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Determination of Fatigue Life of a Connecting Rod of a Motorbike Using FEA

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ABSTRACT

The connecting rod is the most relevant part of an automotive engine. The connecting rod is subjected to an extremely complex state of loading. High compressive and tensile loads are due to the combustion of fuel and connecting rod's mass of inertia respectively. The objective of this dissertation is to investigate the failure analysis of the connecting rod of motorbike. Static structural analysis using ANSYS and experimental analysis is conducted on connecting rod. The purpose of this study is to show the performance of connecting under different loading condition. After that, the work is carried out for geometry change and fatigue life. The Results of Analysis is compared with the Experimental results.
Keywords : Connecting Rod (CR), Unigraphics, static structural analysis in ANSYS and Fatigue Life, Universal Testing Machine (UTM).

I. INTRODUCTION

Connecting rod is the intermediate link between the piston and the crank. In addition, is responsible to transmit the push and pull from the piston pin to crank pin, thus converting the reciprocating motion of the piston to rotary motion of the crank. For automotive it should be lighter should consume less fuel and at the same time they should provide comfort and safety to passengers, that unfortunately leads to increase in weight of the vehicle. This tendency in vehicle construction led the invention and implementation of quite new materials that are light and meet design requirements.

Suraj Pal this paper deals with Finite element analysis of single cylinder four stroke petrol engines is taken for the study; Structural systems of Connecting rod can be easily analyzed using Finite Element techniques in the present design connecting rod for the given loading conditions
G. Naga Malleshwara Rao et al. main objective of this work is to explore weight reduction opportunities in the connecting rod of an I.C. engine by examining various materials such as Genetic Steel, Aluminium, Titanium and Cast Iron. This was entailed by performing a detailed load analysis.

Therefore, this study has dealt with two subjects, first, static load and stress analysis of the connecting rod and second, Design Optimization for suitable material to minimize the deflection.

Vivek. C. Pathade et al. investigate the stress analysis of connecting rod by finite element method using pro-e wild fire 4.0 and ANSYS workbench 11.0 software. it concluded that the stress induced in the small end of the connecting rod are greater than the stresses induced at the bigger end, therefore the chances of failure of the connecting rod may be at the fillet section of both end.
H.B. Ramani et al. performed detailed load analysis of connecting rod., In order to calculate stress in Different part of connecting rod, the total forces exerted connecting rod were calculated. It was observed that maximum stresses in different parts of connecting rod were determined by Analysis. The maximum pressure stress was between pin end and rod linkages and between bearing cup and connecting rod linkage.

B. Anusha, Dr. C Vijaya Bhaskar Reddy performed modelled connecting rod imported to the analysis software i.e. ANSYS. Static analysis is done to determine von-misses stresses, strain, shear stress and total deformation for the given loading conditions using analysis software i.e. ANSYS. In this analysis, two materials are selected and analyzed. The software results of two materials are compared and utilized for designing the connecting rod.

Priyank D. Toliya, Ravi C. Trivedi, Prof. Nikhil J. Chotai, the objective of this research is to investigate the failure analysis of the connecting rod of the automotive engine. Apart from conventional material of connecting rod I choose the connecting rod of FM-70**.**Diesel engine which is made of Aluminium 6351. Static analysis is done to determine the von Misses stress, elastic strain, total deformation in the present design connecting rod for the given loading conditions using the FEM Software Ansys 12.1 .In the starting of the work, the static loads acting on the connecting rod, After that the work is carried out for safe design and life in fatigue. Fatigue Analysis is compared with the Experimental results.

The automobile engine connecting rod is a high volume production critical component. It connects reciprocating piston to rotating crankshaft and transmits the thrust of piston to the crankshaft and thus, it converts the linear, reciprocating motion of a piston into the rotary motion of a crankshaft.

Figure 1.1. Connecting Rod

Classification:

The classification of connecting rod is made by the cross sectional point of view i.e. I – section, H – section, Tabular section, Circular section. In low speed engines, the section of the rod is circular, with flattened sides.

