Design and Analysis of Reinforced Aluminium Alloy-AMC225XE Connecting Rod using FEA

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Abstract

The connecting rod forms an integral part of an internal combustion engine. The connecting rod is the link between the piston and the crankshaft. Its primary function is to transmit the push and pull from the piston pin to the crank pin, thus converting the reciprocating motion of the piston into rotary motion of the crank.

This paper focuses on the design and analysis of connecting rod using a novel material i.e. reinforced aluminium alloy AMC225XE by finite element analysis. This paper illustrates the procedure for analytical design of aluminium alloy AMC225XE connecting rod using specifications of four stroke single cylinder engine of Bajaj Kawasaki motorcycle. This work predicts the maximum stress and critical region on the aluminium alloy connecting rod using FEA. The theoretical and experimental values of stress are determined and compared. Thereafter, from the results of stress analysis, the critical area of concentrated stress for appropriate modifications is located. Static stress analysis is performed by using ANSYS 12.1.

Keywords: Connecting rod, Reinforced Aluminium Alloy AMC225XE, Static stress, Load, Big end, Small end, ANSYS 12.1

1. Introduction

Fig 1.1 Connecting Rod

The function of connecting rod is to transmit the thrust of the piston to the crank shaft, and as the result the reciprocating motion of the piston is translated into rotational motion of the crank shaft. Connecting rod has three main zones: the piston pin end, the center shank and the big end. The piston pin end is the small end, the crank end is the big end and the center shank is of I cross section. The connecting rods are subjected to a complex state of loading 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, stress analysis etc.

This analysis used the maximum load which was measured theoretically and the maximum stresses at variable loads are found experimentally which suggests the reduction of the inertia load of the connecting rod mass. Connecting rods must have the highest possible rigidity at the lowest weight.

In modern automotive internal combustion engine, the connecting rods are most usually made of aluminium and steel. In high performance engines such as two wheelers the connecting rod is mostly made of aluminium alloys due to high strength to weight ratio. Besides its lower density, it has a high resistance to corrosion under the majority of service conditions. In this paper, for the designing of the connecting rod the specifications of the Bajaj Kawasaki motorcycle and mechanical properties of AMC225XE are used.

AMC225XE is a high grade aluminium alloy (AA2124) reinforced with 25% by volume of ultrafine particles of silicon carbide. It is manufactured by a special powder metallurgy route using a proprietary high-energy mixing process which ensures excellent particle distribution and enhances mechanical properties. Powder metallurgy and mechanical alloying techniques are used to combine the aluminium alloy (AA2124) matrix with fine (2-3 micron) Silicon Carbide (SiC) particles. Process conditions are controlled to produce an even distribution of these particles, whilst maintaining the purity of the matrix alloy. Powder is compacted to fully dense billet by hot isostatic compaction. Billets are available for direct manufacture to component or for fabrication by forging, extrusion or rolling techniques. Selection of the process route depends on property requirements, component shape and the resulting process cost.

After getting dimensions of the different parts of the connecting rod, modelling is done on the ANSYS 12.1. The idea behind finite element analysis is to divide a model connecting rod into a fixed finite number of elements. The ANSYS 12.1 generates and predicts the overall stiffness of the entire connecting rod.

1.1 Characterization of Material

The material chosen for this work is Reinforced Aluminium Alloy AMC225XE for an internal combustion engine connecting rod.
The key benefits of AMC225XE for structural applications include:

- Weight saving
- Increased component stiffness
- High fatigue resistance.

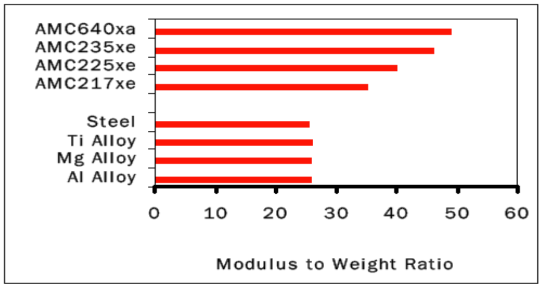


Fig 1.2 Modulus to weight ratio

Table 1.1 shows the relevant mechanical and thermal properties of Reinforced Aluminium Alloy AMC225XE.

