

Justification of Induced Stresses in Connecting Rod of Two Stroke Petrol Engine through Photo-Elasticity and FEM

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Abstract

The connecting rods are subjected to loading which is in a complex state. It undergoes high cyclic loads which are high compressive loads and high tensile loads due to combustion and inertia forces. In this paper, the design of connecting rod for two stroke petrol engines and analysis of stresses by photo-elasticity, analysis software and analytical methods are considered. It is also intended to use different materials so as to give unique solution to use it for two stroke engine. The materials used here are 40C8 carbon steel, forged steel, Cast iron respectively. The connecting rod is first designed by using analytical method and stresses induced are determined. The photo-elasticity models are prepared and analyzed the stress pattern through series of experiments in design laboratory using Research Polariscopes. The stress analysis is also carried out through FEM and finally a comparison of all stresses is made. The costs of materials are also compared. It is also suggested to use the connecting rod for the two stroke petrol engines.

Key Words: *Complex state, inertia forces, Cyclic loads, Connecting rod, Photo-elasticity, FEM etc.*

1. INTRODUCTION: A connecting rod is the link between the reciprocating piston and the rotating crank shaft. The reciprocating mechanism is used to convert the reciprocating motion of the piston into the rotary motion of the crankshaft. The connecting rods are subjected to fluctuating loads which are either compression or tension in nature. Also, it undergoes high cyclic loads of the order of 10⁸ to 10⁹ cycles, which range from high compressive loads, high tensile loads due to combustion and inertia forces. This necessitates the checking of the stresses induced in the connecting rod.

The connecting rod of an automobile engine is an important component and produced in large quantity. The connecting rods must have highest rigidity to lowest weight. The stress induced in the connecting rod is a combination of axial and bending stresses. The axial stresses are due to the cylinder gas pressure (both

tensile and compressive), inertia forces are due to reciprocating masses and bending stresses are due to centrifugal effects. Ultimate results are stresses developed at the fillet section of big and small end bearings.

In this paper a connecting rod for a stroke engine is taken for the design and analysis of stresses through photo-elasticity and numerical methods. Hence the objective of the paper is to design a connecting rod of two stroke petrol engine using analytical method for rectangular and I cross-sections. Then photo-elastic models of connecting rods are prepared and stress distribution are studied using research polariscopes for varied loads.

Also, it is intended to build the models of connecting rods of rectangular and I cross-sections using ANSYS 12 and to study the stress distribution for varied loads. The max stresses that can be sustained by connecting rods

are initially estimated analytically. The results by two methods are correlated.

2. BRIEF LITERATURE REVIEW

Vivek.c.pathade [1] performed stress analysis of connecting rod by FEM. Anusha B et al. (2013)[2] carried out the analysis and comparison of the cast iron connecting rod and structural steel. Here, Hero Honda Splendor was taken as case study. It was observed that stresses induced in structural steel connecting rod were lesser than cast iron connecting rod use structural Steel connecting rod. Rao G N M (2013) [3] compared genetic steel, Aluminium, Titanium and Cast Iron for weight reduction opportunities of a connecting rod. Pathade V.C. et al. (2013) [4] used three methods for performing the stress analysis of con rod. The three methods were Numerical method, photo-elasticity and theoretical method. Prakash O. et al. (2013) [5] worked for the case study of con rod of Universal Tractor (U650). They re-optimized connecting rod. Furthermore they also performed static and fatigue analysis. CATIA was used to model the rod and ANSYS V12 was used for its analysis. Sarkate T. S. et al. (2013) [6] studied aluminium 7068 and AISI 4340 alloy steel. Static analysis and comparison of both the above materials were performed. Pro/E Wildfire 4.0 was used to model the rod and ANSYS V12 was used for its analysis. As a result of analysis 63.95% weight of the rod was lowered and a decrement in stresses by 3.59% was identified with aluminium 7068 alloy.

3. ANALYTICAL DESIGNS OF I AND RECTANGULAR CROSS SECTION CONNECTING ROD

The following are the steps to the design process.

- Material selection and properties.
- Analytical design of con rod & related parts.
- Checking for induced stresses.
- Drawings.
- Checking for strength of material.

