

WEIGHT OPTIMIZATION OF CONNECTING ROD USING TITANIUM INSERT

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ABSTRACT

Connecting rod is integral component of internal combustion engine; it acts as a linkage between piston and crankshaft. It is a pin jointed strut in which more weight is concentrated towards the big end. In the point of view that location of the CG point of connecting rod lies more towards the big end. Material used to manufacture connecting rod in mass is steel, but it can also be made of Aluminium due to its lightness and the ability to absorb high impact at the expense of durability or Titanium for combination of strength and lightness at the expense of affordability for high performance engines, or of cast iron.

Connecting rods can be produced either by casting, powder metallurgy or forging. The forged rods are free from blow holes over the cast rods. Rods manufactured by powder metallurgy process have the advantage of being near net shape, reducing material waste. However, the cost of the blank is high due to the high material cost and sophisticated manufacturing techniques.

The design and weight of the connecting rod have influence on car performance. The main objective of this work is to optimize the weight of steel connecting rod. Titanium inserts are to be used for weight reduction without changing the original strength. Modifications are to be done by inserting Titanium at various positions of connecting rod using software UG NX7.0. Optimization is to be done by identifying the correct load conditions and magnitudes using software like ANSYS R15.0. Stress concentration is observed using modal analysis.

Key Words: ANSYS, Composite Materials, Connecting Rod, Ti Inserts, Weight Optimization.

I. INTRODUCTION

The automobile engine connecting rod is a high volume production, critical component. It connects reciprocating piston to rotating crankshaft, transmitting the thrust of the piston to the crankshaft. Every vehicle that uses an internal combustion engine requires at least one connecting rod depending upon the number of cylinders in the engine.

The connecting rod are most made of steel for production engines, but can be made of Aluminium (for lightness and the ability to absorb high impact at the expense of durability) or titanium (for combination of strength and lightness at the expense of affordability) for high performance engines, or of cast iron. They can be produced either by casting, powder metallurgy or forging.

Automotive should be light in weight so as to consume less fuel and at the same time they should provide comfort and safety to passengers, which unfortunately leads to increase in weight of the vehicle. This tendency

in vehicle construction led the invention and implementation of quite new materials which are light and meet design requirements. Lighter connecting rods help to decrease lead caused by forces of inertia in engine as it does not require big balancing weight on crankshaft. Application of composite material enables safety increase and advances that leads to effective use of fuel and to obtain high engine power.

Automobile industry always require cost efficient and high quality product. This gives us an opportunity to study design methodology so as to improve and provide industrial requirement. The time spent in trial and error analysis in the design process need to be eliminated in order to sustain in this fast moving market. Therefore, computational methods have been used in early stage of the design. Finite element method is applied for modal analysis and structural analysis of connecting rod. Modal analysis is the process of determining the inherent dynamic characteristics of a system in form of natural frequencies, damping factors and mode shapes, and using them to formulate a mathematical model for its dynamic behavior. Whereas structural analysis gives idea about stress distribution at loading condition. Mesh determination is too critical in order to ensure that the best mesh size is to be used in carrying out the analysis for other parameter involved. As stability and convergence of various mesh processing applications depend on mesh quality, there is frequently a need to improve the quality of the mesh.

II. PROBLEM DEFINITION

2.1 Objective

The objective of this work is to optimize the steel connecting rod for its weight. The optimization of steel rod is more intended to work with different material so as to have light weight and adequate strength. Optimization begins with identifying the correct load conditions and magnitudes. Overestimating the loads will simply raise the safety factors. The idea behind optimizing is to retain just as much strength as is needed. The component is already a part of assembly, by doing reverse engineering same part is to be generated but with sufficient amount of load. The design and weight of the connecting rod have influence on car performance. Hence, it affects on the car manufacture credibility. Change in the design and material results a significant increment in weight and also performance of the engine. The structural factors considered for weight reduction during the optimization include the buckling load factor, stresses under the loads, bending stiffness, and axial stiffness. Thus, the component can give the higher strength, efficient design and lighter that would create a major success in the automotive industry.

2.2 Calculations of Boundary Conditions

The dimensions of connecting rod are mentioned in the CAD model and the forces to be applied on connecting rod are discussed below.

We can say that if the diameter of bolt is known then the inertial load of reciprocating parts can be found out. Therefore we can write the following equation.

$$F_i = \text{force on bolt} = \frac{\pi}{4} d^2 \sigma_t * N$$

F_i = Inertia force due to reciprocating part

d = diameter of bolt = 8 mm

$\sigma_t =$ allowable tensile stress = 125 N/mm^2

N = number of bolts = 2

Using CAD model of connecting rod diameter of bolt was measured and it measured 8mm.

