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Optimization for thermal analysis connecting rod of internal combustion engine by using two different materials

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Abstract
This paper describes the study of optimization for connecting rod of internal combustion engine by using two different materials like forged steel and C-70 connecting rods. The performance of connecting rod will be evaluated with two types of materials.
Connecting rods operate under high loads needs high strength in both tension and compression and high fatigue strength. For fulfilling that need here we have selected typical forged steel or ultra-high strength steel. This steel has strength level above 900MPa and this steel generally have carbon content ranging from 0.01-0.45%. It is well known that, as strength increases, toughness reduces. So toughness of ultra-high strength steel is an important consideration. As strength increases, critical length/size of defect decreases. Once the critical length of the defect is reached during processing or application, the material fails catastrophically without any prior warning. Ultra high strength steels are classified according to their composition microstructure. The steel C-70 has been introduced from Europe as crack able forging steel. Alloying elements in the material enables hardening of forged connecting rods when they undergo controlled cooling after forging. Hence a comparative study of these two materials for fatigue loading is the main goal of this paper. The model was developed in Pro/E wildfire 5.0 and then imported as parasolid (IGES) form in ANSYS workbench.

Keywords: Optimization, fatigue analysis, connecting rod, internal combustion engine

1. 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.
Connecting rods are widely used in variety of car engines. The function of connecting rod is to transmit the thrust of the piston to the crankshaft, and as the result the reciprocating motion of the piston is translated into rotational motion of the crankshaft. It consists of a pin-end, a shank section, and a crankend. Pin-end and crank-end pin holes are machined to permit accurate fitting of bearings. One end of the connecting rod is connected to the piston by the piston pin. The other end revolves with the crankshaft and is split to permit it to be clamped around the crankshaft. The two parts are then attached by two bolts. Connecting rods are subjected to forces generated by mass and fuel combustion. These two forces results in axial and bending stresses. Bending stresses appear due to eccentricities, crankshaft, case wall deformation, and rotational mass force. Therefore, a connecting rod must be capable of transmitting axial tension, axial compression, and bending stresses caused by the thrust and pull on the piston and by centrifugal force (Afzal and Fatemi, 2003).
Connecting rods that function in internal combustion engines are subjected to high cyclic loads comprised of dynamic tensile and compressive loads. They must be capable of transmitting axial tension and compression loads, as well as sustain bending stresses caused by the thrust and pull on the piston and by the centrifugal force of the rotating crankshaft. Figure 1 presents schematic illustrations of a connecting rod and its location and function in an engine.

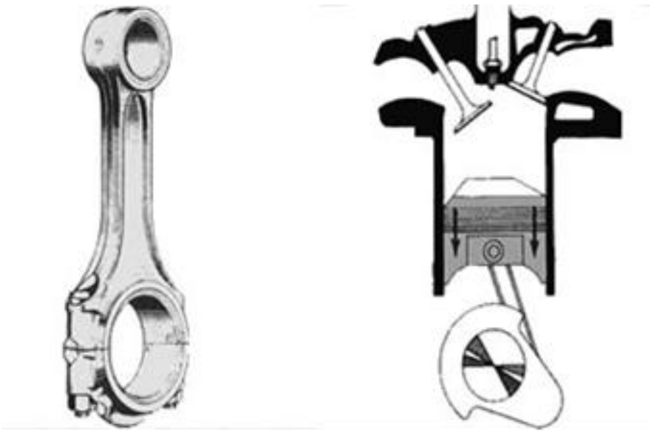


Fig 1: Schematic illustrations of a connecting rod

Connecting rods are highly dynamically loaded components used for power transmission in combustion engines. The optimization of connecting rod had already started as early year 1983 by Webster and his team. However, each day consumers are looking for the best from the best. That's why the optimization is really important especially in automotive industry. Optimization of the component is to make the less time to produce the product that is stronger, lighter and less cost. The design and weight of the connecting rod influence on car performance. Hence, it is effect on the car manufacture credibility. Change in the structural design and also material will be significant increments in weight and performance of the engine.
As connecting rod is a mass production component, it is only logical that optimization of the connecting rod for its weight or volume will result in large-scale savings. It can also achieve the objective of reducing the weight of the engine component, thus reducing inertia loads, reducing engine weight and improving engine performance and fuel economy.
The connecting rod is subjected to a complex state of loading. It undergoes high cyclic loads of the order of 108 to 109 cycles, which range from high compressive loads due to combustion, to high tensile loads due to inertia. Therefore, durability of this component is of critical importance. Due to these factors, the connecting rod has been the topic of research for different aspects such as production technology, materials, performance simulation, fatigue, etc. For the current study, it was necessary to investigate finite element modeling techniques, optimization techniques, and developments in production technology for new materials and strength of material under fatigue loading.