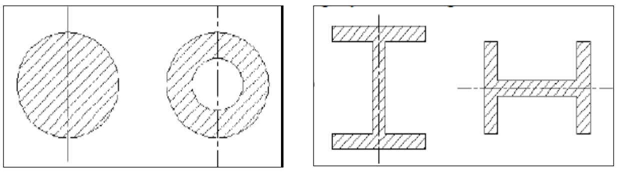

Figure 1.2. Different C/S of connecting rod

Forces acting on the connecting rod are,

- Forces on the piston due to gas pressure and inertia of the reciprocating parts.
- Force due to inertia of the connecting or inertia bending forces.
- Force due to friction of the piston rings and of the piston, and
- Forces due to friction of the piston pin bearing and crank pin bearing.

II. THEORETICAL CALCULATIONS OF CONNECTING ROD

A connecting rod is a machine member, which is subjected to alternating direct compressive and tensile forces. Since the compressive forces are much higher than the tensile force therefore, the cross-section of the connecting rod is designed as a strut and the Rankine formula is used.

Let,

A = cross sectional area of the connecting rod.

L = length of the connecting rod.

σc = compressive yield stress.

F = crippling or buckling load.

Ixx = moment of inertia of the section about x-axis respectively.

Iyy = moment of inertia of the section about y-axis respectively.

Kxx = radius of gyration of the section about x-axis.

Kyy = radius of gyration of the section about y-axis.

A. Specification of Existing Connecting Rod

Engine Specification

Engine type air-cooled 4-stroke

Bore = 56 mm

Stroke = 60.7 mm

Crank Throw r = 30.35 mm

Peak Pr Pr = 72.5 Bar

Engine speed @ Torque Pt

N_{Torque} = 7500 rad/s

Angular velocity @ Torque Pt

V_{Torque} = 785.40 rpm

Engine speed @ Peak Power

N_{Power} = 8500 rad/s

Angular velocity @ Peak Power

V_{Power} = 890.12 rpm

Engine speed @ Redline

$N_{Redline}$ = 12500 rad/s

Angular velocity @ Redline

$V_{Redline}$ = 1309.00 rpm

B. Design Calculation:

The standard dimension of I – Section are,

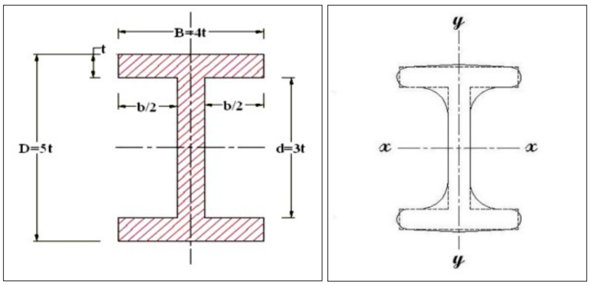

Fig 2. Standard Dimension of I – Section

Let us consider an I – section of the connecting rod as shown in figure, with the following proportions, so that the connecting rod to be equally resistant to buckling in either plane, the relation between moment of inertia must be,

$$I_{xx} = 4\ I_{yy}.$$

C. Mathematical Calculation:

Maximum force on the piston due to pressure,

Gas Force = Pressure x c/s area of piston

$$F_G = P \times \frac{\pi}{4} \times D^2$$

$$= 7.25 \times \frac{\pi}{4} \times (56)^2$$

$$= 17856.81\ N$$

Calculations for other forces is given in the form of chart,

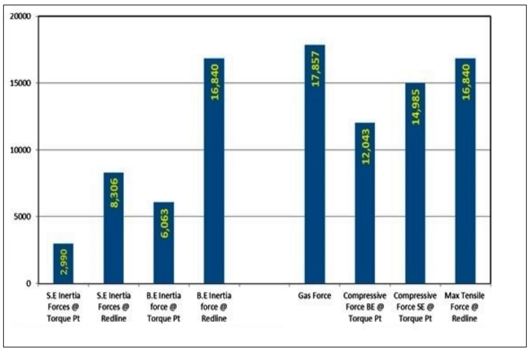

Figure 2.1: chart for Force Calculation of FEA

III. MODELING

Connecting rod is modelled by taking the designed parameter of existing conrod with the help of Nx10 saved in IGES format then imported in ANSYS for further analysis.