PARAMETERS	VALUES
Elastic Modulus	115 GPa
Ultimate Tensile Strength	650 MPa
0.2% Yield Strength	480 MPa
Poisson's Ratio	0.3
Thermal Conductivity	150 W/m/°C
Density	2.88 g/cm^3

Table 1.1 Typical Properties of AMC225XE

1.2 Engine Specifications

The engine used for this work is a single cylinder four stroke air cooled type Bajaj Kawasaki petrol engine. The engine specifications are given in Table 1.2.

PARAMETERS	VALUES
Engine Type	Four stroke, Petrol engine
Induction	Air cooled type
Number of cylinders	Single cylinder
Bore	51 mm
Stroke	48.8 mm
Length of connecting rod	97.6 mm
Displacement volume	99.27 cm^3
Compression ratio	8.4
Maximum power	6.03 KW at 7500 rpm
Maximum Torque	8.05 Nm at 5500 rpm
Number of revolutions/cycle	2

Table 1.2 Engine Specifications

2. Problem Formulation

The connecting rod is one of the most critical components of an engine. Therefore, it must be designed to withstand from damage that is caused due to high pressure of combustion process. The objective of the present work is to design and analysis of connecting rod made of Reinforced Aluminium Alloy AMC225XE under service conditions of Bajaj Kawasaki petrol engine. After generating the dimensions through analytical design the accurate Finite Element Model is generated and analysis is done by ANSYS to calculate the critical stresses and total deformation by considering the gas pressure. The different loading conditions were applied at one end i.e. small end and the big end is kept fixed. The stresses are calculated theoretically and found out numerically by FEM.

3. Methodology

- Analytical design of connecting rod using specifications of Bajaj Kawasaki petrol engine.
- Creation of 3D model of connecting rod using ANSYS.
- Meshing of 3D model using ANSYS.
- Analysis of connecting rod using static stress analysis method.
- Determination of the theoretical stresses at small end and big end of the connecting rod.
- Determination of stresses at different loading conditions experimentally using FEM.

3.1 Analytical Design

The connecting rod is subjected to axial compressive force equal to maximum gas load on the piston. Therefore the connecting rod is designed as a column or a strut. The buckling of the connecting rod is in two planes: plane of motion and a plane perpendicular to the plane of motion.

Let

A = cross sectional area of connecting rod (mm^2).
L = length of the connecting rod (mm).

σ_c= compressive yield stress (MPa).

I_{xx} and I_{yy} = moment of inertia of the section about x-axis and y-axis respectively (mm^4).
K_{xx} and K_{yy} = radius of gyration of the section about x-axis and y- axis respectively (mm).
t = thickness of flange & web of the section (mm).
B = 4t = width of section (mm).
H = 5t = height of section (mm).
A_1 = area of piston (mm^2).
D = diameter of the piston (mm).
L_1 = stroke length (mm).
W_B = buckling load (N).
H_1 = height at the small end (piston end) (mm).
H_2 = height at the big end (crank end) (mm).
P = indicating pressure (N/mm^2).
N = number of revolutions (rpm).
F.O.S = factor of safety = 5
W = force on the connecting rod (N).

