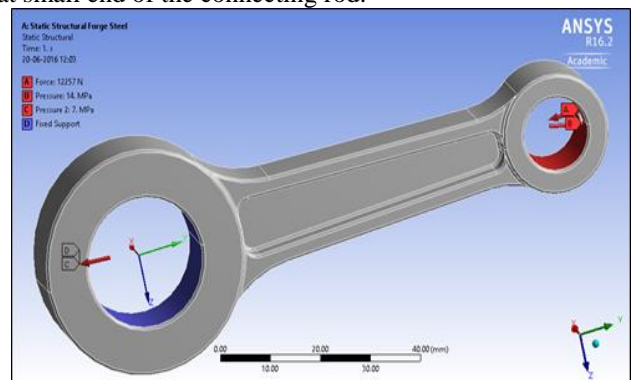


Fig. 4: Boundary conditions for FEA in ANSYS

#### C. Structural Analysis of Forged Steel Connecting Rod

The figure 5, indicates the von-mises stress distribution in the forged steel connecting rod for the given loading conditions. The maximum value is 354.27 MPa and minimum value is 0.055422 MPa.

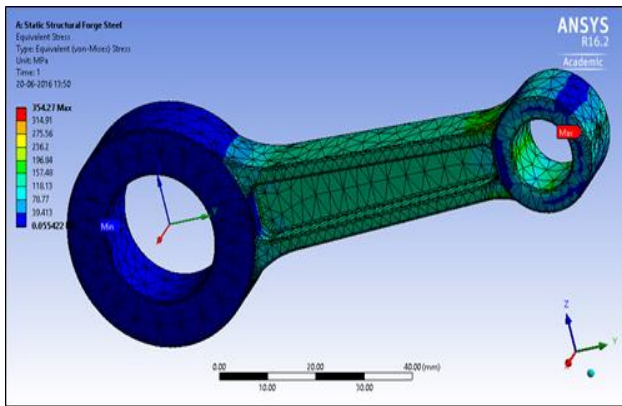


Fig. 5: Equivalent von-mises stress distribution in the forged steel connecting rod

The figure 6, indicates the Total deformation distribution in the forged steel connecting rod for the given loading conditions. The maximum value is 0.051198 mm and minimum value is 0 mm.

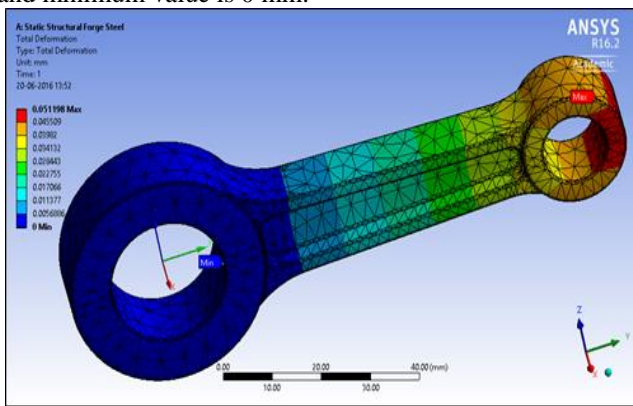


Fig. 6: Total deformation distribution in the forged steel connecting rod

The figure 7, indicates the shear stress distribution in the forged steel connecting rod for the given loading conditions. The maximum value is 93.239 MPa and minimum value is -87.914 MPa.

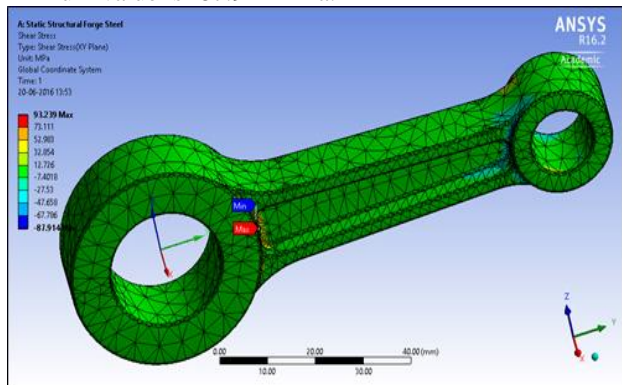


Fig. 7: Shear stress distribution in the forged steel connecting rod

The figure 8, indicates the Equivalent elastic strain distribution in the forged steel connecting rod for the given loading conditions. The maximum value is 0.0016077 mm/mm and minimum value is 2.8569e-7 mm/mm.