2. Design of Connecting Rod

The connecting rod (con rod) is a bit of metal that connects the crankshaft to the pistons. Forces from the combustion in the cylinder push the pistons down and rotate the crankshaft via the con rods. The rotation of the crankshaft is eventually transferred to motion in your wheels. A rather important function of a car when you think about it. Yes, quite right.
RPM in your car is a measure of how many times the crankshaft completes a full cycle in one minute. At an average redline of 7,000rpm the crankshaft is spinning 117 times per second! In other words, hauling ass. As the con rods need to be connected to move around with the hauling crankshaft the points of contact have to be something special. The job is given to your con rod bearings (also called insert bearings).

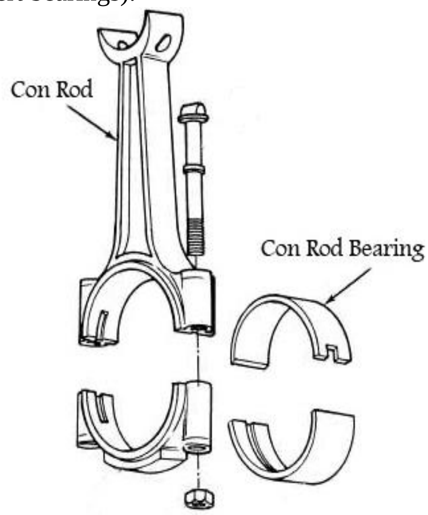


Fig 2: Connecting rod with bearing

3. Finite Modelling of the Connecting Rod

Table 1: Specifications of engine connecting rod

Parameters	Dimensions
Bore	88mm
Stroke Length	125mm
Crank Radius	62.5mm
Connecting Rod Length	200mm
Top Speed @ idle load	2875 rpm
Top speed @ full load	5000 rpm
Peak Firing Pressure	40.24 MPa
Mass of Connecting Rod	670.24 gms

3.1 Boundary Conditions

In the analysis carried out, the axial load was 21800 N in both tension and compression. FEA for both tensile and compressive loads are conducted. In this study four finite element models are analyzed. For both material as Forged steel and C-70 Finally the comparisons are done for material optimization purpose.
The main aim of this study is to find out the fatigue life of connecting rod for two different material. The analysis is done with four type of loading and comparison is made in order to judge the fatigue life of the connecting rod.
Case Study:

- Compressive loading at Piston End with Crank End fixed
- Tensile loading at Piston End with Crank End fixed.
- Compressive loading at Crank End with Piston End fixed.
- Tensile loading at Crank End with Piston End fixed

