# Dynamic Load Analysis and Optimization of a Fracture-Split Connecting Rod

Dipak Sarmah, Athar M Khan and Anirudh Jaipuria

Ashok Leyland Ltd. India.

*Abstract: This paper summarizes the methodology to design fracture-split (FS) connecting rod using CAE tools, ensuring product quality with reliability and rapid response in terms of study and implementation.*

*FS connecting rod is first manufactured as single piece, then precisely cracked-off, aided by laser score-line, to produce jagged surfaces which provides perfect alignment, higher strength and keeps production costs low.*

*A Finite Element model of the FS connecting rod, bolts, bearing-shells, bush, piston pin and crank pin is built based on 3D CAD models. Symmetric boundary condition is utilized to simplify the analysis and reduce computational time. Von mises stress and fatigue due to maximum gas and inertia loading are determined considering bolt pre-load and bearing interference. Split line evaluation is done with inertia load under minimum bolt pre-load to determine local gaping between big-end mating surfaces.*

*Con-rod material was also changed to C-70 steel due to its fracture crackability, which facilitates separation of cap from rod without additional machining of mating surfaces and also delivers better performance and gives cost reduction of 12%. Based on FEA results the conrod geometry is optimized and 5% reduction in mass of conrod forging is achieved. By using FS con-rod we achieved a total saving of Rs 200 per engine. Also FEA analysis with virtual prototypes helped in reducing the time and resources involved.*

*Keywords: Bolt Loading, Forging, Fracture-split, C70, Gas force, Inertia loading, FEA, Connecting Rod*

## Introduction

The connecting rod in an internal combustion engine couples the piston to the crank shaft. The small end of the connecting rod has a small bore that is coupled to the piston pin on piston and big end of the connecting rod is coupled to the crank pin. Because of the physical construction of the crank shaft, the big end of the connecting rod has to be separated into two pieces in order to mount on the pin. In the past the normal practice was to initially mould and machine the connecting rod

in two pieces that would then bolted together on the crank pin. Recently in order to improve accuracy and reduce manufacturing cost, the fracture splitting method is being considered.
In FS method, the cap and the rod are forged and machined together as a one body. Then they are separated into two pieces by making an impact. The fracture is guided by a notch made precisely in the inside diameter. As a result the machining of the split surface is not required, also additional positional constrain not required in production line as irregularities in the split surfaces acts as assembly position. This method also reduces the machining cost due to integration of machining of cap and the rod and the elimination of machining the end faces and positioning. Also the accuracy of the big end bore increased due machining as a single piece and proper positioning. A typical fracture split connecting rod process sequence is shown in table.1.

| | |
|---|---|
| 1 | Rough Grinding Rod |
| 2 | Small End (S.E.) Drilling & Boring |
| 3 | Bolt Seat milling |
| 4 | Bolt Hole Drilling & Tapping |
| 5 | Big End (B.E.) semi finish Boring |
| 6 | Laser notching |
| 7 | Fracturing |
| 8 | Assembly Rod And Cap. |
| 9 | B.E.Facing and Chamfer |
| 10 | B.E.Finish and S.E.Bush Bore |
| 11 | Notch Milling |
| 12 | B.E. Honing |
| 13 | Deburing, Filling & Inspection |
| 14 | Cleaning, Packaging & Despatch |

Table 1.Process sequence for fracture split connecting rod

In order to have a precise positioning of the spited surfaces the fracture should be brittle fracture. But normal forged steel connecting rod undergoes plastic deformation before actual fracture. So the material of the fracture split should be properly selected. Generally C70 steel is used because of its crankability, high strength and low cost.

## Analysis Details

An axis-symmetric model of Connecting Rod Subassembly has been modeled in Pro-E and imported to ABAQUS 6.7-1.The model is meshed, assembled and material properties are applied.

## Software used:

**CAD Package:** Pro-E WF2

**Pre & Post Processing Software:** ABAQUS / CAE 6.7-1

**Simulation Software:** ABAQUS / Standard 6.7-1

## Finite Element Model:

The finite element model & meshing details of the connecting rod is shown below.