Table 1: Dimensions of Connecting Rod

Sr. No.	Parameters	Value
1	Length of connecting rod Lcr	104.5 mm
2	Outer Diameter of Big end	48 mm
3	Inner Diameter of Big end	38 mm
4	Outer Diameter of small end	25.8 mm
5	Inner Diameter of small end	17 mm
6	Mass of total piston assembly	0.124 kg
7	CG from Big end	34.39 mm
8	Total mass of CR Mcr	0.150 kg
9	Reciprocating mass of CR M_{cr} reci	0.049 kg
10	Rotary mass of CR M_{cr} rot	0.101 kg

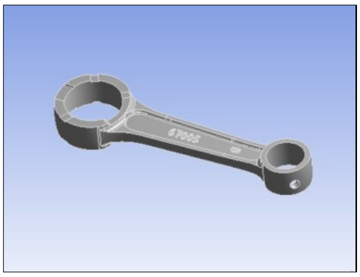

Figure 3. Model of Connecting Rod

Table 2: Material Properties

Selected Material	Structural Steel
Young's Modulus(E)	2.0×10^5 MPa
Poisson's Ratio	0.3
Density	7860 Kg/m^3
Tensile ultimate Strength	460 MPa
Tensile Yield Strength	250 MPa
Compressive Yield Strength	250 MPa

A. Meshing

The next step after modeling is meshing of connecting rod model. The mesh model of present connecting rod is as shown in figure 3.1. Meshing is the initial step in the analysis of finite element method. Ansys creates the proper mesh of the total object for further analysis. Thus after meshing of connecting rod in the Ansys workbench 18.0 load and boundary conditions are applied.

Nodes - 83435 Elements -384648 Element Size - 1 mm

Figure 3.1: Mesh Model of connecting rod

B. Load and Boundary Condition of Connecting Rod

A model of connecting rod is created by Nx.10 is imported for analysis in ANSYS Workbench 18.0. Analysis is done with the given loading is applied at small end i.e. piston end of connecting rod by fixing the big end. Part A i.e. big end is fixed and at the part B, i.e. small end force is applied on connecting rod as shown in figure 3.2.

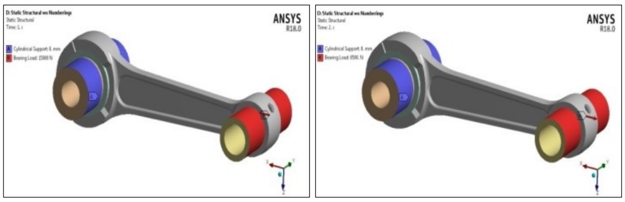

Figure 3.2: Loads & Boundary Condition

IV. RESULTS AND DISCUSSIONS

For the analysis of connecting rod the loading conditions are applied as per the numerical results obtained in the design calculations at small end keeping big end of connecting rod fixed. The analysis is done using software ANSYS workbench 18.0. The maximum and minimum values of parameters like von-mises stress, strain and deformation are noted in the present connecting rod analysis model.

Results of Existing connecting rod Analysis

Equivalent Stress

Equivalent stresses are minimum at both the ends and moderate at shank.

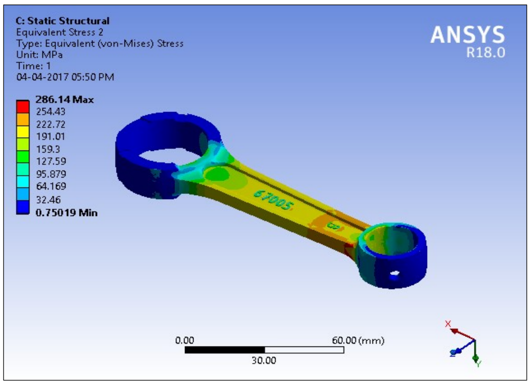

Figure 4: Equivalent Stress 1

From the fig 4 the Equivalent von Mises stress occurs at the piston end of the connecting rod is 286.61 MPa and minimum stress occurs at the crank end of the connecting rod is 0.79236 MPa.

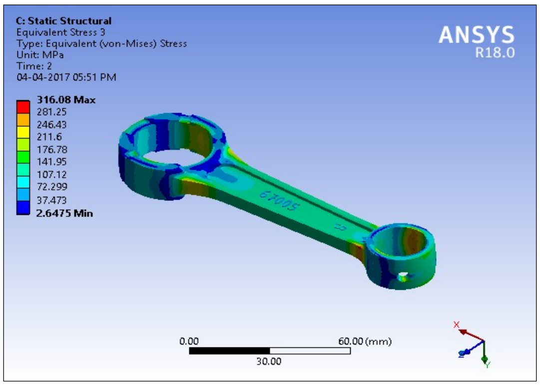

Figure 4.1: Equivalent Stress 2

From the fig 4.1 the Equivalent von Mises stress occurs at the piston end of the connecting rod is 309.83 MPa and minimum stress occurs at the crank end of the connecting rod is 3.404 MPa.