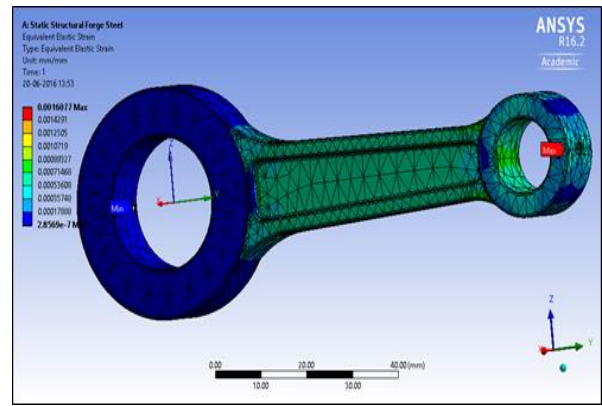


Fig. 8: Equivalent elastic strain distribution in the forged steel connecting rod

The maximum and minimum values of the structural analysis results for the given loading conditions to the forged steel connecting rod are mentioned in the following table 7.

Parameters	Max. value	Min. value
Equivalent Von-Mises stress (MPa)	354.27	0.055422
Total deformation (mm)	0.051198	0
Shear stress (MPa)	93.239	-87.914
Equivalent elastic strain (mm/mm)	0.0016077	2.8569e-7

Table 7: the maximum and minimum values of the structural analysis results for forged steel connecting rod

#### D. Structural Analysis of Aluminium Alloy A16T Connecting Rod

The figure 9, indicates the Equivalent von-mises stress distribution in the Aluminium Alloy A16T connecting rod for the given loading conditions. The maximum value is 259.47 MPa and minimum value is 0.057346 MPa.

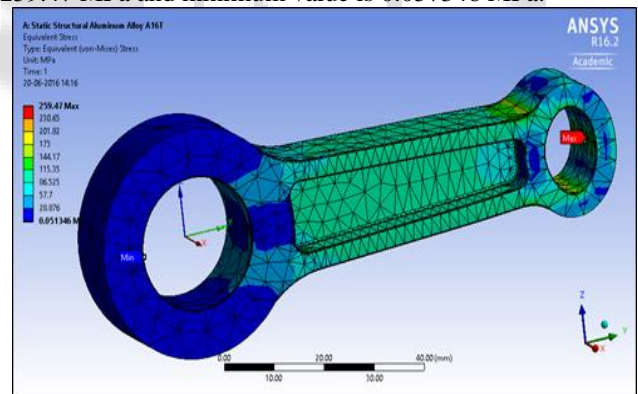


Fig. 9: Equivalent von-mises stress distribution in the Aluminium Alloy A16T connecting rod

The figure 10, indicates the total deformation distribution in the Aluminium Alloy A16T connecting rod for the given loading conditions. The maximum value is 0.11635 MPa and minimum value is 0 MPa.

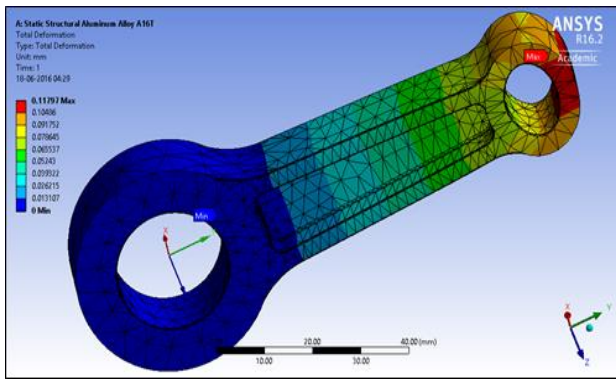


Fig. 10: Total deformation distribution in the Aluminium alloy A16T connecting rod

The figure 11, indicates the shear stress distribution in the Aluminium Alloy A16T connecting rod for the given loading conditions. The maximum value is 75.894 MPa and minimum value is -62.757 MPa.