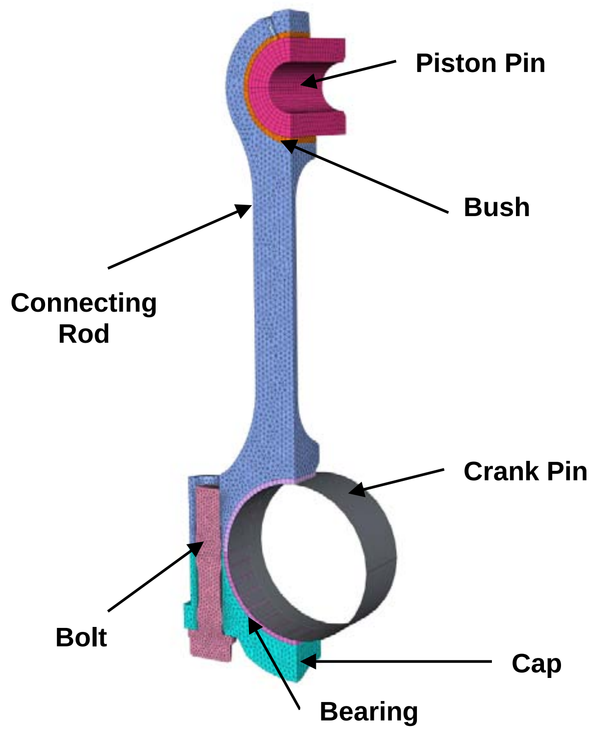


Fig 1.FEA Model of Connecting Rod

| Component | No. of Nodes | No. of Elements | Element Type |
|---|---|---|---|
| Bearing | 468 | 200 | C3D8R |
| Bolt | 3518 | 15793 | C3D4 |
| Bush | 662 | 1918 | C3D4 |
| Con-Rod | 11202 | 51456 | C3D4 |
| Cap | 6226 | 29341 | C3D4 |
| Piston Pin | 3014 | 2310 | C3D8R |
| **Total** | **25090** | **101018** | |

Table 2. Meshing details of the connecting rod FEA model

The following material properties are applied to the parts of the connecting rod.

| Sl.No | Component | Material | Young’s Modulus (GPa) | Poisson Ratio |
|---|---|---|---|---|
| **1** | Bearing Shell | Steel | 206 | 0.29 |
| **2** | Bush | Steel | 206 | 0.29 |
| **3** | Bolt | Steel | 206 | 0.29 |
| **4** | Piston Pin | Steel | 206 | 0.29 |
| **5** | Con-Rod & Cap | C70S6 | 210 | 0.3 |

Table 3. Material details of the connecting rod FEA model

The fractured surface is modeled as normal surfaces but while defining the contact between the surfaces, the coefficient of friction is considered more than the normal plain surface contact. This is helpful to get correct stress in the bolt during the complex loading pattern of the connecting rod. The accuracy of the simulation depends upon the assumption of precise coefficient of friction because the fractured surfaces are not plain.

## Load Cases:

### 1. Case 1: Bolt Preload & Bearing and Bush Interference

The bolt pre load is taken as 91.7 kN for 10.9 grade bolt material. Considering the symmetry of the FEA model, half of this load is applied as pre tension on the bolts. The Bush and bearing over-closure in radial direction is taken as 90 μm and 88 μm respectively.

### 2. Case 2: Gas Pressure Loading

The contact condition of the piston pin and the bush is considered as clearance fit. Similarly the clearance between the crank pin and the bearing is considered. The crank pin is modeled as rigid surface and constrained in all 6 degree of freedom. The bolt is included in the model, but not preloaded.

**Clearances**:
Bush-Piston Pin = 36 μm
Bearing-Crank Pin = 82 μm

**Gas Force Calculation:**

| | | |
|---|---|---|
| Cylinder Bore | 104 | mm |
| Pick Firing Pressure | 120 | bar |
| Force on piston | 101938 | N |

One fourth of this maximum gas force is applied on the piston pin. For application of this force a reference point is created and then it is coupled to the piston pin upper surface.

## 3. Case 3: Inertia Loading

The inertia force due to the piston assembly and the connecting rod is calculated at maximum over-speed. The bolt is included in the model, but not preloaded.