A. Specification of Hero Honda 100 cc bike

Engine type: two stroke air cooled engine

Bore: 50mm

Stroke: 49.5mm

Volume Displacement: 97.2 cc

Max power: 5.74 KW (7.8Ps) at 7500 rpm

Max Torque: 8.04 N-m at 4500 rpm

Compression Ratio: 9:1

Density of petrol (C₈H₁₈): 737.22kg/m³

Flash point of petrol: - 430 C

Auto ignition temp: 280 C

Temperature: 600 F = 288.8550 k

Mass: Density x volume = 737.22x10⁻⁹ X 97.22x10³ = 0.0716Kg

Molecular weight of petrol: 114.2289/mole = 11423 Kg mole

From gas equation, PV = mRT

Wr, Ro = 8314.8 Nm / mole k

R = Gas constant, Nm /Kg K

R = Ro/M = 8.3148/0.11423 = 72.87 Nm/kgk

P = 0.0716 x 72.787 x 288.855

P = 15.48 Mpa

B. Problem statement

Hero Honda splendor bike of 100 cc is taken for the study and it is intended to check for induced stresses in the big end and small end bearings. Firstly, the con rod is designed using 40C8 carbon steel material. The study is also made for the other materials and checked for induced strengths.

C. Material selection

The connecting rod is usually made of forged steel. Aluminium alloy is also used for connecting rods for low to medium capacity high speed engines. Lighter the connecting rod and piston, greater the resulting power and less the vibration. The reason is the reciprocating weight is less. The different connecting rod steels are (40C8, 37Mn6, 35Mn6 MO3, 35Mn6 MO4, 40Cr4, 40Cr4 Mo3, 40NiCr4MO2) etc.

D. Design of I-c/s connecting rod

$$F_c = \frac{f_c A}{1 + K \left[\frac{1}{k_{xx}} \right]^2}$$

$$K = \text{constant}, \frac{4}{25000}$$

$$K = 0.00016$$

$$A = 11t^2$$

$$L = 120\text{mm}$$

$$K_{xx} = 1.78t$$

$$f_c = \frac{\text{yield stress}}{\text{FOS}}$$

$$\text{Assume F.O.S} = 4$$

$$F_c = 378/4$$

$$f_c = 94.5 \text{ Mpa}$$

$$29105 = \frac{94.5 \times 11t^2}{1 + 0.00016 \left[\frac{120}{1.78t} \right]^2}$$

$$29105 = \frac{94.5 \times 11t^2 \times 1.78t^2}{1.78t^2 + 0.00016 \times 120^2}$$

$$29105 = \frac{1850.31 t^4}{1.78 t^2 + 2.304}$$

$$0.06 t^4 - 1.78 t^2 - 2.304 = 0$$

$$t^2 = 30.09$$

$$t = 6 \text{ mm}$$

$$B = 4 \times t$$

$$= 4 \times 6$$

$$B = 24 \text{ mm}$$

$$H = 5 t$$

$$H = 5 \times 6$$

$$H = 30 \text{ mm}$$

$$A = 11 t^2$$

$$A = 396 \text{ mm}$$

E. Design of rectangular c/s connecting rod

$$F_c = \frac{f_c A}{1 + K \left[\frac{1}{k_{xx}} \right]^2}$$

$$K = \text{constant}, \frac{4}{25000}$$

$$K = 0.00016$$

$$A = 11 t^2$$

$$L = 120 \text{ mm}$$

$$K_{xx} = 1.78 t$$

$$F_c = \frac{\text{yield stress}}{\text{FOS}}$$

assume F.O.S = 4

$$f_c = \frac{378}{4}$$

$$f_c = 94.5 \text{ Mpa}$$

$$29097 = \frac{94.5 \times 20 t^2}{1 + 0.00016 \left[\frac{120}{0.28 t} \right]^2}$$

$$29097 = \frac{94.5 \times 20 t^2 \times 0.28 t^2}{0.28 t^2 + 0.00016 \times 120^2}$$