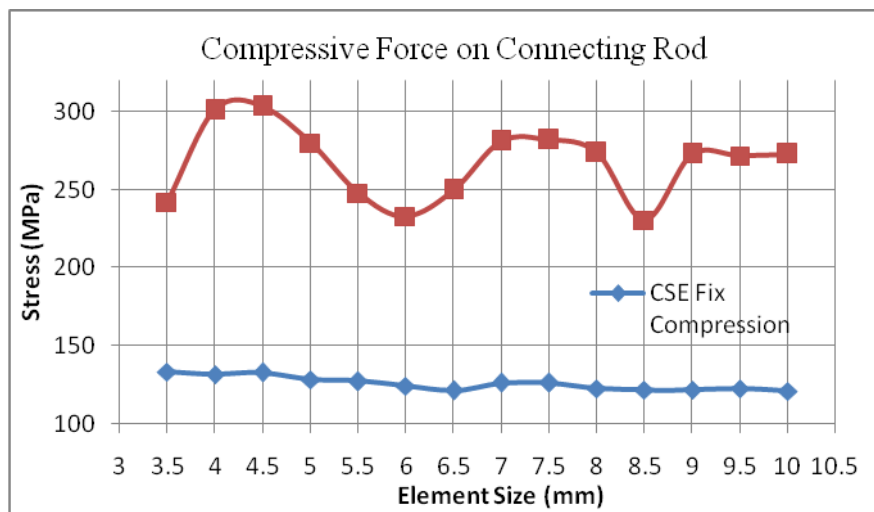
$$F_1 = \frac{\pi}{4} * 8^2 * 125 * 2$$

$$F_1 = 12566.37 \text{ N} \approx 12570 \text{ N}$$

This load of 12570 N is the force that will be applied as a tensile load when the engine is working. While performing the analysis an extra amount of force is considered. The total force applied while performing the analysis is 14kN.

III. RESULTS AND DISCUSSION

We know that connecting rod is subjected to repeated tensile and compressive forces, for which corresponding stresses are to be determined. In order to get correct value of stress, proper element size is calculated by applying a constant load of 14kN. It was applied for both compression and tension.



Graph I. Stress vs. Element size for Compressive Force on connecting rod

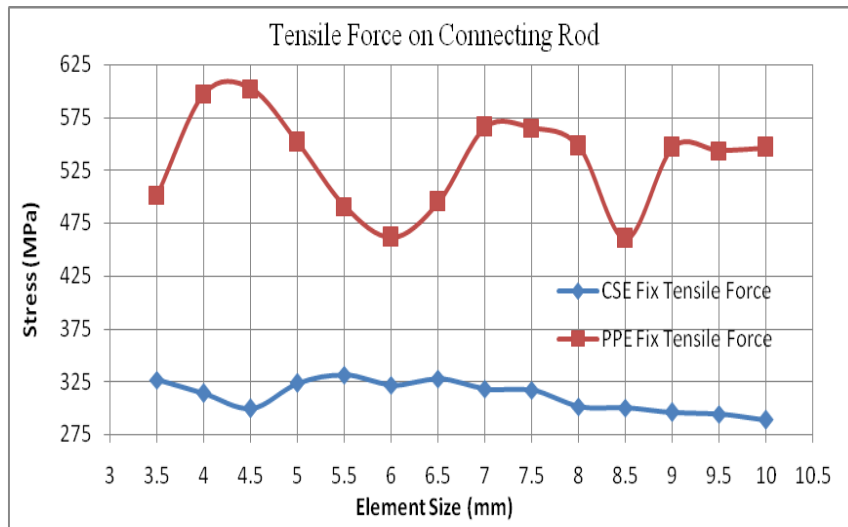
In this analysis value of force is not important because we are concern with the element size which is varied from 3.5mm to 10mm. Variation of stress to element size is shown in graph.

The graph contains study of element size (mm) and stress (MPa) for a connecting rod made of steel. The small end of connecting rod is Piston Pin End (PPE) and big end is Crank Shaft End (CSE). In the analysis there are four cases. Force is applied on one end keeping another end of connecting rod fixed.