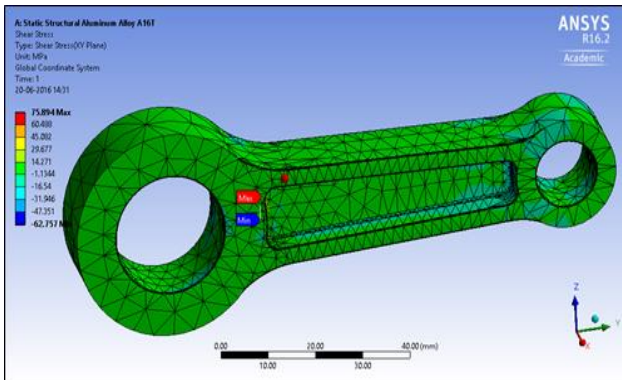


Fig. 11: Shear stress distribution in the Aluminium Alloy A16T connecting rod

The figure 12, indicates the Equivalent elastic strain distribution in the Aluminium Alloy A16T connecting rod for the given loading conditions. The maximum value is 0.0036609 mm/mm and minimum value is 1.0232e-6 mm/mm.

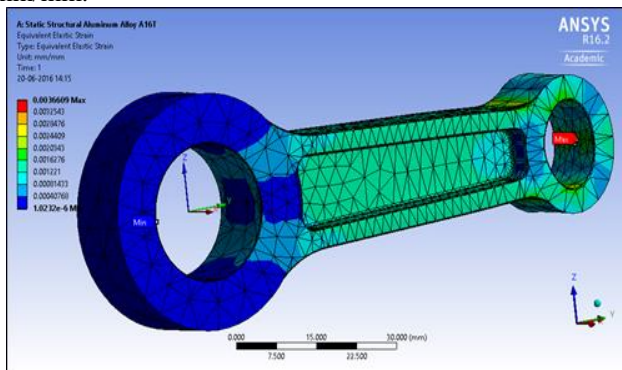


Fig. 12: Equivalent elastic strain distribution in the Aluminium Alloy A16T connecting rod

The maximum and minimum values of the structural analysis results for the given loading conditions to the Aluminium Alloy A16T connecting rod are mentioned in the following table 8.

Parameters	Maximum	Minimum
Equivalent Von-Mises stress (MPa)	259.87	0.05734
Total deformation (mm)	0.11625	0
Shear stress (MPa)	75.894	-62.757
Equivalent elastic strain (mm/mm)	0.0036609	1.0232e <sup>-7</sup>

Table 8: Maximum and minimum values of the structural analysis results for Aluminium Alloy A16T connecting rod

### E. Fatigue Analysis of Aluminium Alloy A16T Connecting Rod

The figure 13, indicates the Fatigue Life distribution in the Aluminium Alloy A16T connecting rod for the given loading conditions. The maximum value is 1e8 and minimum value is 99507.

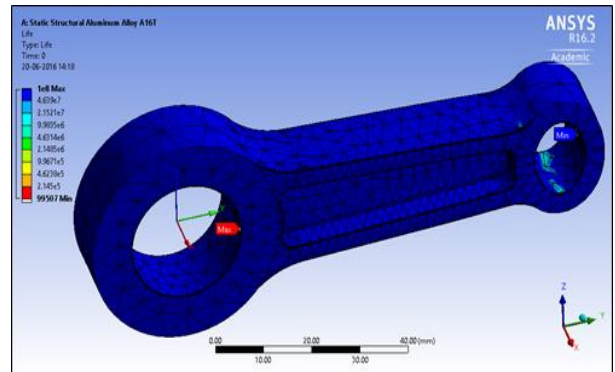


Fig. 13: Fatigue Life distribution in the Aluminium Alloy A16T connecting rod

The figure 14, indicates the Fatigue Damage distribution in the Aluminium Alloy A16T connecting rod for the given loading conditions. The maximum value is 10050 and minimum value is 10 MPa.

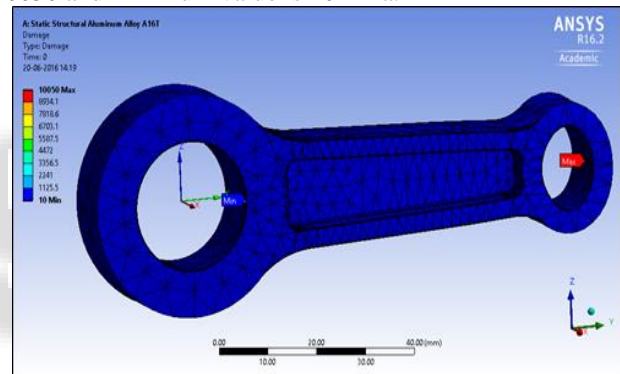


Fig. 14: Fatigue Damage distribution in the Aluminium Alloy A16T connecting rod

The figure 15, indicates Fatigue safety factor distribution in the Aluminium Alloy A16T connecting rod for the given loading conditions. The maximum value is 15 and minimum value is 0.54053.

