DESIGN AND ANALYSIS OF TWO WHEELER CONNECTING ROD USING 3 DIFFERENT MATERIALS

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Abstract— The main objective of this project is to determine the total deformation, stress, stiffness and fatigue life of three different material connecting rods like structural steel [A-36], aluminium alloy [T6-6061] and grey cast iron [HT-250] and comparison also made on these three connecting rods under above-mentioned aspects for selection in 155cc Suzuki Gixxer SF motorcycle. In this project, we are designed new three connecting rods using theoretical design calculations and 3D modelling is carried out using CAD software like Unigraphics NX8.5 and simulation is carried out using FEA software, like Ansys Workbench V15. In this simulation software we are performing Static structural and Fatigue analysis for all three connecting rods. The boundary condition is also applied on the basis of its working principle. Thus connecting rods are subjected to different loading conditions due change in the mass as per design calculation. After completion of analysis process, All results were checked under above-mentioned aspects and confirm that these connecting rods are within the safest region or not. We have to achieve cost optimization of different materials as well as the reduction in the manufacturing cycle time.  

Keywords— Static structural and Fatigue analysis; Ansys Workbench V15; Unigraphics NX8.5; Cost optimization; Connecting rod;

I. INTRODUCTION

The main function of connecting rod is to convert reciprocating motion of the piston into rotary motion of the crank as well as responsible for transfer power from the piston to the crankshaft and distribution to the transmission. It is extremely strong, rigid and as light as possible, it consists of piston pin-end, shank section and crank end. The cross-section of the shank may be rectangular, circular, tubular, I-section or H-section. Generally circular section is used for low speed engines, while I-section is used for high speed engines. The material for a connecting rod is selected depending upon the requirement of the IC engines. These connecting rods are usually made of steel for production engines, but can be made of aluminium [for weightlessness and the capacity to take up high crash at the cost of durability] or titanium [for a mixture of strength and weightlessness at the expenditure of affordability] for elevated performance engines, or of cast iron for applications such as motor scooters. Connecting rod materials must have good fatigue and shock resistances.

Durability is one of the critical importance of this component; this can be achieved by getting the knowledge about different aspects such as production technology, materials, performance simulation, and fatigue. When building a high performance engine, great attention is paid to the connecting rods, eliminating stress risers by such techniques as grinding the edges of the rod to a smooth radius, shot peening to induce compressive surface stresses (to prevent crack initiation). Time and effort were necessary to create the best design for a connecting rod to allow it to handle high stresses while minimizing weight. The reduction of weight of connecting rods is important to ensure that the engine can operate safely in higher RPM’s due to the decreased inertia held within the lighter rods. The goal has become to remove as much material from these rods while still maintaining their strength and integrity so as to safely perform under the conditions of each engine.
II. OBJECTIVE

Selection of suitable connecting rod for 155cc Suzuki Gixxer SF motorcycle. Design of connecting rods using theoretical design calculations and geometric modelling is carried out in Unigraphics NX8.5 and simulation is carried out in Ansys WorkbenchV15 software. Perform Static structural and Fatigue analysis for all three connecting rods. Check for all results under aspects like total deformation, stress, stiffness and fatigue life and Finally confirm that these connecting rods are within the safest region or not. Also check for cost optimization of different materials as well as reduction in the manufacturing cycle time.

III. MATERIAL SELECTION

In this project, there are totally 3 different materials taken into account for the production of connecting rod.


It is mild steel containing low carbon percentage, easy to machining, fabricate and securely welded. It provides good strength and high ductility. This is available in rectangle bar, square bar circular rod and steel shapes such a channels, angles, H-beams and I-beams form.

Table 1. Chemical composition

<table>
<thead>
<tr>
<th>Elements</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe)</td>
<td>98%</td>
</tr>
<tr>
<td>Carbon (C)</td>
<td>0.25 – 0.29%</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>0.20%</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>Max 1.03%</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>Max 0.04%</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>0.28%</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>Max 0.05%</td>
</tr>
</tbody>
</table>

Table 2. Mechanical properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Metric [S.I unit]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>7850 [kg/ m³]</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>2.1E+5 [MPa]</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Rockwell hardness</td>
<td>68 [HRB]</td>
</tr>
<tr>
<td>Tensile yield strength</td>
<td>250 [MPa]</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>400 [MPa]</td>
</tr>
<tr>
<td>Melting point</td>
<td>1425 - 1540 [°C]</td>
</tr>
</tbody>
</table>

3.2. Aluminium alloy – ASM grade [T6-6061]

It is a versatile heat treatable extruded alloy with medium high strength capability material. In this T6 term represents solution heat treated and artificially aged. Light weight and provides good surface finish. It is available in tube, bar, pipe and rod form.

