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Fatigue analysis and life predictions of Forged steel and Powder Metal connecting rods

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Abstract: *The report investigates on fatigue behavior of forged steel connecting rods. They must be capable of transmitting axial tension and compression loads. Altair Hyper works software is used for applying tension and compression loads, Altair Hyper mesh for preprocessing, Altair Radioss for solving tension and compression analysis at the same time fatigue analysis for checking the life of the material based on tension and compression condition are solved. Conclusion is based on the result of material life. Modeling incorporated three-dimensional geometry, tension and compression loading, and symmetry conditions. 3-D model geometry was developed in CATIA V5R19. These analyses were performed iteratively at different element lengths until the solution obtained appropriate accuracy. Convergence of stresses were observed, as the mesh size was successively refined. The element size of 1.27 mm was finally considered. The result obtained were discussed and reported.*

Keywords: *forged steel, connecting rods Altair Hyper works element size.*

I. Introduction

The function of connecting rod is to translate the transverse motion to rotational motion. It is a part of the engine, which is subjected to millions of repetitive cyclic loadings. It should be strong enough to remain rigid under loading, and be light enough to reduce the inertia forces produced when the rod and piston stop, change directions and start again at the end of each stroke. The connecting rod should be designed with high reliability. It 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 without bending or twisting. The connecting rod experiences inertia forces plus direct forces that produce bending in a plane perpendicular and parallel to the crankshaft longitudinal axis. Connecting rod is typically designed for infinite life. Failures of connecting rods are often caused by bending loads acting perpendicular to the axes of the two bearings. Failure in the shank section as a result of these bending loads occurs in any part of the shank between piston-pin end and the crank-pin end [1]. At the crank end fracture, can occur at the threaded holes or notches for the location of headed bolts. Pin-end failures can occur from bore against a fitted bushing.

II. Modeling Of Connecting Rods

A 3-D model is designed in CATIA V5 and then imported in to Altair Hypermesh, after completing preprocessing it is solved using ALTAIR RADIOSS. Dimensions of the connecting rod were taken from three different connecting rods and the averages of these dimensions are used to generate the model. Due to symmetry of the geometry, the component was first half modeled, and then the entire geometry was created by reflecting (mirror imaging) the half geometry. The density of 7.9e-09 kg/mm3 was used as material property in the FEA model. It is an indication of the FEA model accuracy [2]. A hexahedral element for different sizing of mesh & Hexamesh was used for the solid geometry, as this was the default option by ALTAIR RADIOSS for any 3-D analysis. Sensitivity analysis was performed to obtain the optimum element size of 1.27 mm was finally considered. Total numbers of elements generated are 80016 and total numbers of nodes generated are 130210 at 1.27 mm element length. The solid meshing module allows user to quickly generate high quality meshes for multiple volumes. After meshing is done for complete connecting rod required material must be applied for existing mesh. material collector using Hypermesh interface which consist of Matfat card which is useful to conduct fatigue test for stress - life (S-N) & strain - life (E-N) by giving material properties such as young's modulus, Poisson's Ratio, yield strength, ultimate tensile strength [3].

III. Type of Analysis

Tension and compression loads were applied as pressure on the bearing surfaces of the connecting rod. Under actual service condition, pin end experiences tension by the piston pin causing distribution of pressure along the upper half of the inner diameter, which is approximated by the cosine function. In compression, the piston pin compresses the bearings against the pin end inner diameter, causing uniform distribution of pressure.

The same phenomenon of pressure distribution caused by the crankshaft was experimentally measured on the crank end of the connecting rod Shown in Fig.1.The connecting rod was constrained in all six degrees of freedom from the bearing surfaces on one end and pressure was applied at the other end [4]. Only longitudinal loading direction was considered as this is the primary loading direction. The typical engine parameters for four cylinder engine are given in Table 1.

Table 1: Typical engine parameters of four-cylinder engine

Engine parameters	Dimensions
Connecting rod length	157 mm
Crankshaft radius	52 mm
Crank to C.G distance	42.50 mm
Engine speed	4000-8000 rpm
Maximum firing pressure	53.70 ATM
Maximum compression pressure	10.00 ATM
Piston diameter	87.5 mm
Piston assembly mass	585.00 g
Forged steel connecting rod weight	430.00 g

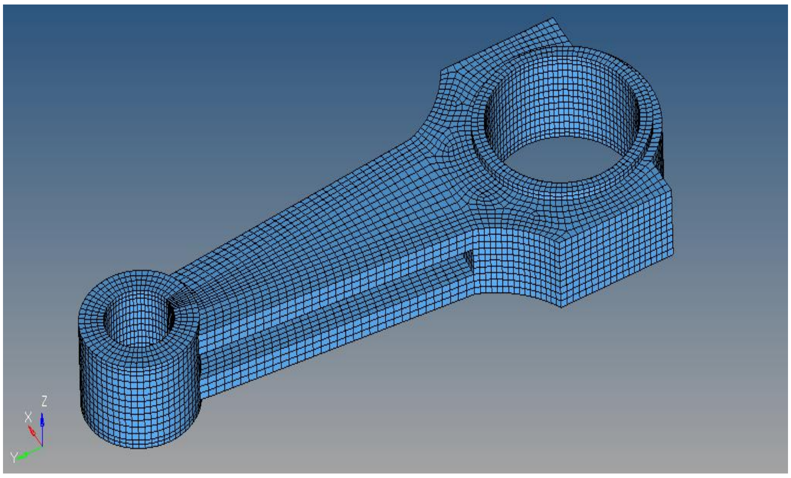

Figure 1: Hexamesh using Hypermesh

Table 2: Summary of connecting rod FE analysis load parameters.