Total Deformation

It is combined measure of deformation is seen from Figure 7.8 & Figure 7.9 that deformation goes on increasing from fixed support end to free end.

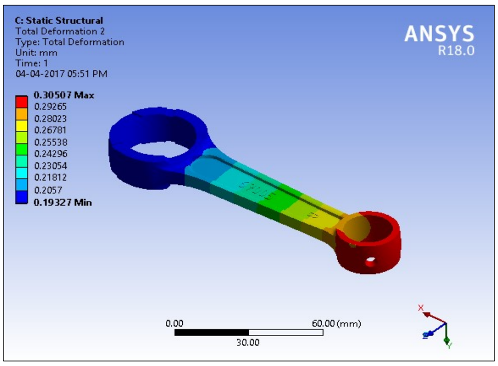

Figure 4.2: Total Deformation1

From the fig 4.2 the maximum total deformation occurs at the piston end of the connecting rod is 0.3058 mm and minimum total deformation occurs at the crank end of the connecting rod is 0.19397 mm.

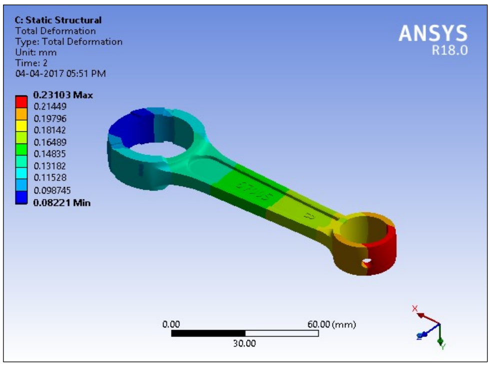

Figure 4.3: Total Deformation 2

From the fig 4.3 the maximum total deformation occurs at the piston end of the connecting rod is 0.23032 mm and minimum total deformation occurs at the crank end of the connecting rod is 0.081685 mm.

Fatigue Analysis Life

It is number of cycles conrod can withstand before any sign of failure occurs.

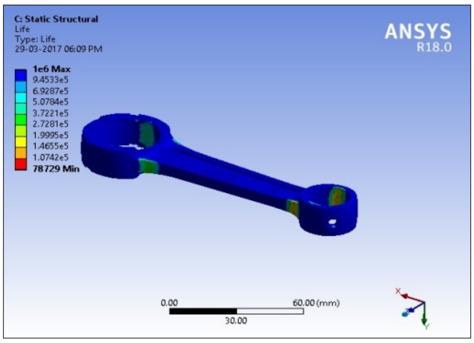

Figure 4.4: Life

Damage

It is ratio of design life to actual life. Damage greater than 1 indicates part will fail before design life is achieved.

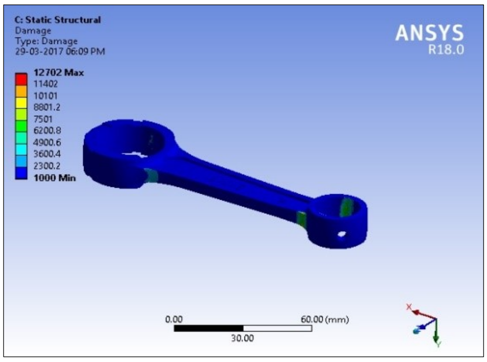

Figure 4.5: Damage

Safety Factor

It is measure of factor of safety for design. Safety factor is Maximum15 is recorded and minimum 0.59368 is recorded. In between moderate FOS is present.