When a compressive force of 14kN is applied on the big end when the small end of connecting rod is fixed, the maximum stress found out nearly about 310MPa. The same amount of compressive force is applied on small end when the big end is fixed then the stress was in the range of 130-140MPa which is lesser than the previous case. Now the case of tensile force, a tensile force of 14kN is applied on small end of con-rod keeping the big end fix. The stress has a maximum value after this analysis nearly about 331MPa. Now the same force is applied on big end keeping the small end fixed and we found that stress has a maximum value of 609MPa with an

approximate element size of 4.4mm. We got maximum stress value for the combination piston pin end fixed and tensile force on crank shaft end among the four combinations. From this combination (result) we fixed the element size of 4.4mm for further detail analysis and calculations.

Tensile analysis is done with an element size of 4.4mm; the value of force is 14000N. The total number of nodes that were obtained after meshing was 28452. When the load of 14kN was applied stress was 501.28MPa. The total deformation at this load was about 0.3085mm.



Graph II. Stress VS. Element Size For Tensile Force on Connecting Rod

For tensile loading we see that maximum stress occurs at oil hole which is present at the interface of big end and I-section. This stress concentration occurs because of removal of material. As we know whenever there is a reduction of material at some region, stress at that region will drastically increase. Same goes in our case; in order to provide lubrication this hole is placed but that result in reduction in strength. To increase the stiffness of the oil-hole material is added which will help the stress to get distributed.

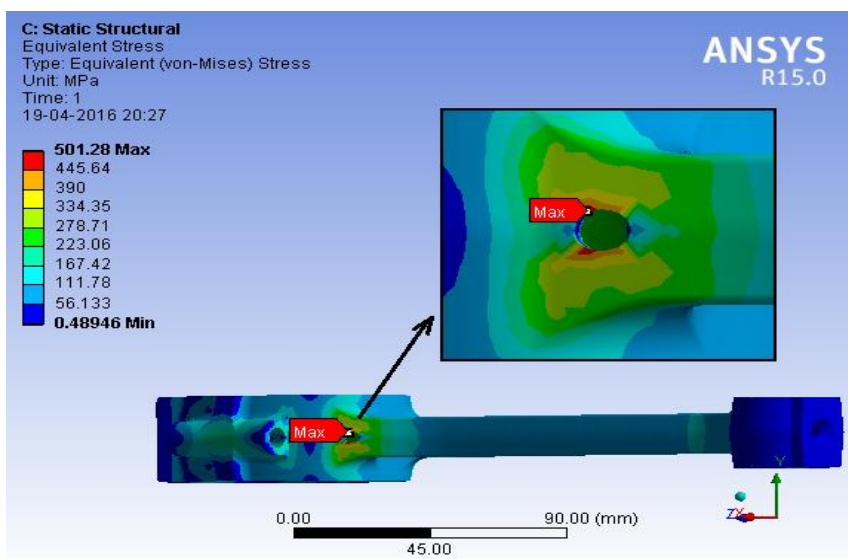


Fig. I. Stress Concentrations on Connecting Rod

While in operation the connecting rod reciprocates as well as oscillates due to sudden momentary compressive and tensile load coming on it and the ends of a connecting rod experience a pressure on its big end and small end. The big end holds a crank shaft surrounded by journal bearing and small end holds a piston pin or gudgeon pin. For our study we considered the pressure acting at an area included by an angle of 32°. The same force was applied on the small end considering the area included by 32° angle.

Table I. Conversion of Force to Pressure

	Complete S/f area in mm ²	S/f area for 32° in mm ²	Pressure in MPa
Small end	1972.1	175.3067	≈79.86
Big end	6208.9	559.5800	≈25.01

***Force applied = 14 kN**

The complete surface area of big end equals 6208.9mm² and surface area for 32° approximately equals 560mm². So a compressive or tensile force of 14kN was applied on 560mm² area. We know that pressure can be found out by force divided by area. The table i. shows the values of pressure applied on the areas.