**Clearance:**
Bush-Piston Pin = 36 µm
Bearing-Crank Pin = 82 µm

**Inertia Force Calculation:**

| | | |
|---|---|---|
| Connecting Rod Mass | 1.85 | kg |
| Con-Rod reciprocating Mass | 0.57 | kg |
| Con-Rod rotating Mass | 1.28 | kg |
| Piston assembly Mass | 1.15 | kg |
| Piston acceleration | 8581.69 | m/s2 |
| Inertia Force due to Piston | 9868.94 | N |
| Rotational Acceleration | 6544.44 | rad/s |
| Con-Rod Mean Acceleration | 7172.13 | m/s2 |

One fourth of this maximum inertia force is applied on the piston pin. For application of this force a reference point is created and then it is coupled to the piston pin lower surface. For the piston pin acceleration field of 8580 m/s2 is applied and for connecting rod mean acceleration field of 7170 m/s2 is applied.
In this case the possibility of split line separation is also evaluated during inertia loading of the connecting rod.

## 4. Case 4: Combined Loading

In this case the two combined loading is simulated.

- Bolt load + Bearing & Bush Interference + Gas pressure loading
- Bolt load + Bearing & Bush Interference + Inertia loading

## Results

**1. Case 1: Bolt Preload & Bearing and Bush Interference**

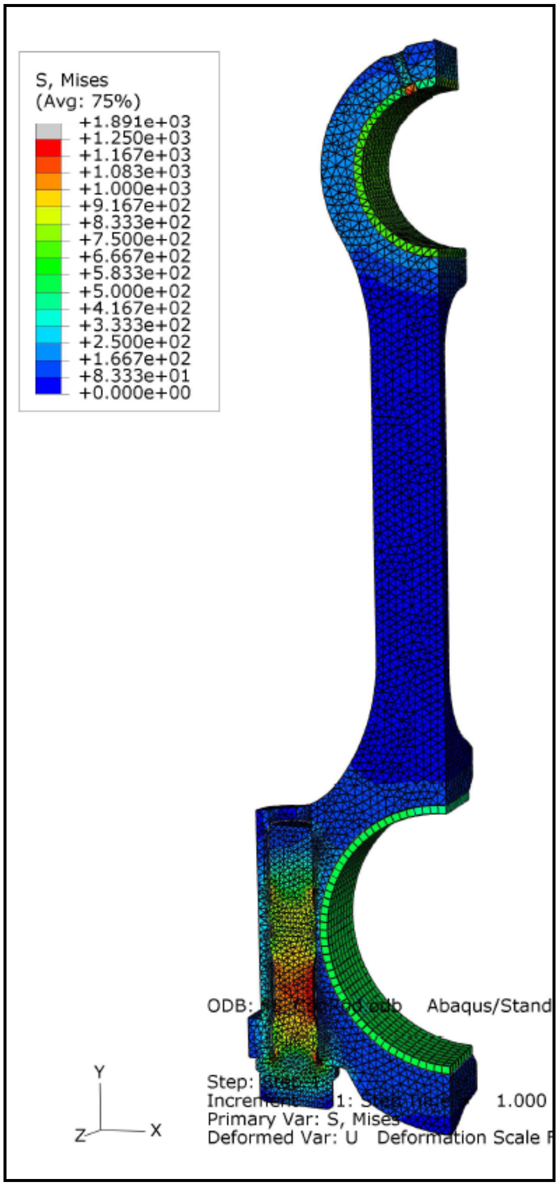


Fig 2. von Mises stresses for bolt preload and bearing & bush interference

## 2. Case 2: Gas Pressure Loading

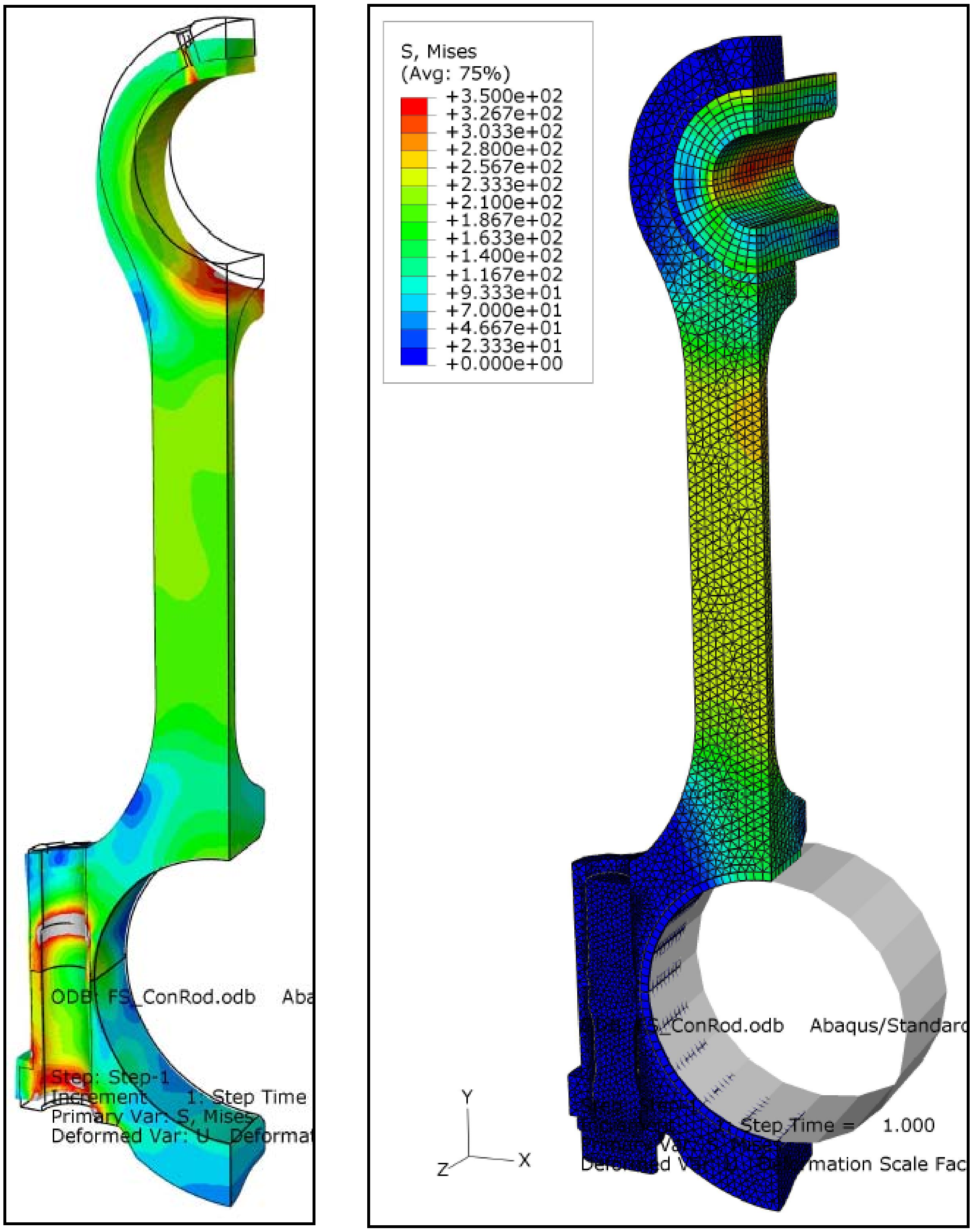