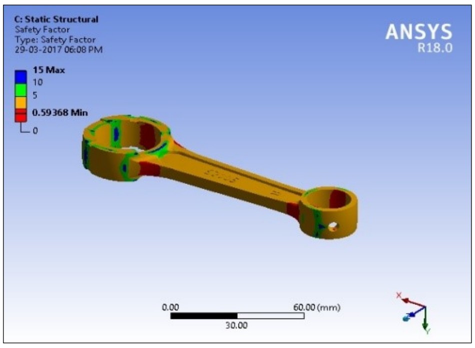

Figure 4.6: Safety Factor

Biaxility Indication

It is qualitative measure of stress. Biaxility indication of -1 represent pure shear, 0 represent uniaxial stresses and 1 represent biaxial stresses.

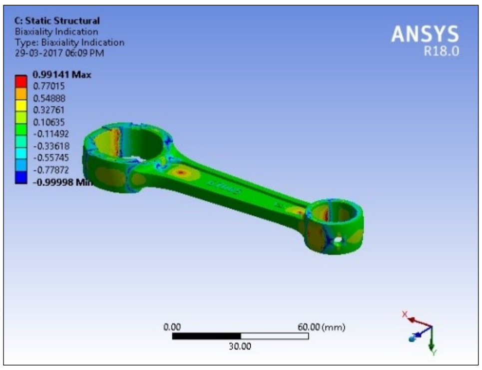

Figure 4.7: Biaxility Indication

Results for Static Loading at Small end with Big end fixed

Table 3: Maximum and Minimum Values of Stress Parameters

Parameter	Time	Structural Steel	
		Max	Min
Equivalent Stress (MPa)	Time 1	286.14	0.75019
	Time 2	316.08	2.6475
Total Deformation (mm)	Time 1	0.30507	0.19327
	Time 2	0.23103	0.08221

Fatigue Tool Results

Table 4: Maximum and Minimum Values of Fatigue Parameters

Parameter	Structural Steel	
	Max	Min
Life	1 e^6	78729
Damage	12702	1000
Safety Factor	15	0.59368
Biaxility indication	0.99141	-0.99998

Summary

1. The existing connecting rod is analysed under S.E Compressive force at torque point is 15000.00 N and S.E inertia force at redline point is 8500 N.
2. The Von-Mises stress observed 286.14 MPa and 316.08 MPa and Displacement Observed 0.30507mm.
3. By observing the above results (Existing Connecting Rod) the stresses are below the yield limit of material used.

Despite all the stresses in the CR are not damaged due to high tensile strength but it may fail under fatigue loading. Thus, it is important to determine the critical area of concentrated stress for appropriate modification.

Since the ultimate aim of the current project is to design a Connecting Rod with maximum life i.e maximum number of cycles which can sustain a given load and had the slightest displacement.

V. NEED OF MODIFIED GEOMETRY

After studying existing model of connecting rod, we found that the stress concentration is more at neck radius portion of crank and pin end so to reduce this stress and improve its fatigue life we modify the geometry by making some changes in the present design of I Section.

Modified Geometry

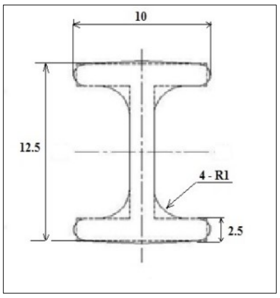

Fig 5.1 Existing Geometry

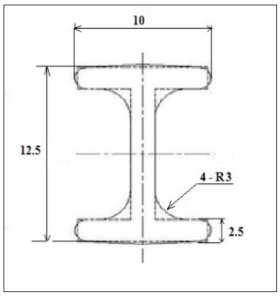

Fig 5.2 Modified Geometry

The above figure shows that Existing Geometry as well as Modified Geometry of I – Section connecting rod.

VI. MODIFIED FEA MODEL

Connecting rod was modelled by taking the designed parameter of Modified conrod with the help of Nx10 solid modeling software and saved in

IGES format. Then the model is imported in ANSYS for further analysis as shown in figure 6.1.

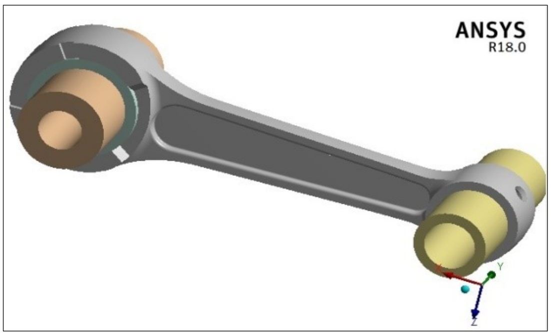

Figure 6.1 Modified Ansys Model

Meshing

The next stage of the modeling is to create meshing of Modified model. The mesh should be finer and accurately represent the geometry in the critical areas i.e. the areas where stress, strain, deformation and loading is going to be important. The elements are selected as tetrahedral & meshed model of connecting rod is shown in fig.6.2.

