Design and Analysis of Metal Matrix Composite Connecting Rod

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Abstract-The connecting rod is the intermediate member 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. Existing connecting rod is manufactured by using Carbon steel. This paper describes modeling and analysis of connecting rod. In this project connecting rod is replaced by Aluminum reinforced with Boron Silicide for Suzuki GS150R motorbike. A 2D drawing is drafted from the calculations. A parametric model of connecting rod is modelled using CATIA V5 software. Analysis is carried out by using ANSYS Workbench software.The best combination of parameters like Von misses stress and strain, Deformation, Factor of safety and weight reduction for two wheeler piston were done in ANSYS software. Compared to carbon steel,and aluminum boron carbide.

Keywords-*Connecting rod, Static analysis, Carbon steel, Aluminum, Aluminum reinforced with Boron Silicide.*

1.INTRODUCTION

The automobile engine connecting rod is a high volume production, critical component. It connects reciprocating piston to rotating crankshaft, transmitting the thrust of the piston to the crankshaft. Every vehicle that uses an internal combustion engine requires at least one connecting rod depending upon the number of cylinders in the engine. Fracture took place on the small head of the connecting rod. Multiple-origin fatigue fracture is the dominant failure mechanism of the fractured connecting rod [1]. High bolt assembly stress coupled with cycle stress during engine operations could cause the generation and extension of the cracks [2]. The spalling of connecting rod, crank pin and roller bearing is attributed to the high-localized interfacial pressure that developed due to the design of the web and flange of the connecting rod [3]. Now, with the acute competition the product quality and price, the aluminum alloy connecting rod of air compressor is being manufactured with advanced liquid die forging technology, replacing common hot die forging and it possessed higher practical useful value [4]. When predicting the critical buckling of connecting rod, complicated shape gradients and actual boundary conditions cannot be reflected in the conventional formula. Thus accurate elastic buckling stress must be calculated by FEA with the real shape and boundary conditions. The critical plastic stress should be taken as the increased yield strength by work hardening during rod forging; both elastic and plastic values are entered to give the buckling stress [5]. The engine collapse as a result of forming laps at the groove tops of on connecting rod bolt. To avoid future failures, some design improvements were suggested:design a flat bolt shank at the cap interface region to reduce stress concentration and increase of the assembly torque to reduce stress amplitude [6]. Numerical 3-D forming simulation is best suited for the quantitative analysis of local process variables, which enables to study the influence of these variables on local microstructure and mechanical properties both governing the performance of the whole component [7]. The thermal expansion behavior of the aluminium silicon carbide fiber reinforced composite relies on the thermal expansion of the fibers, and influenced by the onset of interfacial strength and residual stress state [8]. The production and wear properties of an in-situ boride particles/ Al–Cu composite have been studied. Aluminium boride particle reinforced composite was prepared by liquid reaction of Al–Cu matrix with boron oxide (B_2O_3) at 1400° C. The reinforcement concentration increased by a mechanical filtration of the matrix alloy following by holding at 1000˚C for 1 h [9]. Static FEA of the connecting rod using the software and said optimization was performed to reduce weight. Weight can be reduced by changing the material of the current forged steel connecting rod to crackable forged steel (C70) [11]. Stress analysis of connecting rod by finite element method using pro-e wild fire 4.0 and ansys work bench software. And 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 [12].

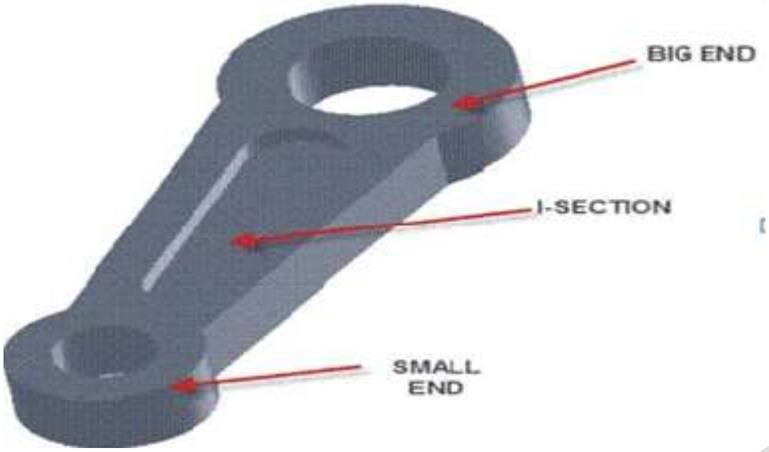


Fig 1:Schematic Diagram of Connecting Rod

2.SPECIFICATION OF THE PROBLEM

The objective of the present work is to design and analyses of connecting rod made of Aluminum LM25 alloy Reinforced with Boron Silicide. Steel and aluminum materials are used to design the connecting rod. In this project the material (carbon steel) of connecting rod replaced with Aluminum Reinforced with Boron carbide. Connecting rod was created in CATIA V5. Model is imported in ANSYS Workbench for analysis. After analyis a comparison is made between exisisting carbon steel and aluminum connecting rod viz., Aluminum Reinforced with Boron carbide in terms of weight, factor of safety, stiffnes, deformation and stress

3.DESIGN 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.