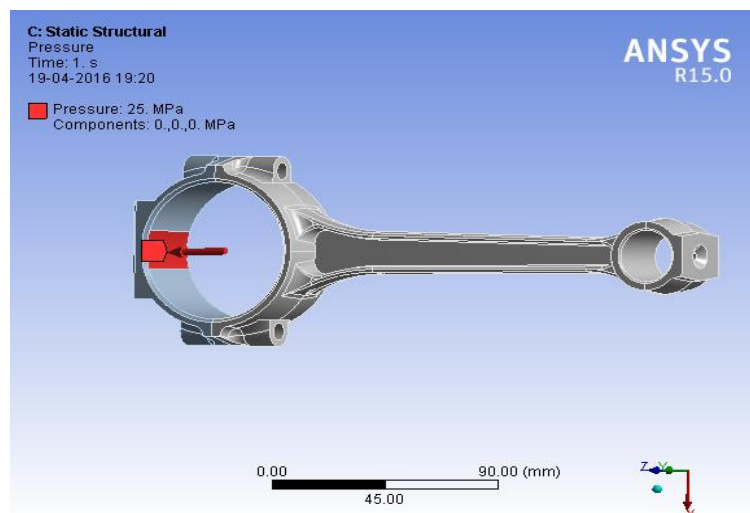


Fig. II. Application of Pressure on Big End of Connecting Rod

Applying the pressures on respective end and keeping other end of connecting rod fixed we found the stress concentration is greater at the oil hole which is at the intersection of the big end and I section. In order to reduce this stress we decided to keep a titanium insert in the oil hole. The dimensions of oil hole were known so it became easy to design a titanium insert with collar. The titanium insert should have a thickness of at least 3mm to make the design safer. The element titanium is light in weight and strong enough to bear load coming on it. It is a very rare element hence costlier. The composites are nothing but the combination of two or more constituent materials with significantly different physical or chemical properties. Here the combination of steel and titanium or combination of aluminium and titanium is desirable and affordable.

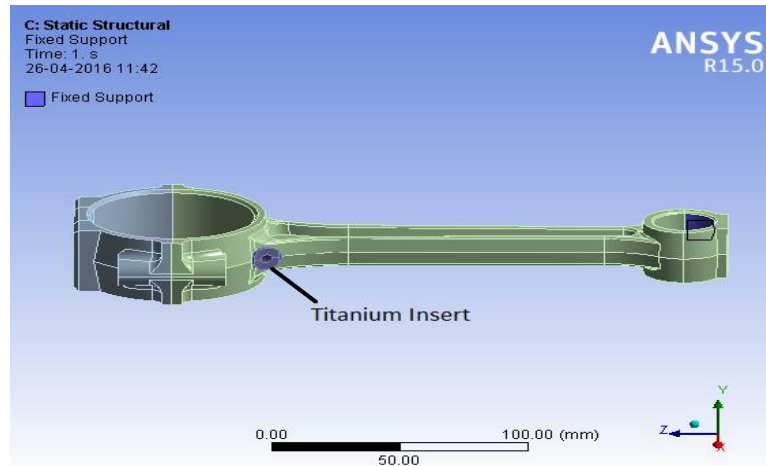


Fig. III. Position of oil-Hole Titanium Insert on Connecting Rod

After putting an insert in the oil hole the connecting rod is applied with a varying and transient load. The applied load is in the form of pressure having a magnitude of 25MPa.

When the connecting rod is in operation, it reciprocates and oscillates. While reciprocating it experiences a compressive and tensile force and when it oscillates, it experiences a pressure along the periphery of the big hole. In other words, it experiences a pressure at certain angles. So we considered the pressure at certain angles from 0° to 32° with a difference of 4° each. This transient load at certain angles is applied for bending stress analysis. At an angle of 32° , the stress found was maximum at the intersection of small end and I-section as shown in Fig. iv.

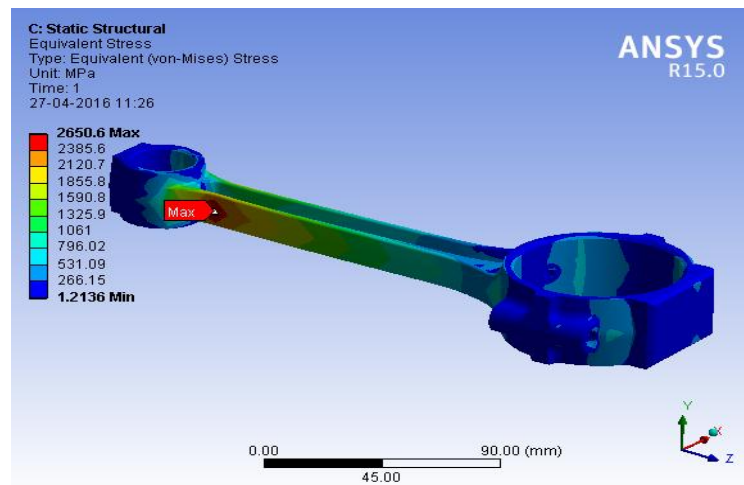


Fig. IV. Equivalent (Von-Mises) Stress and Position of Maximum Stress Concentration

After applying a pressure of 25MPa on big end at an angle of 32° , the connecting rod bent and the maximum stress point shifted to the intersection of small end and I-section as said above.