Parameter	Crank end loading		Pin end loading	
	Tension	Compression	Tension	Compression
Load magnitude	26688 N	26688 N	26688 N	26688 N
Load distribution	Cosine distribution over180°	Uniform Distribution over 180°	Cosine distribution over 180°	Uniform distribution over 180°
Pressure on the surface	35.7 MPa	32.4MPa	72.6 MPa	65.9 MPa

IV. Load And Stress Analysis

Connecting rods are submitted to mass and gas forces. The superposition of these two forces produces axial force which acts on the connecting rod. Connecting rods also experience bending moments due to eccentricities, crankshaft and rotational mass forces. Axial loading can be calculated by the knowledge of engine pressure and rotational speed, whereas bending moment can be determine by strain analysis in an engine. Critical areas of failure are the transition regions from the small end to the shank and from the shank to the big end. Local stress amplitudes are obtained for the critical areas. They concluded that an error in the moment of inertia of connecting rod using this model could predict incorrect engine forces and dynamics [5]. With the actual connecting rod model, the inertia forces of the distributed mass model become more complicated to analyze. The small end of the rod has a reciprocating motion along the bore, whereas, the big end of the rod moves in rotational motion. However, the center of rod mass path describes an ellipse, which makes it difficult to analyze. Therefore, a two lump mass connecting rod model was introduced for simplification. The connecting rod is divided into reciprocating and rotating masses so that the distributed connecting rod mass is replaced by

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lumped masses at each end located at the bore center [6]. The following equations have to be satisfied to make the rod model equivalent to the actual rod model:

mc = mc,a + mc,b
mc,a L1 = mc,b L2
Jc = mc,a L12 + mc,b L22 + Jf

Where,

mc is the mass of connecting rod,
mc,a is the reciprocation mass of connecting rod,
mc,b is the rotating mass of connecting rod,
L1 is the distance from connecting rod mass center to piston pin center,
L2 are the distance from connecting rod mass center to crank pin center,
Jc is the actual moment of inertia,
Jf is the inertia error.

V. Mesh Size Sensitivity Analysis

To recognize the effect of element size on the stresses, mesh size sensitivity analysis was carried [7]. The stress changes as a result of element size changes. These analyses were performed iteratively at different element lengths until the solution obtained appropriate accuracy. For this analysis, the rod was constrained at the pin end and cosine distribution pressure was applied at the crank end. For the first analysis, a 7.77 mm default mesh size was used and von mises stresses were obtained at three different locations. For the second iteration, a mesh size of 2.54 mm was used, and for the third iteration a mesh size of 1.52 mm was used. For final iteration, an element length of 1.27 mm was used. Table 2 summarizes the results of the convergence of stresses at different locations. shown in Fig.2

Mesh sensitivity analysis is done by using different mesh sizes as mentioned in Table 2. As per the mesh sensitivity the mesh size is given accurate results Shown in Fig.3. In finite element analysis based on number of nodes these results are accurate because when large mesh size is used it may not give good results because of its less number of nodes, so that it will not capture high stress location and displacement location[8]. For checking the fatigue behavior of two materials same load is used as mentioned above. By taking the load of 26688N, converting as a pressure based on tension and compression values and applying to the connecting rod [9]. Pressure load is applied because load should be radial shown in Fig.4. Compression values and applying to the connecting rod and is shown in Fig.5

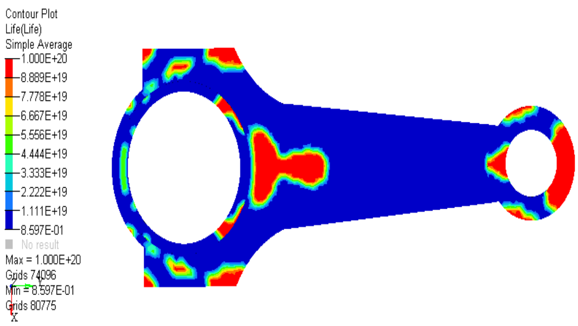

Figure 2: Life of the forged steel component is 1E20 cycles

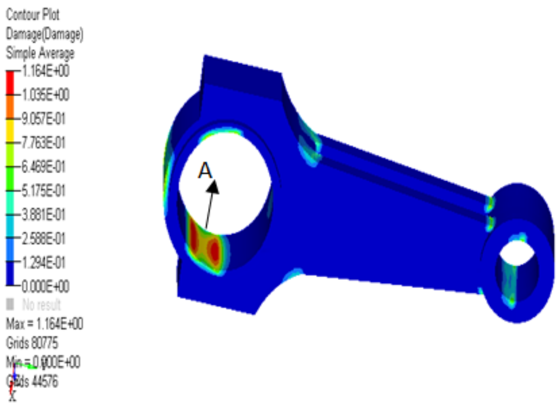

Figure 3: forged steel rod damage (A)