If a connecting rod is designed in such a way that it is equally resistant to buckling in either plane then

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

Mechanical efficiency of the engine (η) = 80 %.

$$\eta = \frac{\text{Brake power (B.P)}}{\text{Indicating power (I.P)}}$$

Therefore, $I.P = \frac{B.P}{\eta} = \frac{6.2}{0.8} = 7.75$ KW

Also, $I.P = P \times A_1 \times L_1 \times N$

$$I.P = P \times \frac{\pi D^2}{4} \times L \times N$$

Substituting the values from Table 1.2, we have

$$7.75 \times 1000 = P \times \frac{\pi\,(0.051)^2}{4} \times (0.0488) \times \left(\frac{5000}{2 \times 60}\right)$$

So, $P = 18.66 \times 10^5\ N/m^2$ or $P = 1.866$ MPa

Force on the connecting rod is given by

$$W = P \times \frac{\pi D^2}{4} = 1.866 \times \frac{\pi\,(51)^2}{4} = 3811.903\ N$$

Then the buckling load is

$W_B = W \times F.O.S = 3811.903 \times 5 = 19059.52$ N

3.1.1 The standard dimension of I SECTION.

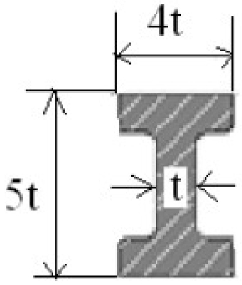


Fig. 3.1 Standard dimension of connecting rod

Area of section $A = 2(4t \times t) + (5t - 2t) \times t = 11\ t^2$

MI of section about x-axis

$$I_{xx} = \frac{1}{12}(4t)(5t)^3 - \frac{1}{12}(4t - t)(5t - 2t)^3 = \frac{1}{12}(500t^4 - 81t^4)$$

$$= \frac{(419)}{12} t^4$$

$$K_{XX}^2 = \frac{I_{XX}}{A} = \frac{(419\ t^4/12)}{(1/11t^2)} = 3.17\ t^2$$

$K_{XX} = 1.78$ t

MI of section about y axis:

$$I_{YY} = 2 \times \frac{1}{12}(t)(4t)^3 + \frac{1}{12}(5t - 2t)(t)^3 = \frac{1}{12}(128t^4 + 3t^4)$$

$$= \frac{(131)}{12} t^4$$

$$K_{YY}^2 = \frac{I_{YY}}{A} = \frac{(131\, t^4/12)}{(1/11\, t^2)} = 0.992\, t^2$$

$K_{YY} = 0.995\, t$

Therefore, $\frac{I_{XX}}{I_{YY}} = \frac{(419\, t^4/12)}{(131\, t^4/12)} = \frac{419}{131} = 3.2$

Hence, $3.2\, I_{YY} = I_{XX}$

$$W_B = \frac{\sigma_C \times A}{1 + a\,(L/K_{XX})^2}$$

$$19059.52 = \frac{480 \times 11\, t^2}{1 + (1/7500)\,(97.6/1.78\, t)^2}$$

On solving the above equation, we get
$t = 2.17$ mm.

$B = 4t = 8.68$ mm.

$H = 5t = 10.85$ mm.

Thickness for web: $t = 2.17$ mm.

Thickness for flanges: $t = 2.17$ mm.

Dimension of middle of I Section of connecting rod
$H = 10.85$ mm

Dimension of small end of I Section of connecting rod:
$H_1 = 0.85 \times H = 9.22$ mm.

Dimension of big end of I Section of connecting rod:
$H_2 = 1.2 \times H = 13.02$ mm.

3.1.2 Dimensions of connecting rod at piston side and crank side

The force acting on the piston side is given by
$W = d_p\, l_p\, (p_b)_p$

Where d_p = diameter of the piston pin (mm).
l_p = length of the piston pin (mm).
$(p_b)_p$ = allowable bearing pressure for the piston pin bush (N/mm^2) = 12.5 MPa.
$(l_p/d_p) = 2$.

Hence, $3911.903 = 2\, d_p^2 \times 12.5$
$d_p = 12.35$ mm.

And $l_p = 2 \times 12.35 = 24.7$ mm.

Inner diameter of the connecting rod at the small end:
$d_{si} = 1.25 \times d_p = 15.44$ mm.