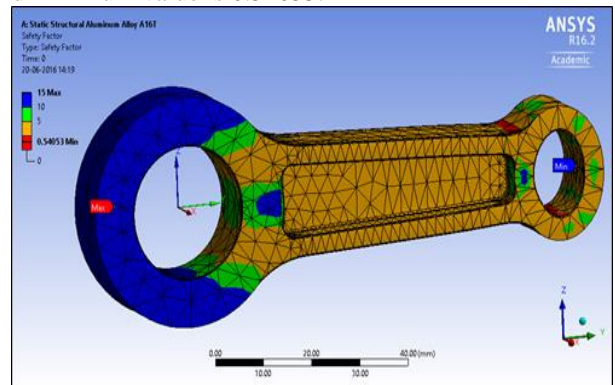


Fig. 15: Fatigue safety factor distribution in the Aluminium Alloy A16T connecting rod

The figure 16, indicates the load Sensitivity distribution in the Aluminium Alloy A16T connecting rod for the given loading conditions. Load Sensitivity factor at the extreme value is but when working load is half it's is highest.

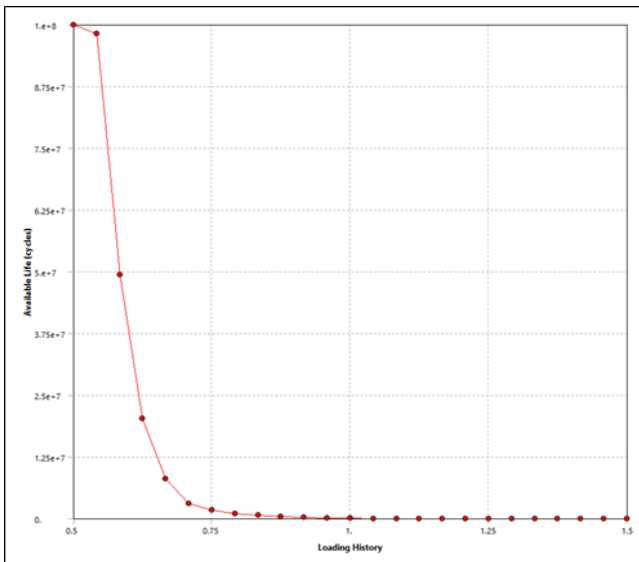


Fig. 16: Sensivity distribution in the Aluminium Alloy A16T connecting rod

The maximum and minimum values of the structural analysis results for the given loading conditions to the Aluminium Alloy A16T connecting rod are mentioned in the following table 9.

Parameters	Maximum	Minimum
Fatigue life	1e <sup>8</sup>	99507
Fatigue damage	10050	10
Safety factor	15	0.54053
Biaxiality indication	0.93526	-0.9998

Table 9: maximum and minimum values of the structural analysis results for the given loading conditions to the Aluminium Alloy A16T connecting rod

#### F. Structural Analysis of Titanium Alloy Ti-6A-4V Connecting Rod

The figure 17, indicates the equivalent von-mises stress distribution in the titanium alloy Ti-6A-4V connecting rod for the given loading conditions. The maximum value is 390.82 MPa and minimum value is 0.073933 MPa

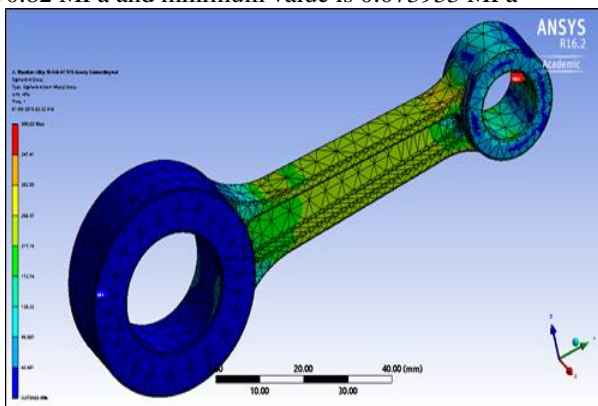


Fig. 11: Equivalent von-mises stress distribution in the titanium alloy Ti-6A-4V connecting rod

The figure 18, indicates the Total deformation distribution in the titanium alloy Ti-6A-4V connecting rod for the given loading conditions. The maximum value is 0.15949 mm and minimum value is 0 mm.