This stress is at the outer side of the connecting rod and diagonally opposite to the applied pressure which can be observed in the Fig. iv. The red area is showing the maximum stress on the connecting rod. Now we focused

on this stress concentration area nearer to small end. In order to reduce this stress we decided to put a rectangular titanium insert of 3 mm at the small end where the maximum stress is observed. The titanium insert should have 3mm thickness. To put this insert we made some changes in the model of the connecting rod using UG NX7.0. And again analysis was done with steel inserts and titanium inserts. The changes in the design can be observed in Fig. v. The green colored parts are titanium inserts covered with steel. Now again the same pressure was applied at 32° angle and analysis is carried out.

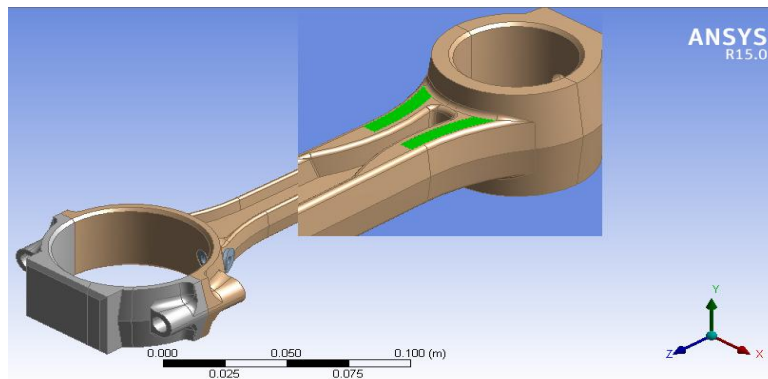


Fig. V. Position of Titanium Insert

In analysis we considered two cases one with steel inserts and another with titanium. The comparison of both gave the result. When steel was the material for inserts, we get the maximum stress concentration value 2447.3 MPa and when titanium was the material, the stress concentration value became 2858.2 MPa. The stress concentration for the composite material (i.e. the combination of steel and titanium) is greater than the single material i.e. steel.

Table II. Volume and Mass Values for Manufacturing a Connecting Rod of Steel

Part Name	Volume (mm ³)	Mass (kg)
Bearing Cover	27873	0.2188
Oil hole Insert	771.66	6.0575 e ⁻³
Steel Inserts 1 & 2	745.79	5.8545 e ⁻³
Connection Link	57257	0.44947
Complete Component	87394	0.68604

*Material for connecting rod is Steel

Table III. Volume and Mass Values for Manufacturing a Connecting Rod of Composite Material (Steel-Ti)

Part Name	Material	Mass (kg)
Bearing Cover	Steel	0.2188
Oil hole Insert	Titanium Alloy	3.5651 e ⁻³
Titanium Inserts 1 & 2	Titanium Alloy	3.4456 e ⁻³
Connection Link	Steel	0.44947
Complete Component		0.67873

Table IV. Volume and Mass Values For Manufacturing a Connecting Rod of Composite Material (Al-Ti)

Part Name	Material	Mass (kg)
Bearing Cover	Aluminium Alloy	7.7208 e ⁻²
Oil hole Insert	Titanium Alloy	3.5651 e ⁻³
Titanium Inserts 1 & 2	Titanium Alloy	3.4456 e ⁻³
Connection Link	Aluminium Alloy	0.1586
Complete Component		0.24627

Table V. Variation in Material and Weight of Connecting Rod

Material	Weight of Connecting rod
Steel	0.68604 kg
Composite (Steel-Ti)	0.67873 kg
Composite (Al-Ti)	0.24627 kg

IV. CONCLUSION

The analysis of connecting rod is done using FEA (Finite Element Method) software. Three different materials and their combinations were considered for analysis and later the variations in the results and weight of connecting rod were compared. The materials considered are Steel, titanium and aluminium.

In general, the use of composite materials helps in reducing the weight of the component without varying the boundary conditions, allowable stresses etc. Forging is the conventional method of manufacturing a connecting rod. Steel is heavier than aluminium and titanium. The combination of steel titanium or aluminium titanium has a better strength than any individual metal.

1. 64.10% is reduction in weight of connecting rod when forged steel and Al-Ti composite is compared.
2. No much reduction in weight is observed for steel and composite of Steel-Ti but increased load carrying capacity.

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