$$29097 = \frac{529.2 t^4}{0.28 t^2 + 2.304}$$

$$0.018 t^4 - 0.28 t^2 - 2.304 = 0$$

$$t^2 = 21.5$$

$$t = 5 \text{ mm}$$

$$B = 4 \times t$$

$$= 4 \times 5$$

$$B = 20 \text{ mm}$$

$$H = 5 t$$

$$H = 5 \times 5$$

$$H = 25 \text{ mm}$$

$$A = 11 t^2$$

$$A = 500 \text{ mm}$$

Table.1 Dimensions of I and Rectangular Cross section

Parameters	I-c/s	Rectangular c/s
Length	120	120
Thickness (t)	6	5
Width (B)	24	20
Height (H)	30	25
Height at small end (H1)	22.5	22.5
height at big end (H2)	33	31.25
Inner dia of small end	31.5	31.5
Outer dia of small end	45.5	45.5
Inner dia of big end	44	44
Outer dia of big end	67	67

F. Drawings of Connecting rod

The 2-D drawings of both rectangular and I cross-section are shown in Fig.1 and Fig.2 respectively.

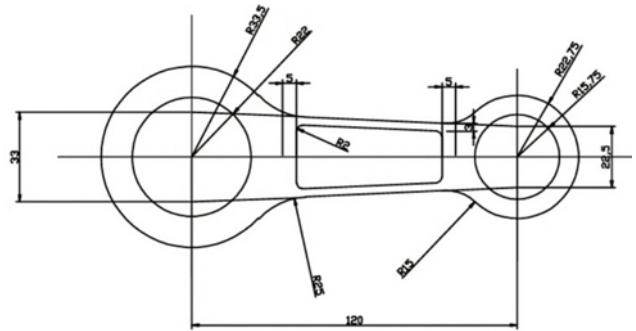


Fig.1 2D Drawing of I cross-section

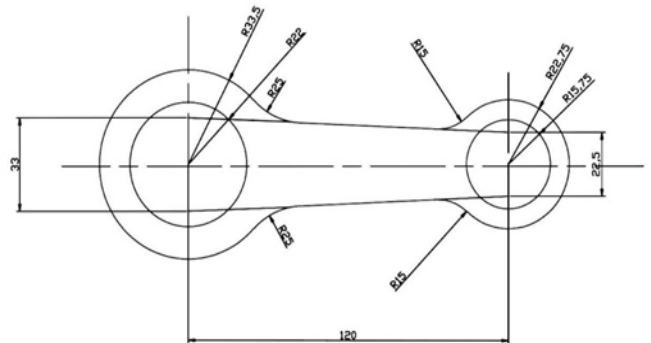


Fig.2 2D Drawing of rectangular cross-section

4. WEIGHT REDUCTION OF CONNECTING ROD FOR DIFFERENT MATERIALS

Table.2 Material Cost Per Kg

Sl.No	Material	Density Kg/mm3	Cost per kg
01	Carbon steel	7.87×10^{-6}	85 Rs
02	Forged steel	7.70×10^{-6}	85 Rs
03	Cast iron	7.19×10^{-6}	18 Rs

A. Weight reduction of connecting rod i-c/s for different materials

40C8 Carbon steel

Weight of connecting rod = $V \times \rho$

$W_r, V = \text{Volume mm}^3$

$\rho = \text{Density kg/mm}^3$

$$\begin{aligned} \text{Weight of connecting rod} &= V \times \rho \\ &= (A \times L) \times \rho \\ &= (396 \times 120) \times 7.87 \times 10^{-6} \\ &= 0.37 \text{ kg} \end{aligned}$$

Forged steel

Weight of connecting rod = $(396 \times 120) \times 7.70 \times 10^{-6} = 0.36$ kg

Cast iron

Weight of connecting rod = $(396 \times 120) \times 7.19 \times 10^{-6} = 0.34$ kg

B. Percentage weight reduction

$$\begin{aligned} &\text{➤ 40C8 Carbon steel} \\ &= \frac{\text{Weight of carbon steel} - \text{Weight of forged steel}}{\text{Weight of carbon steel}} \end{aligned}$$

$$\begin{aligned} &= \frac{0.37 - 0.36}{0.37} \\ &= 0.02 \% \end{aligned}$$

$$\begin{aligned} &\text{➤ Forged steel} \\ &= \frac{\text{Weight of forged steel} - \text{Weight of cast iron}}{\text{Weight of forged steel}} \end{aligned}$$