Table 3. Chemical composition

<table>
<thead>
<tr>
<th>Elements</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium (Al)</td>
<td>95.8 – 98.6%</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>0.04 – 0.35%</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>0.15 – 0.40%</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>Max 0.15%</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>0.4 – 0.8%</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>Max 0.7%</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>0.8 – 1.2%</td>
</tr>
<tr>
<td>Titanium (Ti)</td>
<td>Max 0.15%</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>Max 0.25%</td>
</tr>
</tbody>
</table>

Table 4. Mechanical properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Metric [S.I unit]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>2770 [kg/ m³]</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>0.71E+5 [MPa]</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.33</td>
</tr>
<tr>
<td>Rockwell hardness</td>
<td>95 - 97 [HRB]</td>
</tr>
<tr>
<td>Tensile yield strength</td>
<td>280 [MPa]</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>310 [MPa]</td>
</tr>
<tr>
<td>Melting point</td>
<td>580 - 650 [°C]</td>
</tr>
</tbody>
</table>
3.3. Grey cast iron – grade [HT-250]
It is a type of cast iron, having graphitic microstructure with low cost and good machinability, which result from the graphite lubricating the cut and breaking up the chips. Having good damping capacity to absorb the energy and converts it into heat.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe)</td>
<td>89%</td>
</tr>
<tr>
<td>Carbon (C)</td>
<td>3 – 3.3%</td>
</tr>
<tr>
<td>Graphite (Gr)</td>
<td>6 – 10%</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>1.4 – 1.7%</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>0.8 – 1%</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>0.15%</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>0.12%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties</th>
<th>Metric [S.I unit]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>7200 [kg/m³]</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>1.26E+5 [MPa]</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.26</td>
</tr>
<tr>
<td>Brinell hardness</td>
<td>190 [HBS]</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>240 [MPa]</td>
</tr>
<tr>
<td>Ultimate compressive strength</td>
<td>820 [MPa]</td>
</tr>
<tr>
<td>Melting point</td>
<td>1200 – 1400 [°C]</td>
</tr>
</tbody>
</table>

IV. THEORETICAL DESGIN CALCULATION OF CONNECTING ROD

4.1. Configuration of Suzuki gixxer SF model
Considering 155cc engine,

- Engine type - Air cooled, 4-stroke, having
  - Bore, B or Piston diameter, D = 56 mm
  - Stroke, S = 62.9 mm
  - Number of Cylinders, n = 1
  - Displacement = 154.9 cm³ i.e. [π/4*B²*S*n]
  - Length of connecting rod, L = 2 * stroke of piston= 2 * 62.9 = 125.8mm
  - Maximum Power, P = 14.8 bhp at 8000 RPM
  - Maximum Torque, T = 14 N-m at 6000 RPM

4.2. Specification of Petrol

- Compression Ratio of PETROL [C₈H₁₈] = 9.35:1
- Density of petrol, ρ = 737.22E-9 kg / mm³
- Molecular weight, M = 114.228 g / mole
- Ideal gas constant, R = 8.314 J / mol-K
- Temperature, T = 27°C+273 = 300 Kelvin (K) [Ideal room temperature]

From perfect gas equation,

\[ PV = mR_{\text{specific}} T \]

\[ P = \frac{mR_{\text{specific}}}{V} \]

\[ m = \frac{V}{R_{\text{specific}} T} \]

Mass, m = Density * Volume

\[ m = 737.22E-9 * 154.9E3 \]

\[ m = 0.1142 \text{ kg} * 9.81 = 1.12 \text{ N.} \]

\[ R_{\text{specific}} = R / M \]

\[ R_{\text{specific}} = 8.314 / 0.11422 = 72.79 \text{ J/kg.K} \]

Substitute all above values in perfect gas equation, we get

Pressure (P) = 16 MPa or 160 Bar.