Outer diameter of the connecting rod at the small end:
$d_{so} = 1.65 \times d_p = 20.38$ mm.

The force acting on the crank side is given by
$W = d_c\, l_c\, (p_b)_c$

Where d_c = diameter of the crank pin (mm).
l_c = length of the crank pin (mm).
$(p_b)_c$ = allowable bearing pressure for the crank pin bush (N/mm^2) = 10 MPa.
$(l_c/d_c) = 1.5$.

Hence, $3811.9 = 1.5\, d_c^2 \times 10$
$d_c = 16$ mm

And $l_c = 1.5 \times 16 = 24$ mm.

Inner diameter of the connecting rod at the big end:
$d_{ci} = 2.03 \times d_c = 32.42$ mm.

Outer diameter of the connecting rod at the big end:
$d_{co} = 2.68 \times d_c = 42.8$ mm.

3.2 Creation of 3D model of connecting rod.

The 3D model geometry is developed in ANSYS 12.1. Various dimensions of the connecting rod are taken from the above analytical design parameters. The finite element model of connecting rod is developed using ANSYS 12.1 modelling tool.

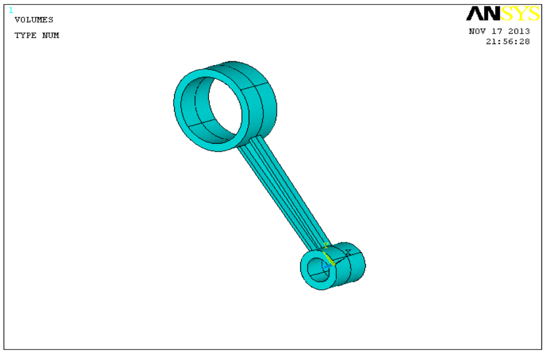


Figure 3.2 3D model of connecting rod

3.3 Meshing of 3D model of connecting rod

The 3D 8 node solid elements SOLID185 is applied to mesh the whole structure. A preliminary mesh convergence analysis showed that this level of mesh refinement was adequate to perform linear static structural analysis of the model. The meshing is shown in the figure below.

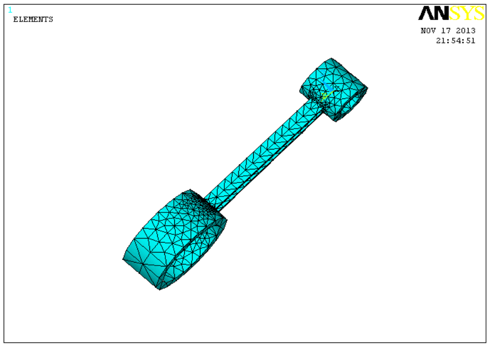


Fig 3.3 Meshing of 3D model

3.4 Static Linear Analysis

The stresses and deformation are determined using Structural Static Linear method. The big end is kept fixed and the gas pressure is applied at the small end of the connecting rod. The maximum and minimum values of stress and deformation are recorded.

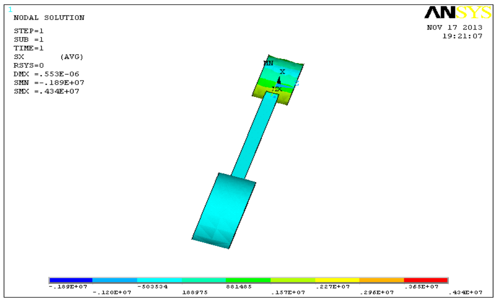


Fig. 3.4(a) Static Stress determination

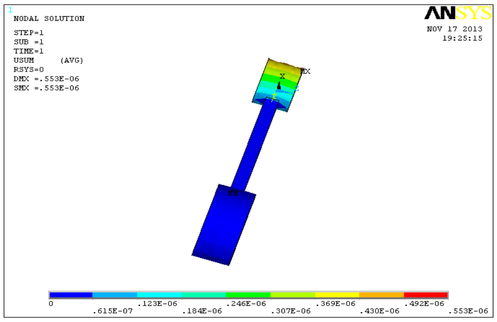


Fig. 3.4(b) Deformation determination

3.5 Determination of theoretical stresses at small and big end of the connecting rod

For calculating the value of stresses, the load is varied from 100 % to 225 % of the mean calculated load with a target value of the mean induced stress.