$$\begin{aligned} &= \frac{0.36 - 0.34}{0.36} \\ &= 0.05 \% \end{aligned}$$

$$\begin{aligned} &\text{➤ Cast iron} \\ &= \frac{\text{Weight of cast iron} - \text{Weight of carbon steel}}{\text{Weight of cast iron}} \end{aligned}$$

$$\begin{aligned} &= \frac{0.34 - 0.37}{0.34} \\ &= -0.08 \% \end{aligned}$$

C. Weight reduction of rectangular c/s connecting rod for different materials.

40C8 Carbon steel

Weight of connecting rod = $V \times \rho$

$W_r, V = \text{Volume mm}^3$

$\rho = \text{Density kg/mm}^3$

$$\begin{aligned} \text{Weight of connecting rod} &= V \times \rho \\ &= (A \times L) \times \rho \\ &= (500 \times 120) \times 7.87 \times 10^{-6} \\ &= 0.47 \text{ kg} \end{aligned}$$

Forged steel

Weight of connecting rod = $(500 \times 120) \times 7.70 \times 10^{-6} = 0.46$ kg

Cast iron

Weight of connecting rod = $(500 \times 120) \times 7.19 \times 10^{-6} = 0.43$ kg

D. Percentage weight reduction

40C8 Carbon steel

$$\begin{aligned} &= \frac{0.47 - 0.46}{0.47} \\ &= 0.02 \% \end{aligned}$$

Forged steel

$$\begin{aligned} &= \frac{0.46 - 0.43}{0.46} \\ &= 0.06 \% \end{aligned}$$

Cast iron

$$\begin{aligned} &= \frac{0.43 - 0.47}{0.43} \\ &= -0.09 \% \end{aligned}$$

5. ANALYSES THROUGH PHOTO-ELASTICITY

Photo-elasticity is an experimental method used for the analysis of stress and strain by 2D and 3D techniques. In particular useful for members having complicated geometry complicated loading conditions, or both. Analytical methods (mathematical methods) may be

impossible, and analysis by an experimental approach maybe more appropriate.

A. Experimental setup and photo-elastic analysis

The photo-elastic model with above mentioned specification is prepared from Araldite CY230 and hardener HY951. The standard research polariscope is used for the investigation. The stresses are calculated experimentally by photo-elasticity and the material fringe value is calculated by the calibration of circular disc and rectangular four point bend specimen, average material fringe value of both standard specimens is taken into account.