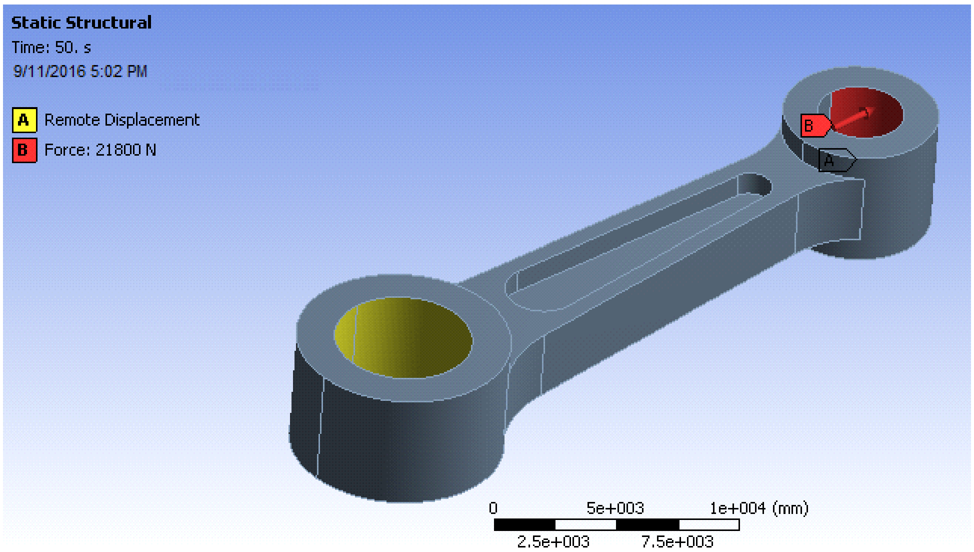


Fig 3: Tensile Loading at piston end

4. Results and Discussion

Through the fatigue analysis of the connecting rod, two loadings were taken into account for both the material. In tension loading for forged steel material which its results were shown in Fig.26,the maximum stress generated is 6.5748e-003 MPawhile in compressive pressure stress (Fig.27), the stress generated 4.4602e-003 MPa was gained. The same stresses for C-70 steel in tension and compression are 6.538e-003 MPa and 4.4572e-003 MPa respectively. Relating to the connecting rod, the most critical area is near the piston pin end where the allowable force exertion cycles with the totally reverse loading were gained $10E^8$ and $10E^6$ for C-70 and Forged steel respectively which increased by decreasing in stress concentration factor.

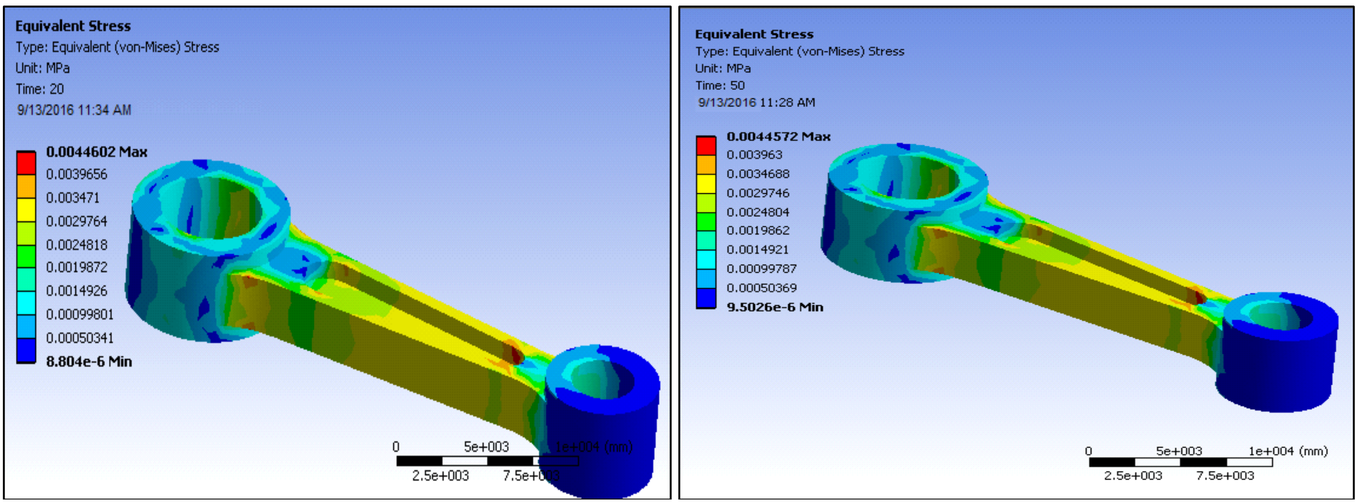
As with the analysis result we can find out the stress result for both material is nearly same but as far as fatigue life is concerned there is major difference.

Summarized the stress and deformation data in tabular format as under:

Table 2: Result Summery

Forged steel			C-70		
Eqiv.Stress	**Deformation**	**Fatigue Life**	**Eqiv Stress**	**Deformation**	**Fatigue Life**
4.4602e-003 MPa	3.4145e-004 mm	$10E^6$	4.4572e-003 MPa	3.2913e-004 mm	$10E^8$
6.5767e-003 MPa	4.5559e-004 mm	$10E^6$	6.538e-003 MPa	4.3905e-004 mm	$10E^8$
4.4774e-003 MPa	3.2893e-004 mm	$10E^6$	4.4748e-003 MPa	3.1717e-004 mm	$10E^8$
6.5748e-003 MPa	5.3109e-004 mm	$10E^6$	6.5514e-003 MPa	5.1198e-004 mm	$10E^8$

