Design and analysis of connecting rod using composite materials (AL7075, AL6061, AL7075+SiC, AL6061+SiC)

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Abstract. Connecting rod is a vital part of an internal combustion engine which forms a link between piston and the crankshaft. Due to huge amount of forces acting on the piston owing to high engine load and rpm, cyclic compressive and tensile forces act on the connecting rod and results in fatigue and failure. So, to avoid this, the existing connecting rod is to be replaced by composite materials. Because these materials have good mechanical properties such as wear resistance, hardness and high tensile strength. A 3D model of connecting rod is modeled using Solidworks and FEA analysis is carried out by ANSYS 18.2. In this paper analysis is performed on the connecting rod using AL7075, AL6061, AL7075+10%SiC and AL6061+10%SiC to find out the best material for construction of connecting rod.

Keywords: Connecting rod; ANSYS; AL7075; AL6061; AL7075+SiC; AL6061+SiC

1. Introduction

India is one of the world’s largest automobile manufacturers. Two wheelers account for around 80% of the vehicle sales. The important part of an automobile is the internal combustion engine. It consists of piston, connecting rod, crankshaft, and crank. The connecting rod forms a link between piston and crankshaft, the function of connecting rod is to transmit force acting on the piston to the crankshaft. The connecting rod is a slider and crank mechanism which converts the reciprocating motion of the piston into the rotational motion of the crankshaft. Connecting rod has two ends, one is pin end and the other is crank end. Pin end is attached with piston by gudgeon pin and crank end is attached to the crank pin by a crankshaft.

So, it is essential to rectify the problems for the better utilization of the engine and better life and performance of the engine. Usually the connecting rods are made up of forged steel, cast iron. The main disadvantage of using these materials is that they have higher density, which leads to produce to heavier engine components and motorcycle. So, a less dense material should be used for the manufacture of the connecting rod in order to reduce weight and inertia forces. In this case, Aluminium is chosen for the manufacture of the connecting rod due to low density.

Aluminium and its alloy possess low density, high thermal conductivity and high resistance to corrosion. These materials have low melting point and high ductility. The mechanical properties can be improved by alloying and cold working. The major alloying elements are zinc, magnesium, silicon, copper etc. Recent attention has been given to the alloys of aluminium and other low-density materials as engineering materials for applications in aerospace, automobile and defense etc.
Aluminum is added with composite materials to make metal matrix composites. These materials improve the mechanical properties of the connecting rod. The most commonly used composite material is Silicon Carbide

Silicon carbide (10%SiC), which is also known as carborundum, is semiconductor containing silicon and carbon. It exists in nature as the extremely rare mineral moissanite. Synthetic 10%SiC powder has been mass-produced since 1893 for use as an abrasive material.

Grains of silicon carbide can be bonded together by the process called sintering to form very hard ceramics that are widely used in applications requiring high endurance such as car brakes, car clutches and ceramic plates in bulletproof vests, cutting tools, grinding materials.

2. Problem specification

The aim of the paper is to design, analyze and determine the mechanical properties, feasibility of the connecting rod made of Al6061, Al7075, Al6061+10%SiC and Al7075+10%SiC. 3D model of the connecting rod was made using Solidworks 2016. Model was imported into ANSYS 18.2 for analysis. Model was analyzed to find the stress, strain, and the deformation.

![Image](image1.png)

**Figure 1**: 3D model of connecting rod

3. Design of connecting rod

A connecting rod is an engine component which is subjected to alternating direct compressive and tensile forces. Due to fact that the compressive forces are predominant over the tensile forces, the cross section of the connecting rod is designed as a strut and the Rankine Gordon formula is employed to find the dimensions of the cross section. A connecting rod subjected to an axial load may buckle in x-axis as neutral axis within the plane of motion of the rod, or y-axis may be a neutral axis. For buckling analysis, the connecting rod is assumed to be fixed at both ends. The connecting rod is to be designed to be strong in both the axes.