Material fringe value ($F\sigma$) = 6.77 N/mm

Model thickness (t) = 6mm

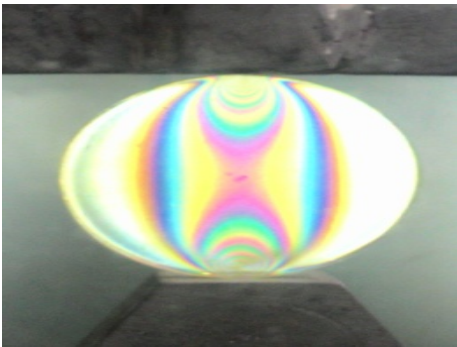


Fig.3 Calibration of circular disc

B. Photo-elastic analysis of I and rectangular cross-section of connecting rod

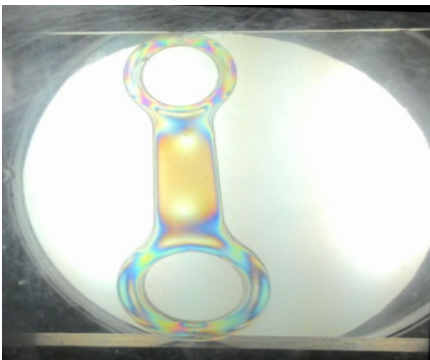


Fig.4 Rectangular c/s thrust load acting on small end

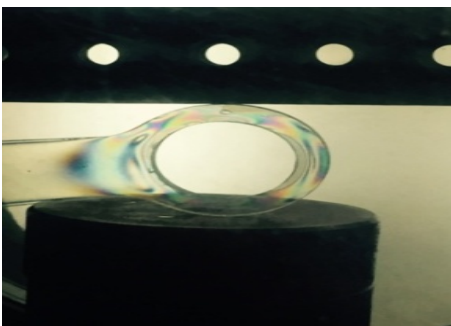


Fig.5 Rectangular c/s radial load acting on small end

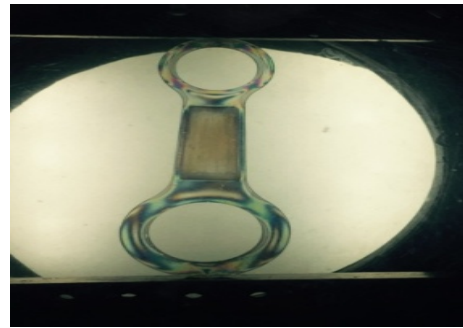


Fig.6 I-c/s thrust load acting on small end

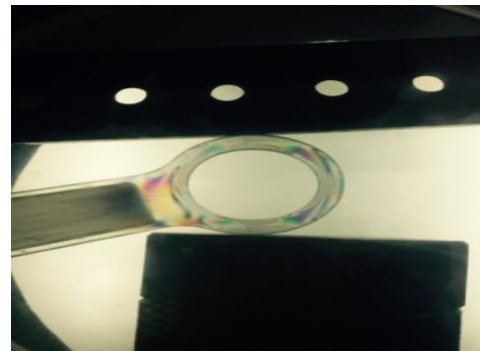


Fig.7 I-c/s radial acting on small end

6. STRESS ANALYSES THROUGH FEM

For FEA compressive radial loads are applied on small and big end of I and rectangular c/s of a connecting rod. The analysis is carried out using Solid edge v19 and ANSYS 12 software.