Nodes - 86465 Elements - 402617
Element Size - 1 mm

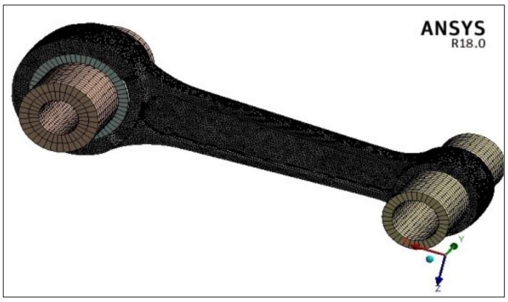

Figure 6.2 Modified Meshed Model

Analysis of Modified connecting rod

Equivalent Stress

Equivalent stresses are minimum at both the ends and moderate at shank.

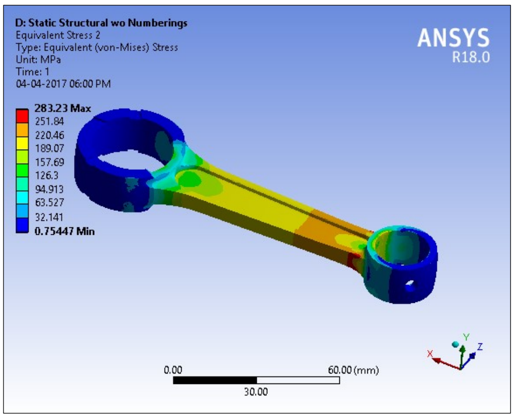

Figure 6.3 Equivalent Stress 1 of Connecting Rod

From the fig 6.3, the Equivalent von Mises stress occurs at the piston end of the connecting rod is 283.23 MPa and minimum stress occurs at the crank end of the connecting rod is 0.75447 MPa.

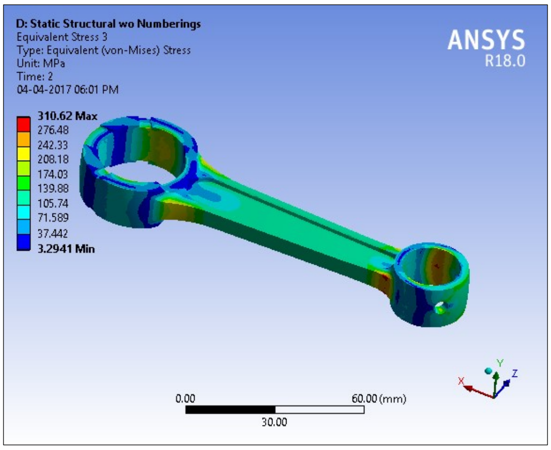

Figure 6.4 Equivalent Stress 2 of Connecting Rod

From the fig 6.4, the Equivalent von Mises stress occurs at the piston end of the connecting rod is 310.62 MPa and minimum stress occurs at the crank end of the connecting rod is 3.2941MPa.

Total Deformation

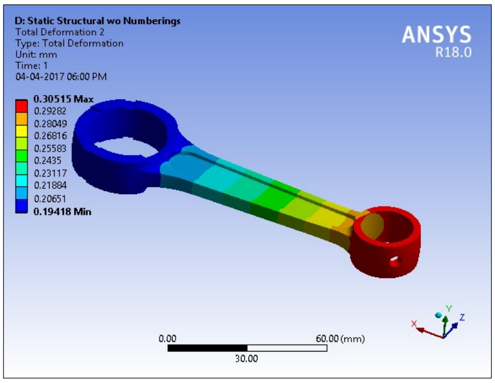

Figure 6.5 Total Deformations 1

From the fig 6.5 shows the maximum total deformation occurs at the piston end of the connecting rod is 0.30515 mm and minimum total deformation occurs at the crank end of the connecting rod is 0.19418 mm.