For small end

$$\sigma = \frac{W}{\pi \times d_{si} \times l_p}$$

At 100 % load, W = 3811.09 N, Hence, σ = 3.19 MPa. Similarly, stress at small end can be calculated at different loading conditions.

For big end

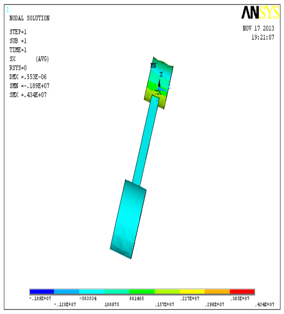
$$\sigma = \frac{W}{\pi \times d_{ci} \times l_c}$$

At 100 % load, W = 3811.09 N, Hence σ = 0.62 MPa. Similarly, stress at big end can be calculated at different loading conditions.

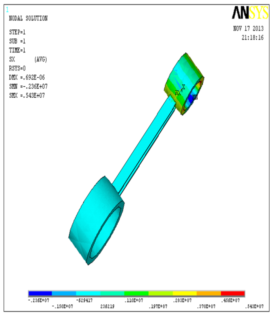
3.6 Determination of stresses at different loading conditions experimentally.

The connecting rod is analysed by two methods i.e. theoretically and experimentally. The results obtained by the two methods are compared at two critical areas of the connecting rods where it is likely to fail. The two areas where the results are compared are at the small end and the big end.

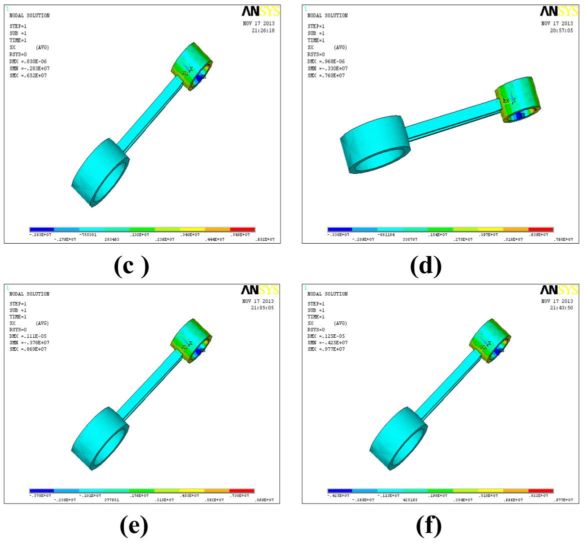
In this work, a load variation analysis is performed for the reinforced aluminium alloy AMC225XE material model. The load is varied from 100 % to 225 % of the mean calculated load with a target value of the mean induced stress being equal to the compressive yield strength of the material.



(a)