4.3. Standard dimension’s of shank ‘I’ section

A connecting rod is a machine member which is subjected to alternating tensile and compressive forces. Thus compressive forces are higher than the tensile forces, thus the cross section of the connecting rod is designed as a strut and rankine formulae is used. A connecting rod is subjected to an
axial load may buckle with X-axis in the plane of motion of the connecting rod, or Y-axis is a neutral axis. Hence this conrod is equally strong in buckling about either axis.

According to Rankine formulae,

\[ \frac{\sigma_c \times A}{1 + a \left( \frac{L}{K_{xx}} \right)^2} = \frac{\sigma_c \times A}{1 + a \left( \frac{1}{K_{xx}} \right)^2} \quad [\because \text{for both ends hinged } L=1] \]

\[ \frac{\sigma_c \times A}{1 + a \left( \frac{L}{K_{yy}} \right)^2} = \frac{\sigma_c \times A}{1 + a \left( \frac{1}{2K_{yy}} \right)^2} \quad [\because \text{for both ends fixed } L=1/2] \]

The connecting rod is equally strong in buckling about both axis, buckling loads must be equal i.e.

\[ \frac{\sigma_c \times A}{1 + a \left( \frac{1}{K_{xx}} \right)^2} = \frac{\sigma_c \times A}{1 + a \left( \frac{1}{2K_{yy}} \right)^2} \]

\[ k_{xx}^2 = 4 \, k_{yy}^2 \quad \text{or} \quad I_{xx} = 4I_{yy} \]

Where ‘k’ is the radius of gyration about the section X and Y axis. Above relation shows that the connecting rod is four times strong in buckling regarding to the Y-axis, if I_{xx} > 4I_{yy}, then the buckling will occur about Y-axis and if I_{xx} < 4I_{yy}, then the buckling will occur about X-axis. In actual practice I_{xx} is kept slightly less than 4I_{yy}. It is usually taken between 3 and 3.5 and the connecting rod is designed for buckling about X-axis.

Area of the cross section = \[ [2(4t^2t) + (3t^2t)] = 11t^2 \]

Moment of inertia about X-axis
\[ I_{xx} = \frac{1}{12} \left[ 4t^2(5t)^3 - 3t^2(3t)^3 \right] = \frac{[419(t^4)]}{12} = 34.9(t^4) \]

Moment of inertia about Y-axis
\[ I_{yy} = \left[ ((1/12) 2^t(4t)^3 + (1/12) 3t (t^3)] = \frac{[131/12] (t^4)}{ } = 10.91(t^4) \]

\[ I_{xx} / I_{yy} = [34.9/10.91] = 3.2 \]

Since the value of \[ I_{xx} / I_{yy} \] lies between 3 and 3.5 therefore I-section chosen is quite satisfactory.
From standards, all dimensions are in [mm]
- Thickness of flange and web of the thickness = [t]
- Width of the section B = 4[t]
- Height of the section H = 5[t]
- Area of section A = 11[t^2]
- Moment of inertia about X-axis, Ixx = 34.9[t^4]
- Moment of inertia about Y-axis, Iyy = 10.91[t^4]
- Radius of gyration about X-axis, kxx = 1.78[t]
- Height at the big end, H1 = [1.1H to 1.125H]
- Height at the small end, H2 = [0.75H to 0.9H]

4.4. Static forces acting on the connecting rod

The stresses in the connecting rod are set up due to following forces acting on it.
- Force on the piston due to gas pressure and Inertia of reciprocating parts.
- Force due to inertia of connecting rod or inertia of bending forces.
- Force due to Friction of piston rings and the piston.
- Force due to friction of the piston pin bearing and the crank pin bearing.

4.4.1. Force on the piston due to gas pressure and Inertia of reciprocating parts

![Figure 2. Forces acting on the connecting rod](image)

1. **Force on the piston due to gas pressure** [$F_{gas}$]

   \[ F_{gas} = (\pi D^2 / 4) P \]

   \[ F_{gas} = (\pi * 56^2 / 4) * 16 = 39,408 \text{ N} \]

   $A$ = Cross-section area of piston in mm$^2$, $D$ = Diameter of piston, mm and $P$ = Maximum gas pressure in MPa.