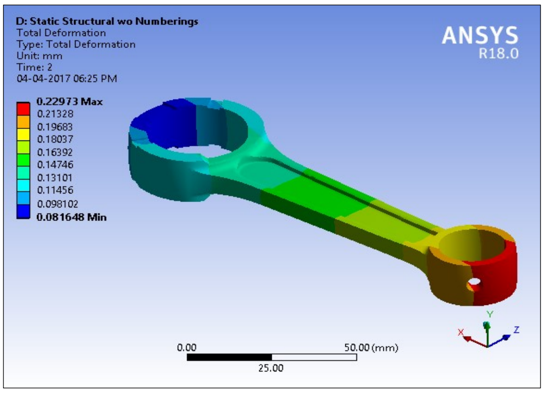

Figure 6.6 Total Deformation 2

From the fig 6.6, the maximum total deformation occurs at the piston end of the connecting rod is 0.22973 mm and minimum total deformation occurs at the crank end of the connecting rod is 0.081648 mm.

Results for Static Loading at Small end with Big end fixed

Table 5 Maximum and Minimum Values of Stress Parameters

Parameter	**Time**	**Structural Steel**	
		Max	**Min**
Equivalent Stress (MPa)	1	283.23	0.75447
	2	310.62	3.2941
Total Deformation (mm)	1	0.30515	0.19418
	2	0.22973	0.081648

FINAL ANALYSIS RESULTS

Parameter	**Life**	
Model	**Existing Model**	**Modified Model**
Max	$1e^6$	$1e^7$
Min	78729	$1e^7$

Parameter		**Total Deformation**	
Model		**Existing Model**	**Modified Model**
Time 1	Max	0.30507	0.30515
	Min	0.19327	0.19418
Time 2	Max	0.23103	0.22973
	Min	0.08221	0.081648

Parameter		**Equivalent Stress (MPa)**	
Model		**Existing Model**	**Modified Model**
Time 1	Max	286.14	283.23
	Min	0.75019	0.75447
Time 2	Max	316.08	310.62
	Min	2.6475	3.2941

VII. EXPERIMENTATION

It has to bear a tensile load and compressive load during its operation in a four-stroke cycle. The loads are so varying in nature and in continuous alternating fashion, which leads to a major Fatigue failure. Therefore, the experimentation is carried out for purpose of stress, deformation and fatigue life of a connecting rod in given loading conditions same as Analysis conditions.

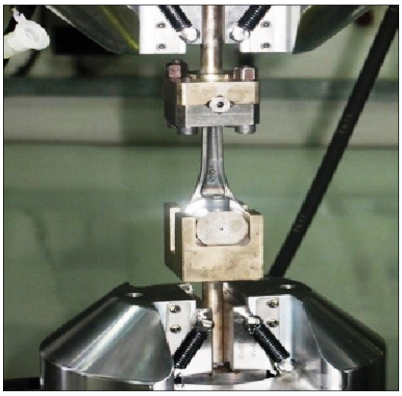

Figure 7.1: Connecting Rod Fixture Concept

A. Fatigue Testing Procedure of Existing Connecting Rod

A simple up-down test process is used as connecting rod is subjected to the alternating load of tensile and compressive nature when it is functioning inside engine..

Test the first proto sample on initial load which is equal to the mean fatigue strength. Now if the first sample fails to meet the acceptance criteria than go to next sample with reduced initial load. This will help us to know at what load it will pass the fatigue life acceptance criteria. If the first sample passes the acceptance criteria than in second new sample needs to increase the incremental load to next higher level, check if that meets the acceptance criteria. After one sample pass the acceptance criteria than in next sample increase the load to the desired intended max load.

Now when the sample passes at this intended max test load than the next three samples should show the consistency in results. This will helps out in making sure that at what load the connecting rod design will pass the fatigue life acceptance criteria.

Figure 7.2 Sample '1' Prototype Failed at near to Small End

Table 6: Fatigue Test Results

No	Sample No	Acceptance Cycles	Cycles Competed	Re mark
1	1	10 million	98.35 Lacs	Failed

Due to above result it is clear that the current design cannot meet the fatigue life of connecting rod.

B. Fatigue Test on Modified Connecting Rod

The modification of cross section at the small end location is applied to the tooling of connecting rod. The fresh samples are procured for fatigue testing. The earlier described procedure is followed to conduct the fatigue testing on these samples.