According to Rankin formulae, $W_{cr}$ About x-axis,

$$W_{cr} = \frac{\sigma_f A}{1+\alpha \left(\frac{L}{k_{xx}}\right)^2} = \frac{\sigma_f A}{1+\alpha \left(\frac{l}{k_{xx}}\right)^2} \quad [\because \text{for both ends hinged } L = l]$$
\[ W_{cr} \text{ About y-axis,} \]
\[ = \frac{\sigma_{cr} A}{1 + \frac{l}{k_{yy}}} = \frac{\sigma_{cr} A}{1 + \frac{l}{2k_{yy}}} \]  \[ : for \ both \ ends \ fixed \ L = l/2 \]

\[ \begin{align*}
\text{Figure 2: Buckling on applying load}
\end{align*} \]

The loads must be equal in order to resist buckling in both axes.
\[ = \frac{\sigma_{cr} A}{1 + \frac{l}{k_{xx}}} = \frac{\sigma_{cr} A}{1 + \frac{l}{2k_{yy}}} \]  \[ \text{[or]} \]
\[ \left( \frac{l}{k_{xx}} \right)^2 = \left( \frac{l}{2k_{yy}} \right)^2 \]
\[ K_{xx}^2 = 4K_{yy}^2 \]  \[ \text{[or]} \]
\[ I_{xx} = 4I_{yy} \]

If \( I_{xx} > 4I_{yy} \), then buckling will occur about the Y-axis, and if \( I_{xx} < 4I_{yy} \), then buckling occurs about the X-axis. But practically \( I_{xx} \) is kept slightly lesser than \( 4I_{yy} \). A value between 3 and 3.5 is taken for it. In practice the connecting rod is only designed to withstand buckling about x axis, since the buckling about y axis is lesser than x axis by 4 times.

Cross sectional area = \( 2[4t^2] + 3t^2 = 11t^2 \)

Moment of inertia about the X-axis = \( 2[4t^2] + 3t^2 = 11t^2 \)

Moment of inertia about x-axis,
\[ I_{xx} = \frac{1}{12} (4t^4) - 3t (3t^3) = \frac{119}{12} t^4 \]

Moment of inertia about y-axis,
\[ I_{yy} = \frac{2}{12} * 4t^4 + \frac{1}{12} * 3t^4 = \frac{131}{12} t^4 \]
\[ I_{yy} = 3.2 \]

The value of \( I_{xx}/I_{yy} \) is found out to be between 3 and 3.5. Hence the chosen proportions are appropriate.
4. Pressure calculation of 100cc engine

| Table 1: Specifications of 100cc Engine |
|-------------------------------|-----------------|
| Displacement                  | 100cc           |
| Bore                          | 50mm            |
| Stroke                        | 49.5mm          |
| Length of rod                 | 99mm            |
| Max power                     | 5500w @ 8000rpm |
| Max torque                    | 8Nm             |
| Compression ratio             | 9:1             |
| Density of petrol             | 737.23 kg/m³    |

4.1 Calculation of gas pressure:

\[ PV = MRT \] (Ideal Gas equation)

Where,

\[ P \] - Pressure \\
\[ V \] - Volume in m³ \\
\[ R \] - Gas constant in Jmol⁻¹K⁻¹ \\
\[ T \] - Temperature in K \\
\[ M \] - Mass in kg

\[ M = \rho \times V = 737.23 \times 9.7 \times 10^{-5} = 0.071 \text{kg} \]

Where,

\[ \rho \] = Density of petrol \\
\[ V \] = volume of the cylinder \\
\[ R = R^* / M_{wt} = (8.314/114.28) = 72.786 \]

\[ R^* = \text{Gas constant} \]

\[ M_{wt} = \text{molecular weight of petrol} \]

\[ P = \frac{MRT}{V} = (0.071\times72.786\times300)/9.72\times10^{-5} \]

\[ = 15.95 \text{MPa} \]

4.2 Calculation of Force due to pressure:

\[ F_p = P \times A \]

Where,

\[ P \] - Gas pressure in MPa \\
\[ A \] - Area in mm²

\[ F_p = 15.95 \times (\frac{\pi}{4}) \times 50^2 \]

\[ = 3.13 \text{KN} \]

4.3 Calculation of Inertia force:

\[ F_I = m \times w^2 \times (\cos \theta + \cos 2\theta/n) \]

Where,

\[ F_I \] - Inertia force \\
\[ w \] - Angular velocity

\[ w = 2\pi N/60 = 837.76 \]

\[ F_I = 0.2488 \times 1.25 \times 24.7510^{-3} \times 837.76^2 \]

\[ = 5232.6 \text{N} \]
5. Design calculations of existing connecting rod

\[ W_{cr} = \frac{\sigma_c A}{1 + d \left( \frac{L}{k_{xx}} \right)^2} \]

Where,
- \( W_{cr} = W_{cr} \times FOS = 156509.375 \text{N} \)
- \( L = \text{length of connecting rod} = 125 \text{mm} \)
- \( d = \text{bore diameter} = 50 \text{mm} \)
- \( A = \text{area of cross section} = 11t^2 \)
- \( \sigma_c = 572 \text{MPa} \)
- \( k_{xx} = 1.78t \)