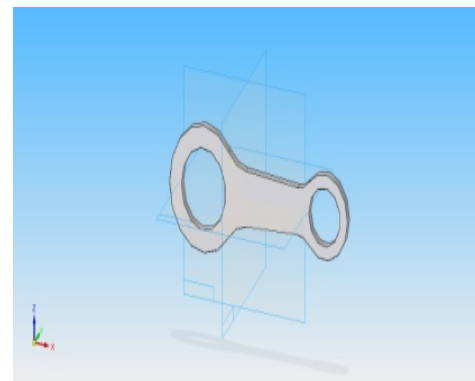


Fig.8 3D Model of rectangular cross-section

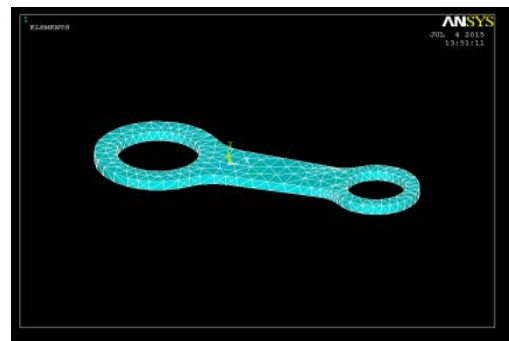


Fig.9 Meshed Model of rectangular cross section

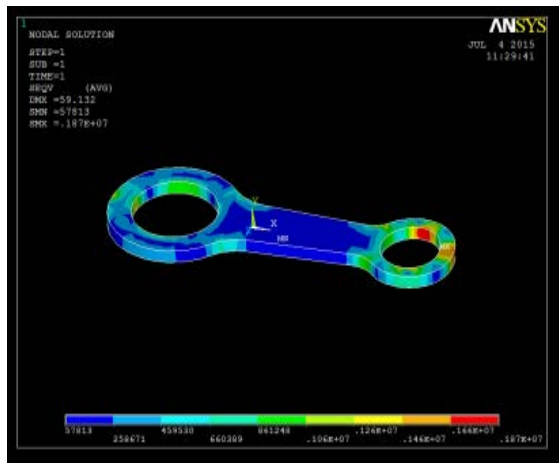


Fig.10 Thrust load acting on small end

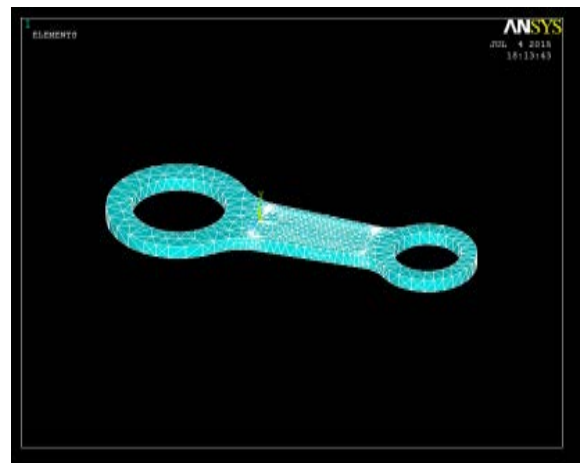


Fig.13 Meshed model of I-cross-section

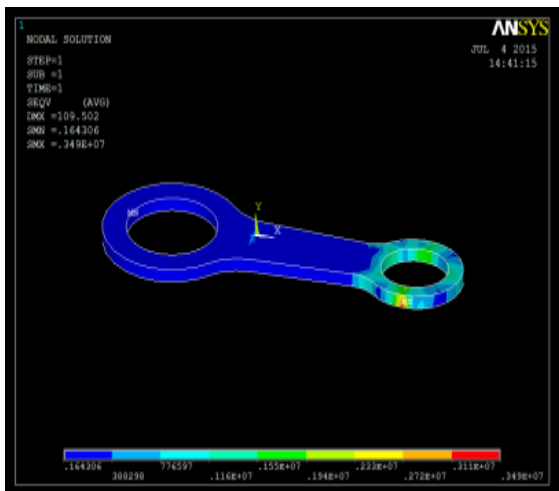


Fig.11 Radial load acting on small end

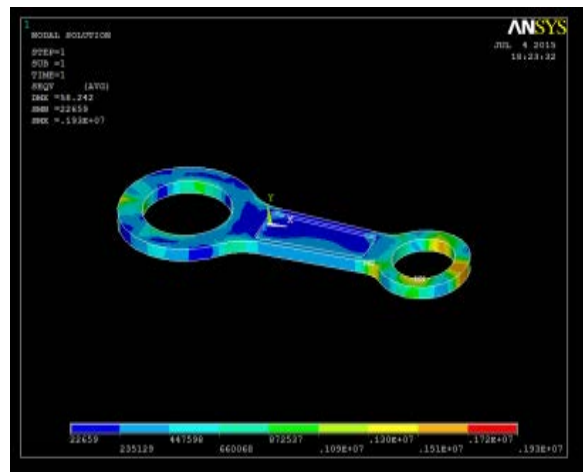


Fig.14 Thrust load acting on small end

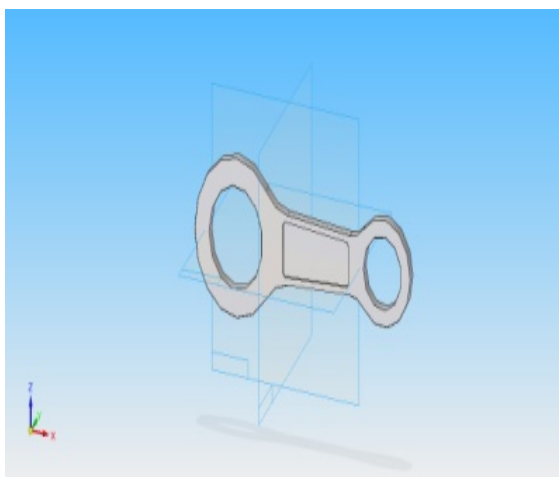


Fig.12 3D model of I cross-section

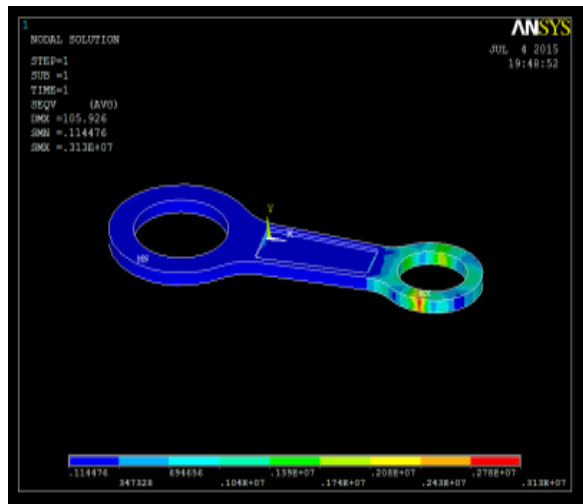


Fig.15 Radial load acting on small end

7 COMPARISONS OF RESULTS

As the methodologies used in present work are three the induced stress results are compared with two methods i.e. The results from photo-elasticity and FEA are compared at small end thrust and radial loading, big end radial loading of rectangular cross section and I-cross section.