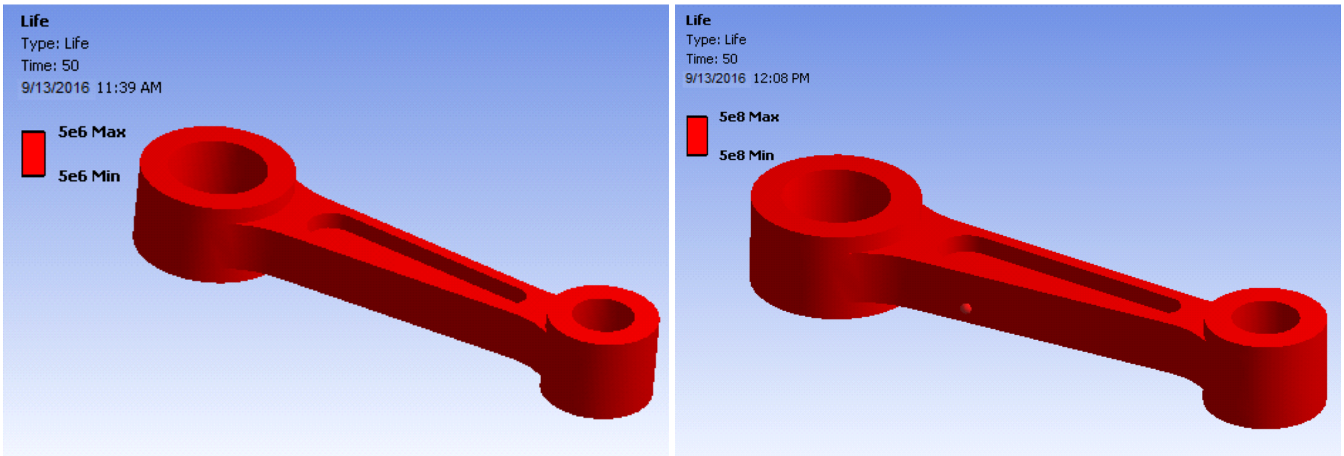
4.1 Compressive loading at Piston End with Crank End fixed



a. b.

Fig 4: Equivalent stress for (a) Forged Steel (b) C-70 Steel

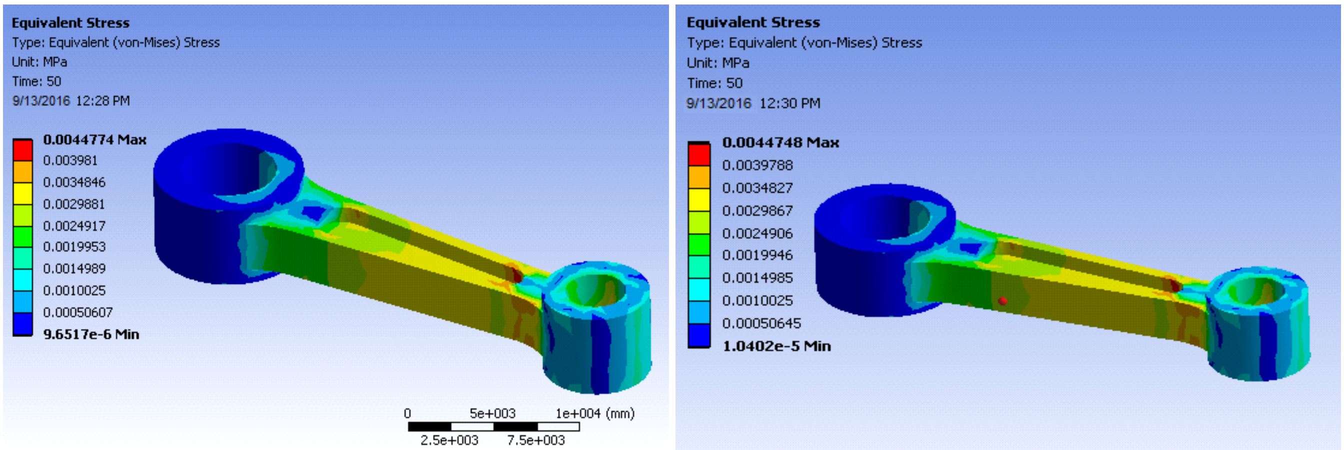
4.2 Tensile loading at Piston End with Crank End fixed



a. b.