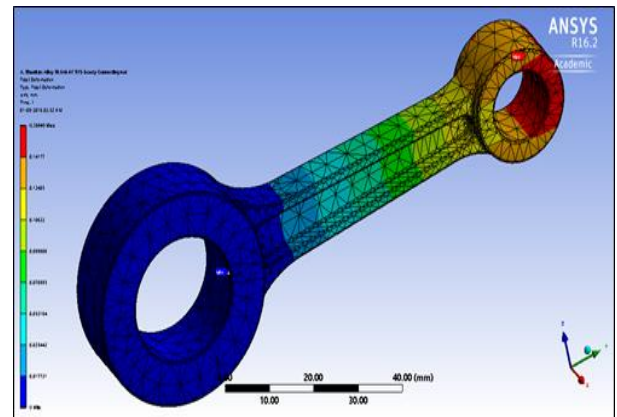


Fig. 18: Total deformation strain distribution in the titanium alloy Ti-6A-4V connecting rod

The figure 19, indicates the Shear stress distribution in the titanium alloy Ti-6A-4V connecting rod for the given loading conditions. The maximum value is 131.62 MPa and minimum value is -134.86 MPa

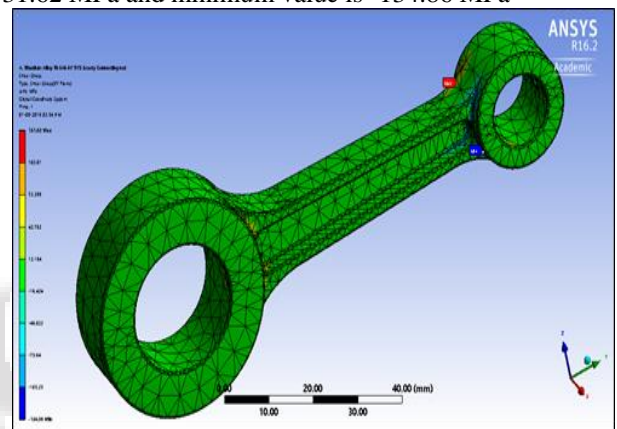


Fig. 19: Shear stress distribution in the titanium alloy Ti-6A-4V connecting rod

The figure 20, indicates the equivalent elastic strain distribution in the titanium alloy Ti-6A-4V connecting rod for the given loading conditions. The maximum value is 0.0037319 mm/mm and minimum value is 8.3458e-7 mm/mm.

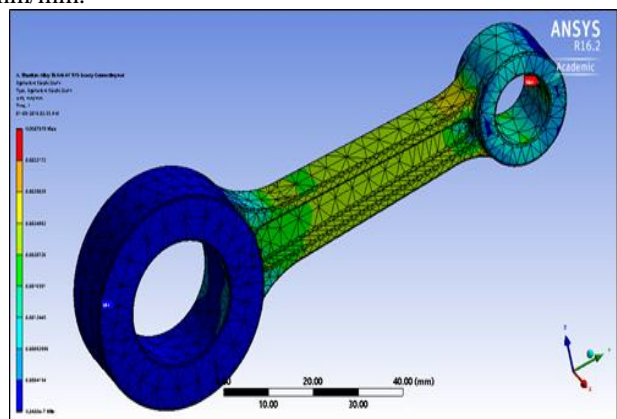


Fig. 20: Equivalent elastic strain distribution in the titanium alloy Ti-6A-4V connecting rod

The maximum and minimum values of the structural analysis results for the given loading conditions to the Titanium alloy Ti-6A-4V connecting rod are mentioned in the following table 10.

Parameters	Maximum	Minimum
Equivalent Von-Mises stress (MPa)	390.82	0.073933

Total deformation (mm)	0.15949	0
Shear stress (MPa)	131.62	-134.86
Equivalent elastic strain (mm/mm)	0.0037319	8.3458e <sup>-7</sup>

Table 10: Maximum and minimum values of the titanium alloy Ti-6A-4V connecting rod

### G. Structural Analysis of Carbon-Fibre Reinforced Polymer Connecting Rod

The figure 21, indicates the Equivalent von-mises stress distribution in the Carbon-fibre reinforced polymer connecting rod for the given loading conditions. The maximum value is 390.96 MPa and minimum value is 0.0076823 Mpa.