Table 3 & 4

SI no	Load P(N)	Stresses (N/mm ²) rectangular c/s thrust load acting on small end at various points						
		Experimental method			Load P (N)	Numerical method		
		1	2	3		1	2	3
01	25.8	0.6	0.8	1.1	5982	1.0	1.2	1.8
02	45.5	1.1	1.3	1.5	10514	1.5	2.3	3.4
03	65.1	1.1	1.3	1.5	15046	1.6	2.6	4.9
04	84.7	2.2	3.0	3.5	19579	2.0	2.9	6.3
SI no	Load P(N)	Stresses (N/mm ²) rectangular c/s radial load acting on small end at various points						
		Experimental method			Load P (N)	Numerical method		
		1	2	3		1	2	3
01	25.89	0.6	1.19	1.36	5982	1.1	1.5	3.4
02	45.51	1.12	1.36	1.56	10514	1.3	2.0	6.7
03	65.13	1.12	1.56	2.62	15046	1.9	2.9	8.7
04	84.75	2.26	2.82	3.01	19579	2.5	3.7	11.4
05	104.37	3.39	3.5	4.06	24109	3.1	4.6	14.0

Table 5 & 6

SI no	Load P(N)	Stresses (N/mm ²) rectangular c/s radial load acting on big end at various points						
		Experimental method			Load P (N)	Numerical method		
		1	2	3		1	2	3
01	25.8	0.6	1.19	1.36	5982	1.2	1.4	2.2
02	45.5	0.8	1.36	1.56	10514	1.3	1.5	3.2
03	65.1	1.19	2.26	2.63	15046	1.4	1.7	3.9
04	84.7	2.63	2.82	3.01	19579	1.4	1.9	4.2
SI no	Load P(N)	Stresses (N/mm ²) I c/s thrust load acting on small end at various points						
		Experimental method			Load P (N)	Numerical method		
		1	2	3		1	2	3
01	25.8	0.6	1.19	1.36	5982	1.0	1.3	1.9
02	45.5	1.19	1.36	1.56	10514	1.1	1.5	3.3
03	65.1	2.26	.63	3.01	15046	1.6	2.1	4.18
04	84.7	2.82	3.5	4.06	19579	2.1	2.8	6.3

Table 7

SI no	Load P(N)	Stresses (N/mm ²) I c/s radial load acting on small end at various points						
		Experimental method			Load P (N)	Numerical method		
		1	2	3		1	2	3
01	25.8	0.6	1.19	1.56	5982	1.0	1.3	3.1
02	45.5	1.12	1.56	2.62	10514	1.2	1.8	5.4
03	65.1	2.25	2.62	2.82	15046	1.7	2.6	7.8
04	84.7	3.38	3.5	4.06	19579	2.2	3.4	10.2

Table 8

Sl no	Load P(N)	Stresses (N/mm ²) I c/s radial load acting on big end at various points						
		Experimental method			Load P (N)	Numerical method		
		1	2	3		1	2	3
01	25.8	0.6	1.19	1.36	5982	1.0	1.3	1.4
02	45.5	0.8	1.19	1.56	10514	1.1	1.4	2.6
03	65.1	1.19	2.62	3.01	15046	1.2	1.6	3.7
04	84.7	1.36	2.82	3.01	19579	1.6	2.1	4.8
05	104.3	2.82	3.01	3.5	24109	1.9	2.6	5.9

8 ADVANTAGES, LIMITATIONS AND APPLICATIONS

A. Advantages

- Furnishes full-field values of the principal stress directions
- Requires only a modest investment in materials for ordinary work
- Conducting experiment is simple
- Reliable method of photo elasticity
- Since the verification of stresses is done through different criteria, one can assure about the results
- Weight reduction in connecting rod