   **For Aluminium alloy [T6-6061] material,**

   \[ F_{gas} = (\pi * 56^2 / 4) * 16 = 39,408 \text{ N} \]

   Force acting on the piston due to gas pressure, $F_{gas} = 39,408 \text{ N}.$

2. **Inertia of reciprocating parts** [$F_i$]

   \[ F_i = M \times \omega^2 \times r \times (\cos \theta + \cos 20/n') \]

   \[ F_i = \text{Mass} \times \text{Acceleration} \]
\[ Wr = \text{Mass of reciprocating parts, N} \]
\[ \omega = \text{Angular speed of crank, rad/sec} \]
\[ r = \text{Crank radius, mm} = \frac{\text{Stroke of the piston}}{2} \]
\[ \theta = \text{Angle between the crank and the center line of the cylinder or angle of inclination of crank from Top Dead Centre (i.e. 0 to 360° at TDC and 180° at BDC), deg} \]
\[ \cos \theta = \text{cosine of the crank angle and varies between 0 and } \pm 1 \text{ through 360° of crank rotation.} \]
\[ n' = \frac{l}{r} = \text{ratio of connecting rod length to radius of crank} \]
\[ F_p = \text{force acting on the piston due to gas pressure and inertia of reciprocating parts, N} \]
\[ F_c = \text{Component of Fp acting along the axis of connecting rod, N} \]
\[ \alpha = \text{Angle between the crank and the center line of connecting rod, deg} \]
\[ \phi = \text{Angle between the center line of piston and the connecting rod, deg} \]

For Aluminium alloy [T6-6061] material,

i. Mass of reciprocating parts, \( Wr = \text{mass of piston} + 0.33 \times \text{mass of connecting rod} \)

Mass of connecting rod, \( m = \text{Density} \times (\text{Area} \times \text{Length}) \)

\( m = 2770 \times [11 \times (5.5 \times 10^{-3})^2 \times 0.1258] = 0.116 \text{ kg} \)

Assuming mass of piston = 1.11 kg.

\( Wr = [1.11 + (0.33 \times 0.116)] \)

Mass of reciprocating parts, \( Wr = 1.15 \text{ kg} \times 9.81 = 11.28 \text{ N.} \)

ii. Angular speed of crank, \( \omega = \frac{2\pi N}{60} \)

Engine speed, \( N = 8000 \text{ RPM} \)

\( \omega = \frac{2\pi \times 8000}{60} = 837.75 \text{ rad/sec.} \)

iii. Crank radius, \( r = \text{Stroke of the piston} / 2 \)

\( r = 62.9 / 2 = 31.45 \text{ mm.} \)

Length of connecting rod, \( l = 125.8 \text{ mm.} \)

iv. \( n' = \frac{l}{r} = 125.8/31.45 = 4 \)

\( \theta = 0, \text{ considering connecting rod is at top dead centre.} \)

Substitute all values in above Equation we get,

\( F_I = (11.28 / 9810) \times (837.75)^2 \times 31.45 [1 + (0.25)] \)

Force of inertia due to reciprocating parts, \( F_I = 31,725 \text{ N.} \)

3. Net force acting on the piston pin \([F_p]\)

It may be noted that the inertia force of reciprocating parts opposes the force on the piston when it moves during downward stroke.

\[ F_p = \text{Force due to gas pressure } \pm \text{ Inertia force} \]

\[ F_p = F_{gas} - F_I \]

After substituting the values of \( F_{gas} \) and \( F_I \) we get,

Net force acting on the piston pin, \( F_p \) or net = 7683 N.

4. Component of \( F_p \) acting along the axis of connecting rod \([F_c]\)

The forces in the connecting rod will be maximum, when the crank and the connecting rod are perpendicular to each other when \( \theta = 90^\circ \).

Component of \( F_p \) acting along the axis of connecting rod, \( F_c = 7935 \text{ N.} \)

Therefore total force acting on the Aluminium alloy [T6-6061] material connecting rod is 7935 N.

The same procedure is followed for other two materials. Hence total force acting on the connecting rod is mention in below table.
Table 7. Parameters of connecting rod

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>Materials</th>
<th>Mass [kg]</th>
<th>Force [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Structural steel (A-36)</td>
<td>0.240</td>
<td>6802</td>
</tr>
<tr>
<td>2.</td>
<td>Aluminium Alloy T6-(6061)</td>
<td>0.116</td>
<td>7935</td>
</tr>
<tr>
<td>3.</td>
<td>Grey Cast Iron (HT-250)</td>
<td>0.160</td>
<td>7587</td>
</tr>
</tbody>
</table>

4.5. Design Calculation

For Aluminium alloy – ASM grade T6 (6061) material,

Buckling load \( (W_B) = F_{gas} \times FOS \)

For Aluminium alloy T6 (6061) \( FOS = 2.25 \) from standard

\( W_B = 39,408 \times 2.25 \)

Buckling load \( (W_B) = 88,668 \) N.