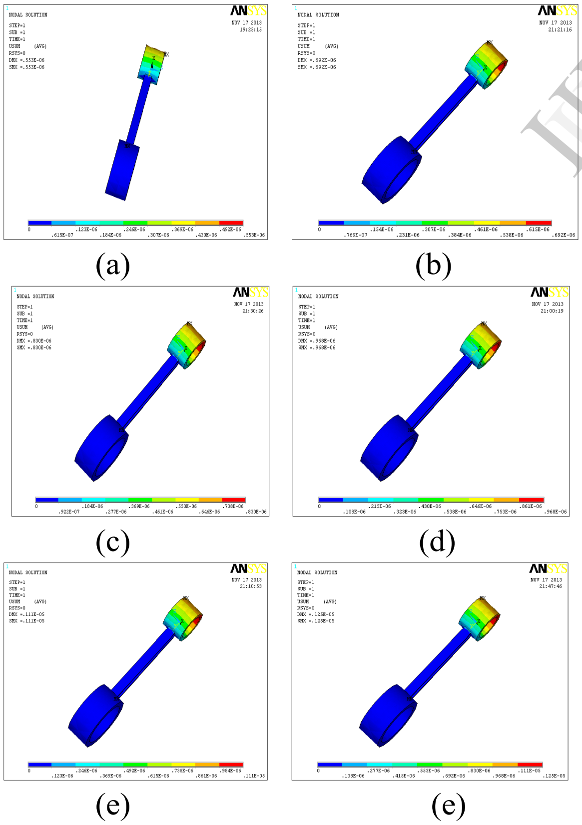
(b)



(c) (d)

(e) (f)

Fig 3.6.1 Stress at different Load conditions
(a) 100% (b) 125 % (c) 150 % (d) 175 %
(e) 200 % (f) 225%



(a) (b)

(c) (d)

(e) (e)

Fig 3.6.2 Deformation at different Load conditions
(a) 100% (b) 125 % (c) 150 (d) 175 %
(e) 200 % (f) 225%

4. Results and Discussion

The connecting rod is designed and modelled using ANSYS 12.1. The values of stress are determined theoretically and experimentally and recorded in Table 4.1.

LOAD (N)	STRESS (MPa)			
	FOR SMALL END		FOR BIG END	
	THEO	EXP	THEO	EXP
3811.09	3.19	2.96	0.62	0.5
4764.87	3.87	3.25	1.95	1.1
5717.85	4.79	4.59	2.28	1.3
6670.83	5.58	5.40	2.76	1.5
7623.80	6.56	5.90	3.15	1.7
8576.78	7.39	7.44	3.55	1.9