Fig 5: Fatigue Life for (a) Forged Steel (b) C-70 Steel

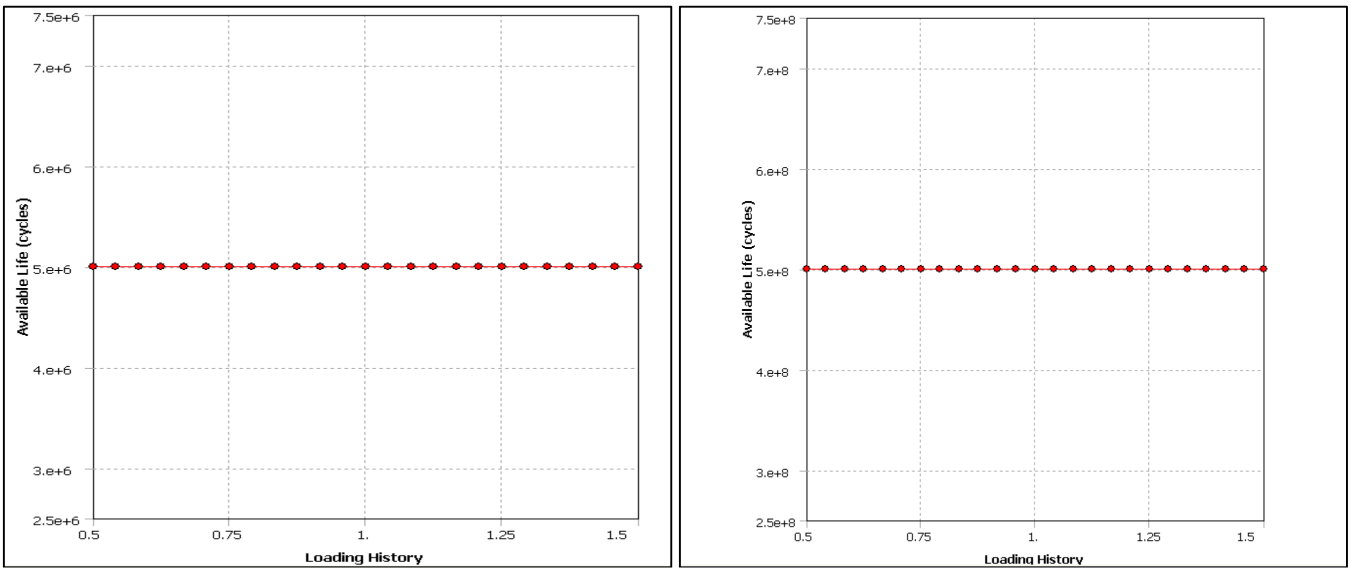
4.3 Compressive loading at Crank End with Piston End fixed.



a. b.

Fig 6: Equivalent stress for (a) Forged Steel (b) C-70 Steel

4.4 Tensile loading at Crank End with Piston End fixed



a. b.

Fig 7: Fatigue Sensitivity plot for (a) Forged Steel (b) C-70 Steel

5. Conclusion

By the finite element analysis method and the assistance of ANSYS software, it is able to analyze the different car components from varied aspects such as fatigue and consequently save the time and the cost. The way that defined loadings was effective on the results achieved. So, they should fit as much as possible the real conditions. As the fatigue analysis requires some static analysis and to define the boundary conditions closest to the real. Stress concentration factors indicated the difference between the real and the working condition. Relating to the connecting rod, the most critical area is near the piston pin end where the allowable force exertion cycles with the totally reverse loading were gained $10E^8$ and $10E^6$ for C-70 and Forged steel respectively which increased by decreasing in stress concentration factor.

The following conclusions can be drawn from the results of this study:

- The von Mises stress contours and critical locations observed under tension and compression loadings. The most highly stressed areas are in the transition regions between the shank and the crank end, as well as the shank and the pin end. Stresses are all symmetric over the entire rod, since geometry and loading were symmetrical. The stresses obtained are below yield strength (elastic); and therefore, the relation between load and stress is linear.
- Table 2 shows the stress and displacement contours. The result shows a maximum longitudinal displacement of 5.31e-4 mm in tension and 3.41e-4 mm in compression for forged steel. Similarly, a maximum longitudinal displacement of 5.11e-4 mm in tension and 4.39e-4 mm in compression were observed for C-70 steel. This means for same loading condition the deformation is less for C-70 material though the difference is very small.
- Similarly the Von-Mises stresses are less for C-70 steel both for compressive and tensile loading.
- The C-70 geometry is having higher the same fatigue life ($10E^8$), as compered to spite of existing forged steel connecting rod geometry which have fatigue life as ($10E^6$).

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