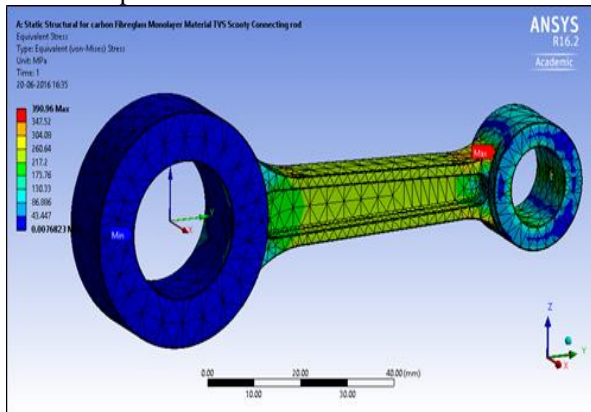


Fig. 21: Equivalent von-mises stress distribution in the Carbon fiberglass monolayer connecting rod

The figure 22, indicates the Total deformation distribution in the Carbon-fibre reinforced polymer connecting rod for the given loading conditions. The maximum value is 2.0841 mm and minimum value is 0 mm.

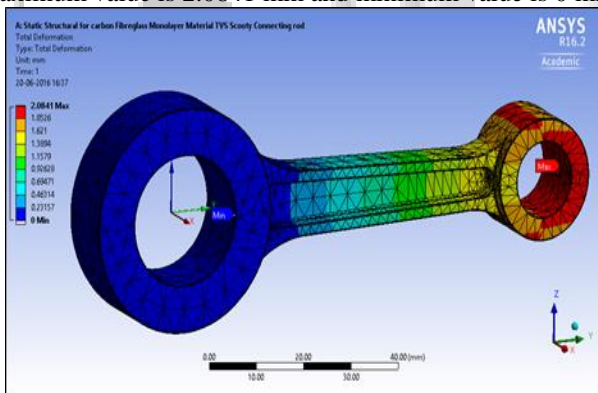


Fig. 22: Total deformation distribution in the Carbon fiberglass monolayer connecting rod

The figure 23, indicates the shear stress distribution in the Carbon-fibre reinforced polymer connecting rod for the given loading conditions. The maximum value is 167.08 MPa and minimum value is -148.86 MPa.

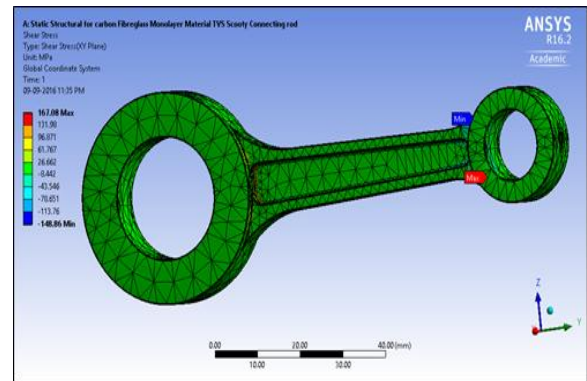


Fig. 23: Shear stress distribution in the Carbon-fibre reinforced polymer connecting rod

The figure 24, indicates the Equivalent elastic strain distribution in the Carbon-fibre reinforced polymer connecting rod for the given loading conditions. The maximum value is 0.051991 mm and minimum value is 1.5877e-6.

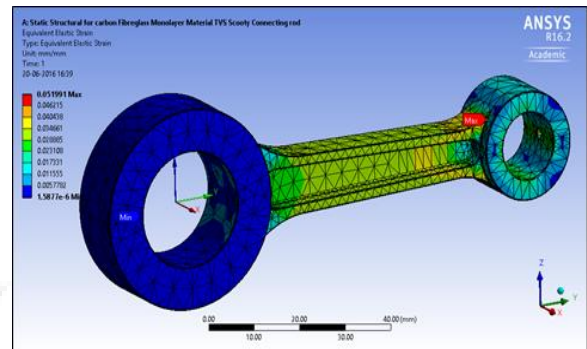


Fig. 24: Equivalent elastic strain distribution in the Carbon fiberglass monolayer connecting rod

Table 11, Maximum and minimum values of the structural analysis results for the given loading conditions to the Aluminium Alloy A16T connecting rod

Parameters	Maximum	Minimum
Equivalent Von-Mises stress (MPa)	390.96	0.0076823
Total deformation (mm)	2.0841	0
Shear stress (MPa)	167.08	-148.86
Equivalent elastic strain (mm/mm)	0.051991	1.5877e <sup>-6</sup>

Table 11: Maximum and minimum values of the titanium aluminium alloy A16T connecting rod

### V. COMPARISON OF CONNECTING ROD FOR DIFFERENT MATERIALS

Comparisons of Increase in factor of safety and reduction in mass of connecting rod of advance materials connecting rod as compare to existing forged steel material connecting rod is shown in graph also shown factor of safety and mass of connecting rod designed for advance materials.