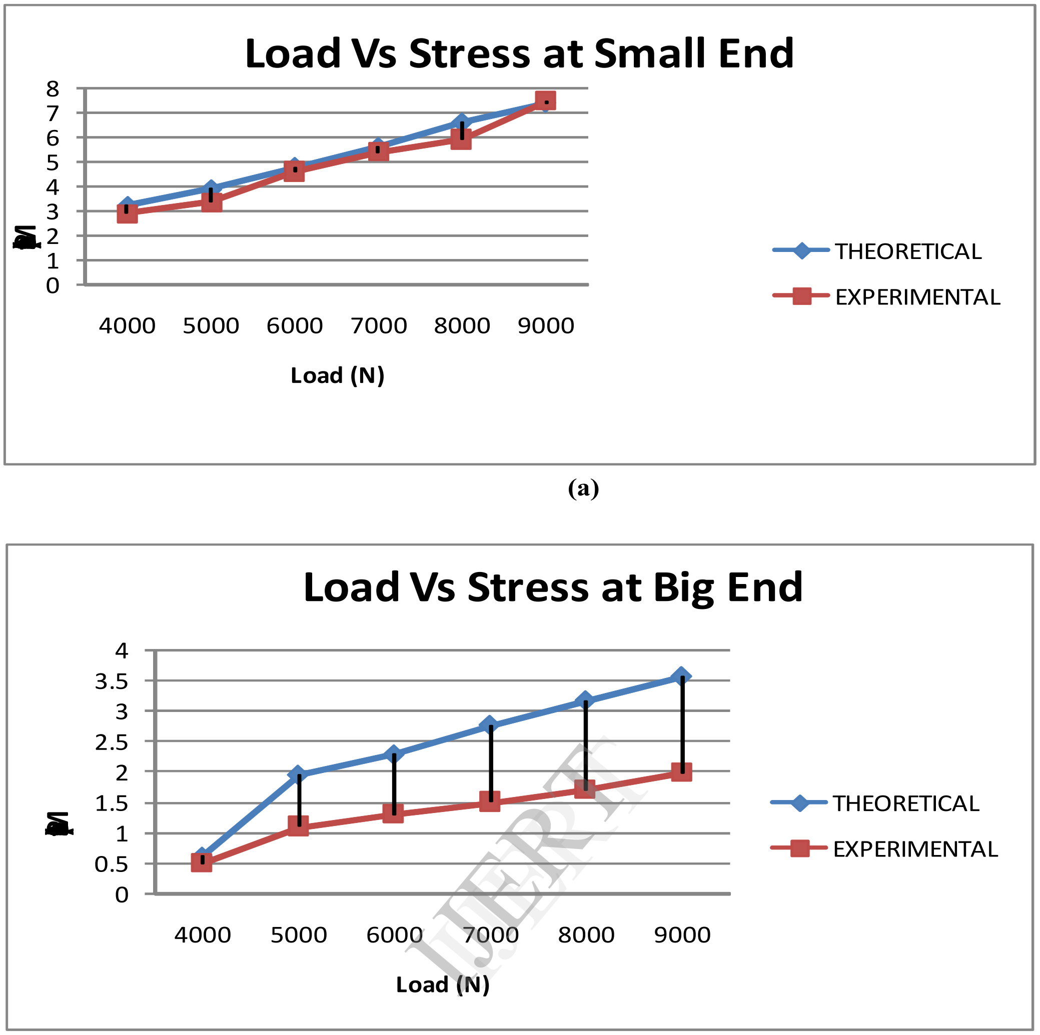
Table 4.1 Observation Table

The results obtained by the two methods i.e. theoretical and experimental are compared at the critical areas of the connecting rod where the connecting rod is likely to fail. The two areas of the connecting rod where results are compared are small end and big end.
It is found that the stresses at the small end are larger than the stresses at the big end.
The graphs between the load and stress are drawn for both at the small end and the big end. The graph contains plots for both theoretical and experimental values of stress and load which are shown in Fig. 4.1 (a) and (b) (next page).
It is found that both the plots in the graph at small end converge while at the big end they diverge from each other.

5. Conclusion

The ANSYS analysis of the model designed on the basis of the specifications in this paper determines whether the design is safe or not and further changed can be made in the design considering the reduction in weight. From this, the conclusion can be drawn that the weight at the big end can be reduced so that inertia forces will be minimum.
Newly developed Reinforced Aluminium Alloy AMC225XE enhances higher fatigue resistance in the critical stress region, allow the realization of the thinner structures.

The analysis can be done with other materials of connecting rod for better design and lighter weight.



(a)

(b)

Fig 4.1 Graph between Load and Stress (a) at small end (b) at big end.

References:

[1] E. Ramjee and K. Vijaya Kumar Reddy, "Performance analysis of a 4-stroke engine using CNG as an alternative fuel", Indian Journal of Science and Technology (IJST), Vol. 4, No. 7, July 2011.

[2] Technical Data, Aerospace Metal Composites Limited, "AMC225XE Particle Reinforced Alloy", www.amc_mmc.co.uk

[3] Vivek C. Pathade, Bhumeshwar Patle and Ajay N. Ingale, " Stress analysis of IC engine connecting rod by FEM", International Journal of engineering and Innovative Technology (IJEIT), Vol. 1, Issue 3, March 2012.

[4] K. Sudershn Kumar, K. Tirupati Reddy and Syed Altaf Hussain, "Modelling and Analysis of two wheeler connecting rod", International Journal of Modern Engineering Research (IJMER), Vol. 2, Issue 5, Sep-Oct 2012.

[5] V. B. Bhandari, "Design of Machine Elements", Third Edition, McGraw Hill.

[6] Tony George Thomas, S. Srikari and M. L. J. Suman, " Design of connecting rod for heavy duty applications produced by different processes for enhanced fatigue life", SASTECH Journal, Vol. 10, Issue 1, May 2011.