B. Limitations

- The connecting rod is the most common cause of catastrophic engine failure.
- Only photo-elastic materials are used for analysis in Polariscope
- When connecting rod get overworked or overheated, causing the bearings to wear.
- It is time consuming in separating the values of principal stresses.
- Very expensive when large components are to be analysed accurately.
- It is also time-consuming for 3D con rod analysis.
- Replacement of connecting rod is expensive

C. Applications

- The models may be used in automotive industry due to the reduction of weight
- Non contact optical method for determining stresses in automobiles
- Used in aerospace and marine applications
- In most high performance applications, the connecting rod is balanced to prevent unwanted harmonics from creating wear
- FEA model verification

9 CONCLUSIONS AND FUTURE SCOPE

A. Conclusion

Based on literature review conducted, experimental results, observations and analysis performed, following conclusions can be drawn.

- Literature review indicates the induced stresses are at the small end bearing and at the fillet radius.
- 40C8 carbon steel material and photo-elastic connecting rod model were used to obtain and compare the induced stress behavior.
- Compressive thrust loading and radial loading were applied on connecting rod model. The analysis conducted includes FEA to obtain stresses and compared with photo-elastic method
- From experimental results and FEA induced stresses are higher at the small end bearing and fillet radius when the loading i.e. compressive, thrust and radial load is applied on small end and big end kept hinged.
- Big end bearing stresses are lower as compared to small end and hence stresses at big end are negligible when the load is applied on big end keeping the small end hinged.
- The values of stresses by two methods are closely related.
- From present investigation one can conclude that maximum stresses are induced at the small end and fillet radius. Therefore failure may probably occur at the fillet radius of small end.

B. Future Scope

The chances of failure are at the small end and fillet radius which leads to failure of the engine. Following considerations must be kept in mind to avoid the failure of connecting rod.




- Material selection
- Design considerations
- Proper lubrication
- Weight reduction
- Manual handling

References

1. Prof. Vivek.C.Pathade, Dr.Dilip S.Ingole "Stress analysis of I.C engine connecting rod by FEM and photo-elasticity" IOSR Journal of Mechanical and Civil

- Engineering (IOSR-JMCE) e-ISSN: 2278-1684 Vol-6, (Mar-Apr 2013), PP 117-125.
2. Anusha B., Reddy C V B (2013) "Modelling and analysis of two wheeler connecting rod by using ANSYS". IOSR-JMCE, Vol.6, Issue5.
 3. Rao G N M (2013), "Design optimization And analysis of connecting rod using ANSYS" IJSR,Vol.2,issue 7.
 4. Pathade. V C, Ingole D S (2013) "Stress Analysis of I. C. engine connecting rod by FEM and Photo elasticity". IOSR-JMCE, Vol 6, Issue 1.
 5. Prakash O, Gupta V, Mittal V. (2013) "Optimizing the design of connecting rod under static and fatigue loading. IJRMST, Vol. 1, No.1.
 6. Sarkate T S, Washimkar S P, Dhulekar S S. (2013) "Optimization of Steel connecting rod by aluminum connecting rod using Finite Element Analysis" Vol. 1, Issue 1.
 7. Singh R (2013) "Stress Analysis of orthotropic and isotropic Connecting Rod using Finite Element Method". IJMERR, Vol. 2 No. 2.
 8. Vazhappilly C V, Sathiamurthi P (2013) "Stress analysis of connecting rod for weight reduction-a review" IJSRP, Vol 3, issue 2.
 9. Kumar A, Grover K, Budania B. (2012) "Optimization of connecting rod parameters using CAE tools" IJLTET, Vol. 1, Issue 3.
 10. Pal S, Kumar S (2012), "Design Evaluation and optimization of connecting rod parameters using FEM". IJEMR, Vol. 2, issue 6.
 11. Pathade C V, Patle B, Ingale A N (2012) "Stress Analysis of I. C. Engine Connecting Rod by FEM". IJEIT , Vol. 1, No 3.
 12. Thomas T G, Srikari S, Suman M L J (2011) "Design of connecting rod for heavy duty Applications produced by different processes for enhanced fatigue life". sasTech Journal, Vol. 10, issue 1.
 13. Ranjibarkohan M, Asadi M R and Dardashti B N (2011) "Stress Analysis of Connecting Rod of Nissan Z24 Engine by the Finite Elements Method"

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