According to Rankine’s formula,

\[
W_B = \frac{\sigma_c \times A}{[1 + a \times l/Kxx^2]} \]

Where,

- Compressive yield strength, \( \sigma_c = 280 \) MPa
- Young’s modulus, \( E = 0.71 \times 10^5 \) MPa
- \( A = 11t^2 \), \( Kxx = 1.78t \)
- Length of connecting rod, \( l = 125.8 \) mm
- Rankine’s constant, \( a = [\sigma_c / \pi^2E] \)
- After calculating we get, \( a = 0.0004 \)
- Substitute all values in Rankine’s formula and simplifying we get, \( 88,668 + [1, 77.153 / t^2] = 3080 \) \( (t^2) \)

Multiplying \( (t^2) \) on both sides and simplifying we get,

\[
t^4 - 28.78t^2 - 57.51 = 0
\]

Using quadratic equation, put \( t^2 = X \) then,

\[
X^2 - 28.78X - 57.51 = 0
\]

\[
X = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}
\]

Where, \( b = -28.78, a = 1, c = -57.51 \) substitute all these values to give equation we get,

\[
X = t^2 = 30.656
\]

Web and flange thickness of connecting rod \( (t) = 5.5 \) mm. Thus

- Area of cross-section, \( A = 11[5.5]^2 = 332 \) mm\(^2\)
- Moment of inertia, \( I_{xx} = 34.9[5.5]^4 = 31,936 \) mm\(^4\)
- Moment of inertia, \( I_{yy} = 10.9[5.5]^4 = 9974 \) mm\(^4\)
- Radius of gyration about X-axis, \( k_{xx} = 1.78[5.5] = 9.8 \) mm

\[
I_{xx} / I_{yy} = [31,936 / 9974] = 3.2
\]

Hence the value of \( I_{xx} / I_{yy} \) lies between 3 and 3.5 therefore I-section chosen is quite satisfactory.

Design of small or piston pin end

Load on the piston pin \( (F_{gas}) = \) Projected area \* Bearing pressure

Projected area = \( dps \times lps \),

Where \( dps = \) diameter of piston pin, \( lps = \) length of piston pin=2*dps.

Therefore, bearing pressure, \( [P_b] = \frac{F_{gas}}{dps \times lps} \)

Assuming allowable bearing pressure = 15 MPa.

\[
dps = \sqrt{\frac{F_{gas}}{2 \times (15)}}
\]
dps = 36 mm.
lps = 2 * 36 = 72 mm.

**Design of inner, outer diameter and length of small end**
Inner diameter of small end (dsi) = (1.1-1.25) dps
dsi = 1.1 * 36 = 40 mm.
Outer diameter of small end (dso) = (1.25–1.65) dps
dso = 1.4 * 36 = 50 mm.
Length of small end (ls) = (0.3–0.45) D
l = 0.45 * 56 = 25 mm.

**Design of big or crank end**
Considering the bearing failure of the crank and assuming the empirical relation.
Diameter of crank pin (dpc) = (0.55 – 0.75) D
dpc = 0.75 * 56 = 42 mm.
Length of crank pin (lc) = 1.5 * dpc
lc = 1.5 * 42 = 63 mm
Bearing pressure (Pb) = \[F_{gas} / dpc \times lc\] = [39,408 / (42 * 63)] = 15MPa.

**Design of inner, outer diameter and length of big end**
Inner diameter of big end (dbi) = (1.1 – 1.25) dpc
dbi = 1.25 * 42 = 52 mm.
Outer diameter of big end (dbo) = (1.25 – 1.65) dpc
dbo = 1.65 * 42 = 69 mm.
Length of big end (lb) = (0.45 – 1) dpc
lb = 0.75 * 42 = 31.5 mm.

The same procedure is followed for other two materials. Hence entire specification of the connecting rod is mention in below table.