On substituting these values, we get
- \( t = 5 \text{mm}, B = 20 \text{mm}, H = 25 \text{mm} \)

Thickness at crank end = 1.5\(H = 31.25 \text{ mm} \)
Thickness at piston end = 0.75\(H = 18.75 \text{ mm} \)

Figure 3: Cross section of the shaft section of the connecting rod
6. Results and discussion

6.1 Stress

Figure 4: AL6061 under load showing stress

Figure 5: AL7075 under load showing stress
Figure 6: AL6061+10%SiC under load showing stress

Figure 7: AL7075+10%SiC under load showing stress
Figure 8: Comparison of stress acting on materials

6.2 Elastic Strain

Figure 9: AL6061 under load showing elastic strain
**Figure 10**: AL7075 under load showing elastic strain

**Figure 11**: AL6061+10%SiC under load showing elastic strain
**Figure 12**: AL7075+10%SiC under load showing elastic strain

**Figure 13**: Comparison of elastic strain acting on materials
6.3 Deformation

Figure 14: AL6061 under load showing deformation

Figure 15: AL7075 under load showing deformation
Figure 16: AL6061+10%SiC under load showing deformation

Figure 17: AL7075+10%SiC under load showing deformation
Figure 18: Comparison of deformation acting on materials

Table 2: Overall values of mechanical properties

| Materials          | Stress (MPa) | Strain    | Deformation (mm) |
|--------------------|--------------|-----------|------------------|
| AL6061             | 174.95       | 0.0025    | 0.1219           |
| AL7075             | 174.95       | 0.0024    | 0.1183           |
| AL6061+10%SiC      | 168.69       | 0.00164   | 0.0796           |
| AL7075+10%SiC      | 162.45       | 0.0025    | 0.1224           |

7. Material cost calculation
Volume of connecting rod = 8.844294*10^{-5}

Table 3: Mass of materials

| MATERIAL           | MASS (kg) |
|--------------------|-----------|
| AL6061             | 0.2387    |
| AL7075             | 0.2485    |
| AL6061+10%SiC      | 0.2441    |
| AL7075+10%SiC      | 0.2512    |

Mass of AL6061 rod = p*V = 2700*8.844294*10^{-5} = 0.2387kg
Mass of AL7075 rod $= \rho \times V = 2810 \times 8.844294 \times 10^{-5}$
$= 0.2485$ kg

Mass of AL6061+SiC rod $= \rho \times V = 2760 \times 8.844294 \times 10^{-5}$
$= 0.2441$ kg

Mass of AL7075+SiC rod $= \rho \times V = 2840 \times 8.844294 \times 10^{-5}$
$= 0.2512$ kg

AL6061 = ₹ 215/ Kilogram
AL7075 = ₹ 600/ Kilogram
Silicon Carbide Powder = ₹ 85/ Kilogram

10% SiC alloy so 90% aluminium and 10% SiC is

Cost of 1 kg of 7075-SiC will be $= 600 \times 0.9 + 85 \times 0.1$
$= ₹ 548.5$

Cost of 1kg of 6061-SiC will be $= 215 \times 0.9 + 85 \times 0.1$
$= ₹ 202$

(The above values are taken from www.indiamart.com)

Cost of connecting rod is

AL6061 = 0.2387 $\times$ 215 = ₹ 51.32
AL7075 = 0.2485 $\times$ 600 = ₹ 149.1
AL6061+10%SiC = 0.2441 $\times$ 202 = ₹ 49.3
AL7075+10%SiC = 0.2512 $\times$ 548.5 = ₹ 137.78

8. Conclusion

On comparing the various result data from the FEA analysis method, we find

- The elastic strain on AL7075 alloy is lesser than AL6061 Alloy by 4% and the total deformation of Al 7075 is lesser than AL6061 Alloy by 3%.
- When comparing the stress of AL7075+10%SiC alloy with AL7075 alloy we find that the stress reduction about 7% and increase in elastic strain by 4% and deformation by 3.5%.
- When comparing AL7075+10%SiC alloy with AL 6061+10%SiC alloy we see that AL7075+10%SiC has a lower stress by 3.7% but higher elastic strain and deformation of 3.5%.

Figure 19: Material cost comparison
We choose AL6061+10%SiC as the alternate material because it is able to withstand the applied load without much deformation or strain and also the fact that AL6061+10%SiC is also lighter in weight compared with AL7075+10%SiC and is also relatively cheap market price.

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