Fig 3. Deflection (Scale x50) & von Mises stresses for gas pressure loading

## 3. Case 3: Inertia Loading

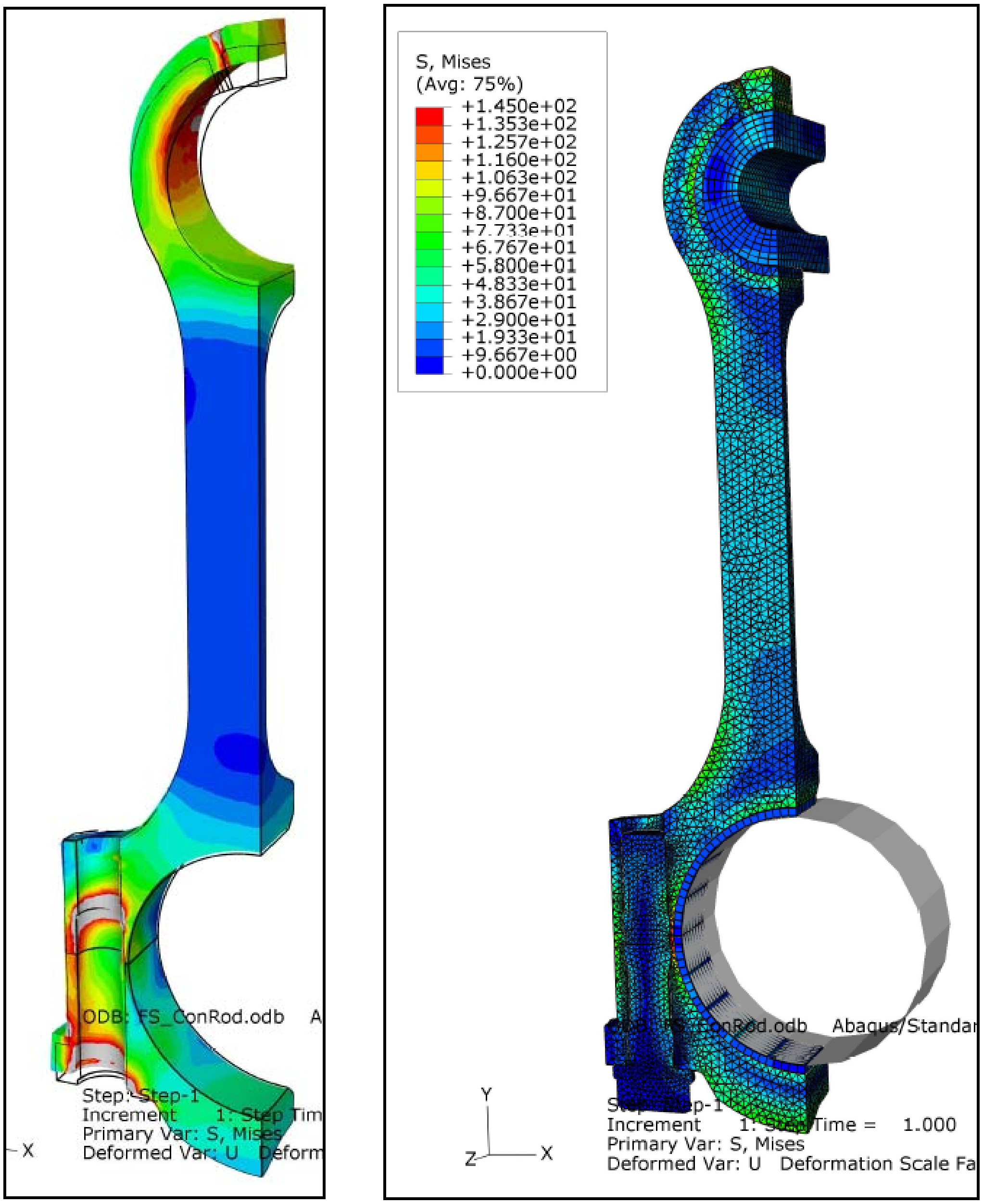


Fig 4. Deflection (Scale x50) & von Mises stresses for inertia loading

## 4. Case 4: Combined Loading

### a. Bolt load + Bearing & Bush Interference + Gas pressure loading

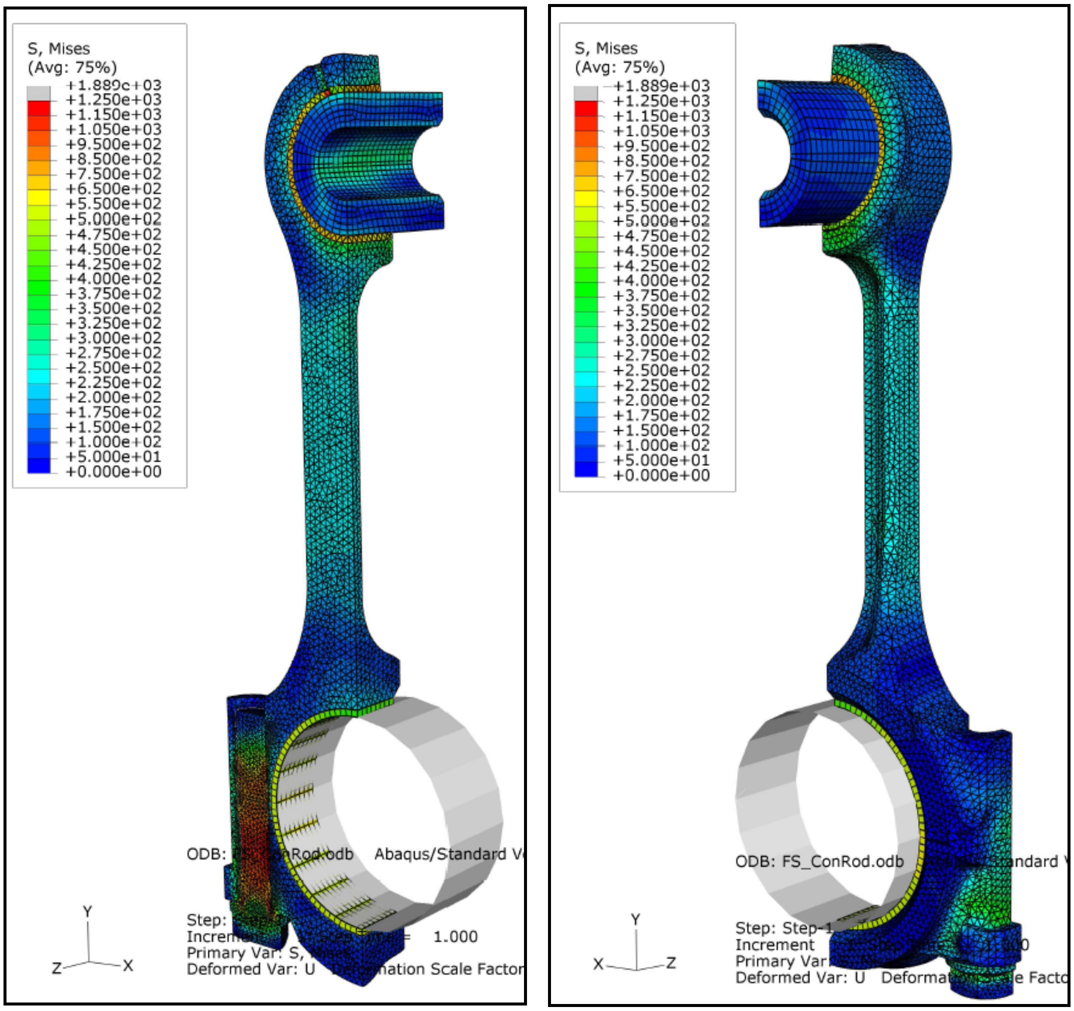


Fig 5. von Mises stresses for combined bolt load + bearing & bush interference + gas pressure