<table>
<thead>
<tr>
<th>Sl.no</th>
<th>Parameters</th>
<th>Aluminium Alloy</th>
<th>Structural Steel</th>
<th>Grey Cast Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Thickness of flange and web of connecting rod [t]</td>
<td>5.5</td>
<td>4.7</td>
<td>4</td>
</tr>
<tr>
<td>2.</td>
<td>Width of the section [B= 4t]</td>
<td>22</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>3.</td>
<td>Height of the section [H=5t]</td>
<td>28</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>4.</td>
<td>Height at the big end H1= [1.1H - 1.125H]</td>
<td>31</td>
<td>26</td>
<td>22</td>
</tr>
<tr>
<td>5.</td>
<td>Height at the small end H2= [0.75H – 0.9H]</td>
<td>21</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>6.</td>
<td>Inner diameter of small end</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>7.</td>
<td>Outer diameter of small end</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>8.</td>
<td>Length of small end</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>9.</td>
<td>Inner diameter of big end</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>10.</td>
<td>Outer diameter of big end</td>
<td>69</td>
<td>69</td>
<td>69</td>
</tr>
<tr>
<td>11.</td>
<td>Length of big end</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
</tbody>
</table>

**V. 3D MODEL OF CONNECTING ROD**

Unigraphics NX8.5 modeling tool is used to create a complete 3D model of connecting rod.
VI. FEA ANALYSIS OF CONNECTING ROD

Analysis of connecting rod is done through Ansys workbench V14.5 software. Here we are performing the Static Stress Analysis, Fatigue Analysis for all three materials i.e. Structural steel A-36, Aluminium alloy T6-(6061) and Grey cast iron (HT-250).
Static structural analysis helps in determining the strength of an object or connecting rod in terms of stress, deformation, stiffness etc.

Fatigue analysis helps in determining the Life cycle of an object or connecting rod in terms of cycles.

6.1. Mesh generation

Figure 6. Structural steel grade [A-36] connecting rod

Figure 7. Aluminium alloy grade [T6-6061] connecting rod

Figure 8. Grey cast iron grade [HT-250] connecting rod
Table 9. Meshing data

<table>
<thead>
<tr>
<th>Material</th>
<th>Elements</th>
<th>Nodes</th>
<th>Element size</th>
<th>Element type</th>
<th>Mesh type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural steel [A-36]</td>
<td>7489</td>
<td>28983</td>
<td>3</td>
<td>Solid 186, 187</td>
<td>Quad mesh</td>
</tr>
<tr>
<td>Aluminium alloy T6-[6061]</td>
<td>6615</td>
<td>27046</td>
<td>3</td>
<td>Solid 186, 187</td>
<td>Quad mesh</td>
</tr>
<tr>
<td>Grey cast iron [HT-250]</td>
<td>7625</td>
<td>28642</td>
<td>3</td>
<td>Solid 186, 187</td>
<td>Quad mesh</td>
</tr>
</tbody>
</table>

6.2. Boundary condition

![Structural steel grade A-36 connecting rod](image)

- **A**: Structural steel A-36
  - Standard Earth Gravity: 9806.6 mm/s²
  - Fixed Support
  - Force: 6802 N

![Aluminium alloy grade T6-6061 connecting rod](image)

- **D**: Aluminium alloy T6-6061
  - Standard Earth Gravity: 9806.6 mm/s²
  - Fixed Support
  - Force: 7935 N

![Grey cast iron grade HT-250 connecting rod](image)

- **G**: Grey cast iron HT-250
  - Standard Earth Gravity: 9806.6 mm/s²
  - Fixed Support
  - Force: 7587 N
Connecting rod is subjected to compressive load or force about 6802N, 7935N and 7587N in ‘Z’-direction on piston pin end region and all DOF [Degree of freedom] is fixed at crank end region.

6.3. Analysis result
6.3.1. Static structural analysis

- Structural steel [A-36] material connecting rod

- Aluminium alloy [T6-6061] material connecting rod
Grey cast iron [HT-250] material connecting rod

Maximum stress and Total deformation occurs at piston pin region of connecting rod for all three materials due to application compressive force at piston pin region.