Table 7: Modified Samples Fatigue Test Results

Parameter	Structural Steel	
	Max	Min
Equivalent Stress (MPa)	275.13	0.70127
	301.92	3.0181
Total Deformation (mm)	0.29915	0.1735
	0.20731	0.07547

Sr. No	**Sample No**	**Accept -ance Cycles**	**Cycles Competed**	**Remark**
1	S1	10 million	10 million	PASS
2	S2	10 million	10 million	PASS
3	S3	10 million	10 million	PASS

C. Experimental Reading:

VIII. Result and Discussion

Table 7: Fatigue testing Results

Sample No	**Load (KN)**	**No Of Cycles**	**FEA Fatigue Life**
1	35	10091	9.79E+03
2	30	21515	2.10E+04
3	27	56512	5.55E+04
4	25	63000	6.47E+04
5	22	96311	9.48E+04
6	20	114157	1.13E+05
7	15	1299170	1.30E+06
8	13	10000000	1.00E+07
9	13	10000000	1.00E+07

S-N Curve of Connecting Rod

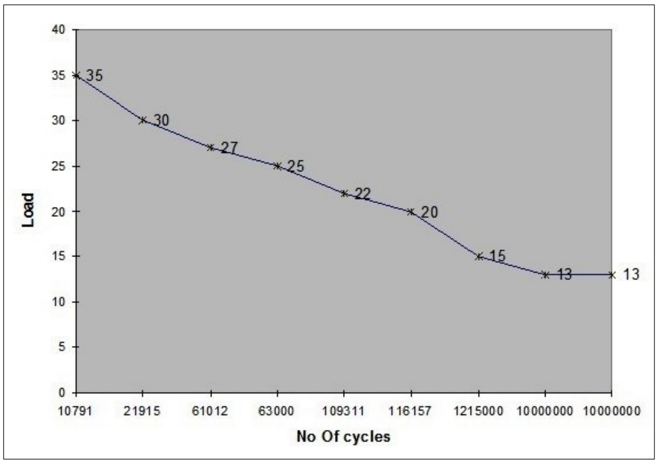

Figure 7.3 Load Vs No of Cycles

Remark:

1) Average static tensile breaking load of Connecting rod is 64KN.
2) Endurance limit in fatigue for connecting rod is 13KN.

IX. CONCLUSION

The research presented in this thesis has mainly concerned to find a superior alternative to existing connecting rod i.e by modifying geometry. The chapter summarizes the main conclusions from this work and discusses possible improvements.

In this dissertation work, the element stress analysis of connecting rod covers the maximum stresses and structure is expected to sustain, without fatigue failure. The connecting rod is analysed under the load.

- The existing connecting rod is modelled and with the help of fatigue tool, a fatigue life is carried out. The modified connecting rod is analysed for same boundary conditions and its mechanical performance is numerically and experimentally evaluated.
- In fatigue we can determine that the minimum and maximum number of cycles can withstand a given connecting rod.
- Maximum stress values observed in the existing and modified connecting rod are 286.14 MPa, 316.08 MPa and 283.23 MPa, 310.62MPa respectively.
- The stress values observed in experimentation are 275.13 MPa, 301.92 MPa these are nearly equal to FEA of modified connecting rod.
- The stress observed after physical experimentation is well below yield stress value of material hence design of modified component is safe.
- The working stress is less than the yield stress, which improves the design life of connecting rod of an I- section.
- Analysis of the connecting rod is clearly shows that by a small modification in the existing design we can increases fatigue life i.e No. of Cycles and decreases stress produced at fillet region.

X. FUTURE SCOPE

The project can be further expanded in various horizons.

- The experimentation must be conducted by using a Photo elasticity method.
- Optimization approach can be considered for future scope. In future the analysis should be carried out on material Optimization like composites and stress analysis on each material should be carried out to observe maximum stress value.
- The modification suggested in this work needs to be analyzed thoroughly. The modification must be analyzed in terms of cost, time effectiveness, worker adaptability, manufacturability also etc.
- The future work consists to develop a computational model. This work consists of developing a computational process to predict the modes of failure in the connecting rod.
- The experiments should be conducted by considering a different loading condition and its effect on connecting rod.

In future Modal Analysis should be carried out on FFT Analyser.

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