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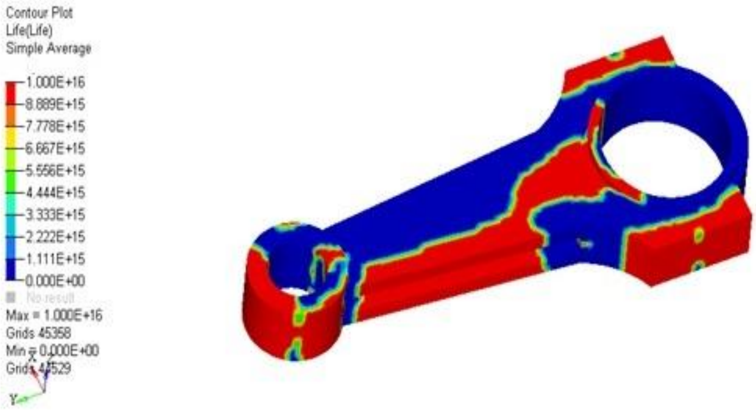

Figure 4: Life of the powder metal component is 1E16 cycles

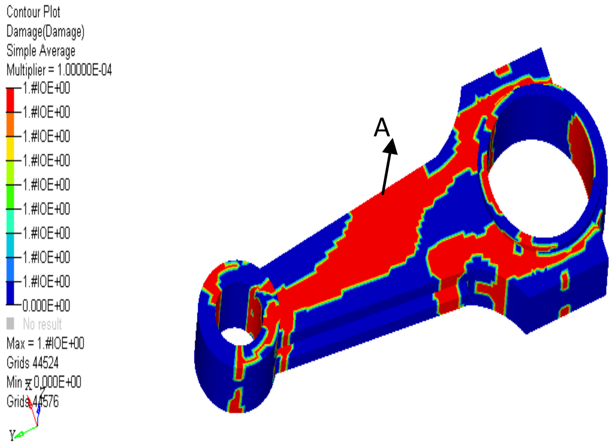

Figure 5: Powder metal connecting rod get damages (A)

VI. Results And Discussion

Materials tests are often classified as monotonic or cyclic. Both kinds of these tests are used to characterize the mechanical properties of metals, composites and many other materials, as well as components made from these materials [10]. The tension and compression are examples of monotonic tests are shown in Table 3. in these tests, an increasing load (positive or negative) is applied to the specimen to identify its yield strength, ultimate strength and other properties [11]. Cyclic tests apply oscillating loads, often until specimen failure, using load schemes that may involve either cyclic tension, compression or a combination of these two properties are shown in Table.4

Table 3: Summary of montonic properties for forged steel.

Montonic properties	Forged steel	Powder metal
Modulus of elasticity, E, GPa	201	199
Yield strength, YS, MPa	700	588
Ultimate strength, Su MPa	938	866
Percentage elongation, %EL (%)	24%	23%
Percentage reduction in area, %RA	42%	23%
Strength coefficient, K, MPa	1,400	1379
Strain hardening exponent, n	0.122	0.152
True fracture strength, sf, MPa	1,266	994
True fracture ductility ef (%)	54%	26%
Hardness	28	20

Table 4: Summary of fatigue material cyclic properties for forged steel.

Cyclic properties	Forged steel	Powder metal
Fatigue strength coefficient, MPa	1188	1493
Fatigue strength exponent	-0.0711	-0.1032
Fatigue ductility coefficient	0.3576	0.1978
Fatigue ductility exponent	-0.5663	0.5304
Cyclic yield strength, Mpa	620	609
Cyclic strength coefficient, MPa	1397	2005
Cyclic strain hardening exponent	0.1308	0.1917
True fracture strength, sf	423	334
Average, GPa	204	197

VII. Conclusions

In this study, Experimental results, observations and analysis performed gives the following conclusions can be drawn:

1. Results of tensile and compressive test of connecting rod, which shows clearly that forged steel has 20% more life than the other metal connecting rods.
2. As per fatigue test, forged steel life shows 1E20 cycles. By this it has been proved that forged steel is better replacement on other metals.
3. 3. Linear elastic finite element analysis of the forged steel connecting rod under axial loading indicated the two transition regions (crank end to the shank and pin end to the shank) to be the critical regions.

VIII. Future Scope Of Work

Recent developments of C-70 and micro alloyed steels, Fatigue analysis and life predictions can be conducted for the C-70 and micro alloyed steel connecting rods using tensile, compressive and fatigue test are to be conducted.

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