6.3.2. Fatigue analysis

 Structural steel [A-36] material connecting rod

Table 10. Alternating stress [S] - cycle [N] data

<table>
<thead>
<tr>
<th>Alternating Stress [MPa]</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>3999</td>
<td>10</td>
</tr>
<tr>
<td>2827</td>
<td>20</td>
</tr>
<tr>
<td>1896</td>
<td>50</td>
</tr>
<tr>
<td>1413</td>
<td>100</td>
</tr>
<tr>
<td>1069</td>
<td>200</td>
</tr>
<tr>
<td>441</td>
<td>2000</td>
</tr>
<tr>
<td>262</td>
<td>10000</td>
</tr>
<tr>
<td>214</td>
<td>20000</td>
</tr>
<tr>
<td>138</td>
<td>1E +05</td>
</tr>
<tr>
<td>114</td>
<td>2E +05</td>
</tr>
<tr>
<td>86.2</td>
<td>1E +06</td>
</tr>
</tbody>
</table>

 Aluminium alloy [T6-6061] material connecting rod

Table 11. Alternating stress [S] - cycle [N] data

<table>
<thead>
<tr>
<th>Alternating Stress [MPa]</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>275.8</td>
<td>1700</td>
</tr>
<tr>
<td>241.3</td>
<td>5000</td>
</tr>
<tr>
<td>206.8</td>
<td>34000</td>
</tr>
<tr>
<td>172.4</td>
<td>1.40E+05</td>
</tr>
<tr>
<td>137.9</td>
<td>8.00E+05</td>
</tr>
<tr>
<td>117.2</td>
<td>2.40E+06</td>
</tr>
<tr>
<td>89.63</td>
<td>5.50E+07</td>
</tr>
<tr>
<td>82.74</td>
<td>1.00E+08</td>
</tr>
</tbody>
</table>
Grey cast iron [HT-250] material connecting rod

For this material the fatigue result is unavailable because of fatigue data for this material is missing in material library, which is stored in ansys workbench software. Therefore fatigue result of this material is calculated by analytical method in calculation part shown below.

VII. CALCULATION

7.1. Fatigue life calculation of grey cast iron [HT-250] material connecting rod

The Grey cast iron is one of the brittle material, hence Goodman equation is used to predict life cycle of the connecting rod.

Goodman equation is given by,

\[
\frac{\sigma_{\text{alternating}}}{\sigma_{\text{endurance limit}}} + \frac{\sigma_{\text{mean}}}{\sigma_{\text{ultimate}}} = 1
\]

Where,

\[
\sigma_{\text{mean}} = \frac{\sigma_{\text{max}} + \sigma_{\text{min}}}{2}
\]

\[
\sigma_{\text{alternating}} = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2}
\]

\[
\sigma_{\text{ultimate}} = \text{Ultimate strength of Grey cast iron material}
\]

From ansys software we got maximum and minimum equivalent stress values on that basis calculating life cycle for grey cast iron connecting rod.

Maximum stress, (\(\sigma_{\text{max}}\)) = 168.17 MPa

Minimum stress, (\(\sigma_{\text{min}}\)) = 22.915 MPa

Mean stress, (\(\sigma_{\text{mean}}\)) = 95.5425 MPa

Alternating stress, (\(\sigma_{\text{alternating}}\)) = 72.6275 MPa

Ultimate strength or stress, (\(\sigma_{\text{ultimate}}\)) = 820 MPa
Substituting above given values into the Goodman equation after simplification we get, Endurance limit stress, $\sigma_{\text{endurance limit}} = 82.205 \text{ MPa}$.
Fatigue life can be calculated by following equation,

$$S = 10^c * N^b$$

$S$ = Alternating stress or Amplitude stress [MPa]
$N$ = Number of cycles [cycles] and $b, c$ are the slope constants.

$$b = \frac{-1}{3} \log\left(\frac{(0.8 \times \text{ultimate strength or stress})}{(\text{endurance limit stress})}\right)$$
$$c = \log\left(\frac{(0.8 \times \text{ultimate strength or stress})^2}{(\text{endurance limit stress})}\right)$$

Substituting the ultimate and endurance stress values in above $b$ and $c$ equation after simplification we get $b = -0.30066$ and $c = 3.7189$.

Hence predicting the life cycles of the connecting rod for endurance stress,

$$S = [\sigma_{\text{endurance limit}}]$$

$$\sigma_e = 10^c * N^b$$ or

$$N = 10^{(\frac{c}{-b})} \cdot \sigma_e^{(\frac{1}{b})}$$

Substitute $c, b$ and endurance stress values in above equation we get,

$$82.205 = 10^{(3.7189)} \cdot N^{(-0.30066)}$$

$$N = 1000319.916 \text{ cycles or } 10.00319E+5 \text{ cycles.}$$

From analytical calculation, we obtain the maximum life cycle of grey cast iron [HT-250] connecting rod is 1.000319E+6 cycles for an endurance stress of 82.205 MPa.