**b. Bolt load + Bearing & Bush Interference + Inertia loading**

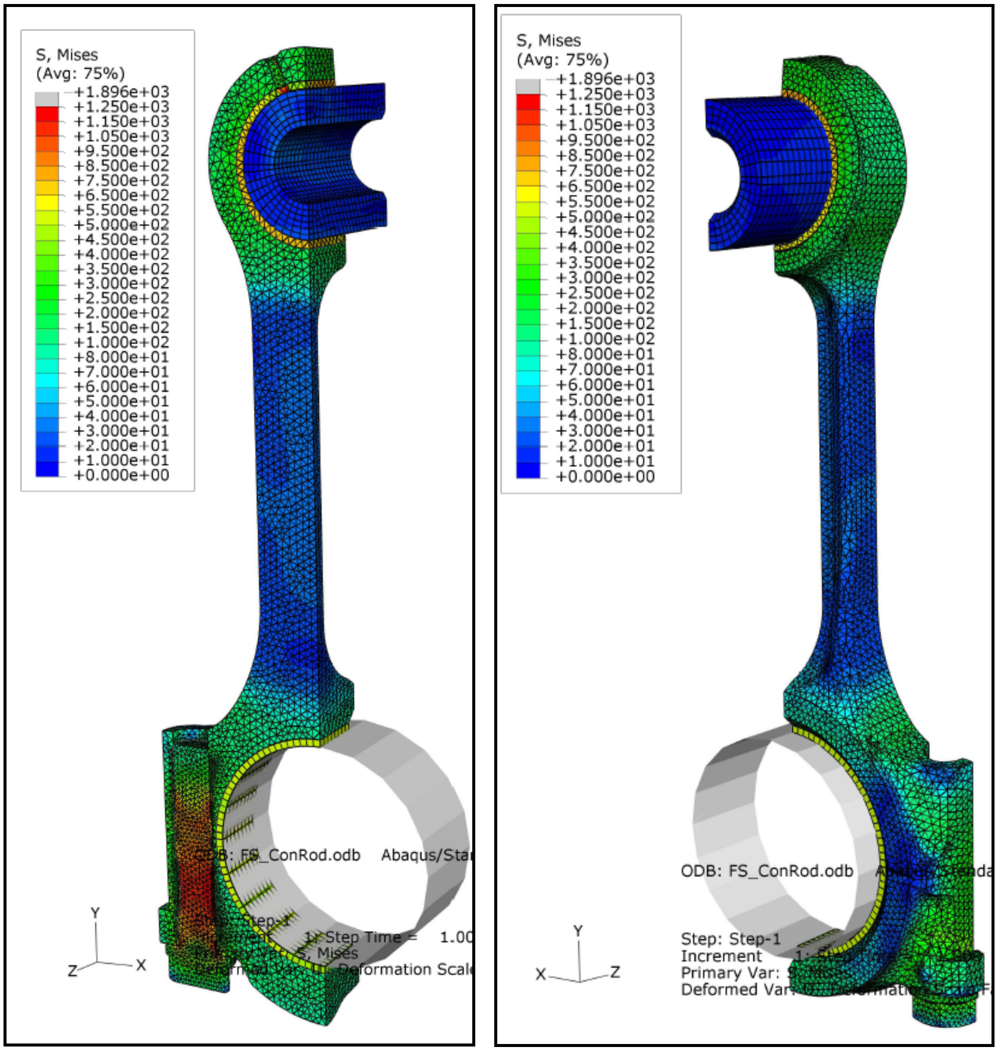


Fig 5. von Mises stresses for combined bolt load + bearing & bush interference + inertia

## Conclusion

The results of all the cases are shown above. The occurring stresses are below the limit of the material with some local exceptions e.g. contact surface connecting rod small end or start of the thread. The high stresses in these areas are result of stress concentrations which are artificial and caused by following assumptions:

- Linear elastic material behavior (no plasticity is considered).
- Presence of sharp edges in the contact area. In practice any edge are not very sharp. eg, the starting of bolt thread is not so sharp, but because of the presence of the sharp edge in the 3D model, the stress shown is more.

Based on the FEA results the design of the connecting rod is further optimized to have weight reduction. Proto samples of the fracture split connecting rod are prepared and endurance test is done on engine.

A cost estimation of the exiting connecting rod and new fracture split connecting rod is done. Because of the low forging weight and less machining required, there is a saving of around Rs.200 per engine when fracture split connecting rod is used.

## References


1. Fatemi A, Zoroufi M, Shenoy P and Afzal A, "Comparative durability study of Competing manufacturing process technologies," Mechanical, industrial and manufacturing engineering department, The university of toledo, toledo, ohio.
2. James R. Dale, "Connecting Rod Evaluation," Metal Powder Industries Federation, Princeton, 2005
3. Pravardhan S. Shenoy and Ali Fatemi, "Connecting Rod Optimization for Weight and Cost Reduction," SAE Paper 2005-01-0987, The University of Toledo, 2005.
4. Tsuyoshi Kubota, Shinya Iwasaki, Tsuneo Isobe, Toshikatsu Koike, "Development of Fracture Splitting Method for Case Hardened Connecting Rods," YAMAHA motors technical review. 2005.
5. Internal Reports.