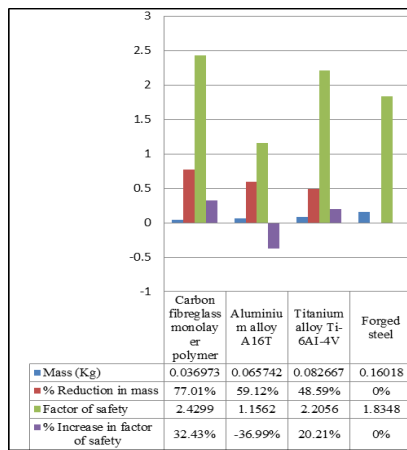


Fig. 25:

### VI. OPTIMIZATION OF EXISTING CONNECTING ROD

The Objective of shape optimization task is to minimize mass of connecting rod under the effect of extreme peak compressive gas load, such that the maximum, minimum, and Equivalent stress amplitude are within the limits of allowable stresses. The buckling load factor under the peak gas load has to be permissible. Optimized model of existing connecting rod is shown in figure 25. Mathematically stated, the optimization statement would appear as follows:

Objective: - Minimize Mass and Cost

- Compressive load = peak compressive gas load.
- Maximum Stress < Allowable Stress.
- Side constraints (component dimension).

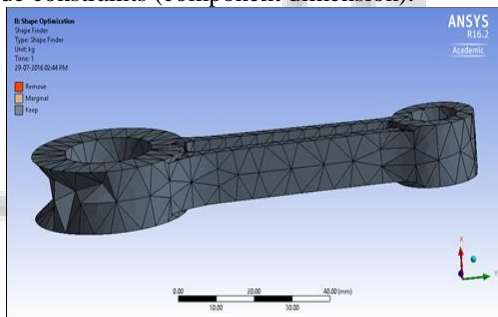


Fig. 25: optimized model of existing connecting rod  
Detail of mass reduction after optimization of existing connecting rod is shown in Table 12,

Original	Optimized	Percentage of Reduction
0.16053 Kg	0.14434 Kg	10.085%

Table 12: Mass optimization of connecting rod

### VII. CONCLUSION

From the static structural analysis it is observed that Von-Mises stresses, shear stresses of forged steel, aluminium alloy A16T, titanium alloy Ti-6Al-4V and carbon-fibre reinforced polymer compared and it is observed that the stresses are less in aluminium alloy A16T, moderate in titanium alloy Ti-6Al-4V and carbon-fibre reinforced polymer and high in forged steel for a given loading conditions.

After carrying out static structural analysis the stresses in loading condition were studied and then areas where excess material can be removed were decided. Optimization was performed to reduce weight of a forged steel connecting rod subjected to the peak compressive gas load.

- Mass of the optimized connecting rod is 144.34 grams and the optimized geometry is 10.85% light-weight than the current connecting rod for the same strength.
- Maximum von-mises stress for forged steel, aluminium alloy A16T, titanium alloy Ti-6Al-4V and carbon-fibre reinforced polymer materials is 354.27 MPa, 259 MPa, 390.82 MPa and 390.96 MPa respectively. Maximum stresses are less than yield stress of their material so these designs of connecting rod are safe.
- Connecting rod made of aluminium alloy A16T, titanium alloy Ti-6Al-4V and carbon-fibre reinforced polymer materials has weight reduction percentage with respect to existing material (forged steel) is 59.12%, 48.59% and 77.01% respectively.
- Minimum factor of safety for connecting rod made of forged steel, aluminium alloy, titanium alloy and carbon-fibre reinforced polymer material is 1.8348, 1.1562, 2.2056 and 2.4299 respectively. Factor of safety is greater than 1 at the extreme peak compressive gas loading.
- Fatigue life at extreme peak compressive gas loading is 99507 cycles and when load is half minimum life is 108 cycles, here considering factor of safety is 2.89 so that taken extreme peak compressive gas load is 2.89 times greater than working load.

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