VIII. RESULTS

8.1. Static structural analysis

<table>
<thead>
<tr>
<th>Sl.no</th>
<th>Materials</th>
<th>Stress [MPa]</th>
<th>Deformation [mm]</th>
<th>Stiffness [N/mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Structural Steel (A-36)</td>
<td>205.59</td>
<td>0.0713</td>
<td>33</td>
</tr>
<tr>
<td>2.</td>
<td>Aluminium Alloy T6 (6061)</td>
<td>196.09</td>
<td>0.2139</td>
<td>5.32</td>
</tr>
<tr>
<td>3.</td>
<td>Grey Cast Iron (HT-250)</td>
<td>168.17</td>
<td>0.1536</td>
<td>10.21</td>
</tr>
</tbody>
</table>

8.2. Fatigue analysis

<table>
<thead>
<tr>
<th>Sl.no</th>
<th>Materials</th>
<th>Fatigue life [Cycle]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theoretical result</td>
<td>Ansys result</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>1.</td>
<td>Structural Steel (A-36)</td>
<td>9.99815E+5</td>
</tr>
<tr>
<td>2.</td>
<td>Aluminium Alloy T6-(6061)</td>
<td>9.97401E+5</td>
</tr>
<tr>
<td>3.</td>
<td>Grey Cast Iron (HT-250)</td>
<td>1.00032E+6</td>
</tr>
</tbody>
</table>

IX. CONCLUSION

Parameters based on,

1. **Mass**
   - Mass of Structural steel grade A36 material connecting rod is 0.240 kg.
   - Mass of Aluminium alloy grade T6-(6061) material connecting rod is 0.116 kg.
   - Mass of Grey cast iron grade HT-250 material connecting rod is 0.160 kg.
   - Percentage reduction of mass in Aluminium alloy with respect to structural steel material connecting rod is 51.66%.
Percentage reduction of mass in Grey cast iron with respect to structural steel material connecting rod is 33.33%. Therefore, Aluminium alloy material is selected for its light weight thus mechanical efficiency of the engine can be improved.

2. Cost
- Structural steel grade A-36 material has market price of approx. Rs.42/kg.
- Aluminium alloy grade T6-(6061) material has market price of approx. Rs.210/kg.
- Grey cast iron grade HT-250 material has market price of approx. Rs.110/kg.
Therefore, Structural steel A-36 material is selected for its low price.

3. Stress
- Structural steel grade A-36 connecting rod generates stress is about 205.59 MPa.
- Aluminium alloy grade T6-(6061) connecting rod generates stress is about 196.09 MPa.
- Grey cast iron grade HT-250 connecting rod generates stress is about 168.17 MPa.
- Percentage reduction of stress in Aluminium alloy with respect to structural steel material connecting rod is 4.62%.
- Percentage reduction of stress in Grey cast iron with respect to structural steel material connecting rod is 18.20%.
- All materials are well below the yield strength hence all materials are safe.
Therefore, Grey cast iron material connecting rod is selected for generation of less stress.

4. Stiffness
- Stiffness of Structural steel grade A-36 material connecting rod is 33 N/mm.
- Stiffness of Aluminium alloy grade T6-(6061) material connecting rod is 5.32 N/mm.
- Stiffness of Grey cast iron grade HT-250 material connecting rod is 10.21 N/mm.
- Percentage increase of stiffness in Structural steel with respect to Aluminium alloy material connecting rod is 520.3%.
- Percentage increase of stiffness in Structural steel with respect to Grey cast iron material connecting rod is 223.21%.
Therefore, Structural steel material connecting rod is selected for maximum stiffness thus it has more capacity to withstand or resist the deformation and material is act as a rigid body.

5. Fatigue life
- With the prediction of high cycle fatigue life, the life of connecting rod is evaluated and obtained a satisfactory result of 1E+6 cycles.
From result table we conclude that, Aluminium alloy material connecting rod has maximum life of 1.0E+8 cycles. Thus increasing in the durability of connecting rod.

REFERENCES