A connecting rod subjected to an axial load W may buckle with x-axis as neutral axis in the plane of motion of the connecting rod,{or} y-axis is a neutral axis. The connecting rod is considered like both ends hinged for buckling about x-axis and both ends fixed for buckling about y-axis. A connecting rod should be equally strong in buckling about either axis.

According to rankine formulae
W_{cr} about x-axis
$= [\sigma_c \times A]/(1+a[L/ K_{xx}])^2 = [\sigma_c \times A]/(1+a[l/K_{xx}])^2$ [$\therefore for\ both\ ends\ hinged\ L=l$]
W_{cr} about y-axis
$=[\sigma_c \times A]/(1+a[LK_{yy}])^2=[\sigma_c \times A]/(1+a[l/2K_{yy}])^2$ [$\therefore for\ both\ ends\ fixed\ L=l/2$]
In order to have a connecting rod equally strong in buckling about both the axis, the buckling loads must be equal. i.e.
$= [\sigma_c \times A]/(1+a[l/ K_{xx}])^2 = [\sigma c \times A]/(1+a[l/2K_{yy}])^2$ [or]
$[l/ K_{xx}]^2 = [l /K_{yy}]^2$
$K^2_{xx} = 4K^2_{yy}$ [or] $I_{xx} = 4I_{yy}$ [$\therefore I=A \times K^2$]

This shows that the connecting rod is four times strong in buckling about y-axis than about-axis. If I xx > 4Iyy, Then buckling will occur about y-axis and if I xx < 4Iyy, then buckling will occur about x-axis .In Actual practice I xx is kept slightly less than 4Iyy. It is usually taken between 3 and 3.5 and the Connecting rod is designed for buckling about x-axis. The design will always be satisfactory for buckling about y-axis. The most suitable section for the connecting rod is I-section with the proportions shown mfg.

Area of the cross section $= 2[4t \times t] + 3t \times t=11t^2$
Moment of inertia about x-axis
$I_{xx} = 1/12\ [4t\ \{5t\}^3-3t\ \{3t\}^3] = 419/12[t^4]$

And moment of inertia about y-axis
$I_{yy} = 2\times1/12\times t\times\{4t\}^3+112\{3t\}t^3 =131/12[t^4]$

I_{xx}/I_{yy} = [419/12] ×[12/131]
=3.2

Since the value of I xx/I yy lies between 3 and 3.5 m therefore I-section chosen is quite satisfactory.

3.1Design Calculations for Existing Connecting Rod

Thickness of flange & web of the section = t
Width of section B = **4t**

The standard dimension of I - SECTION.

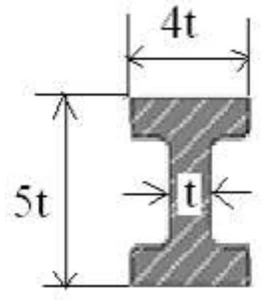


Fig2: Standard Dimension of I – Section

Height of section H **= 5t**
Area of section A = 2(4t×t) +3t×t
A **= 11t²**

Moment of inertia about x-axis

$$I_{xx} = 1/12\ [4t\ \{5t\}^3 - 3t\ \{3t\}^3]$$

$$= 419/12[t^4]$$

And moment of inertia about y-axis

I_{yy} $=2\times1/12\times t\times\{4t\}^3+112\{3t\}t^3$
$=131/12[t^4]$
I_{xx}/I_{yy} = [419/12] x [12/131]
=3.2

Length of connecting rod (L)= 2 times the stroke
L **= 117.2 mm**

Buckling load W_B = maximum gas force × F.O.S

W_B $=(\sigma_c \times A)/(1+a\ (L/K_{xx}))^2$
= **37663N**

σ_c = compressive yield stress
= **415MPa**

K_{xx} = I xx/A×t
K_{xx} = 1.78t
a $= \sigma_c/\pi^2 E$
a = **0.0002**

By substituting σc, A, a, L, K_{xx}on W_B then
$4565t^4-37663t^2-81639.46 = 0$
t^2 = 10.03
t = 3.167mm
t **= 3.2mm**

Width of section $B = 4t$
$= 4\times3.2$
$= \mathbf{12.8mm}$

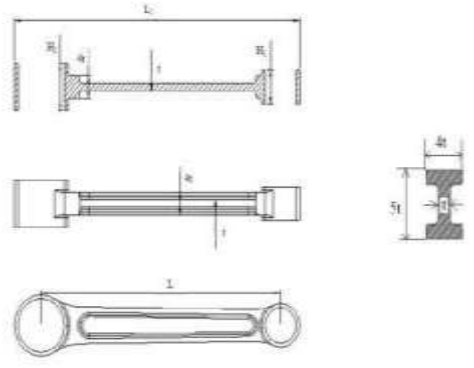
Height of section $H = 5t$
$= 5\times3.2$
$= \mathbf{16mm}$

Area $A = 11t^2$
$=11\times3.2\times3.2$

$= \mathbf{112.64mm^2}$

Height at the big end (crank end) $H_2 = 1.1H to 1.25H$
$= 1.1\times16$
H_2 $\mathbf{=17.6mm}$

Height at the small end (piston end)
$H_1 = 0.9H to 0.75H$
H_1 $\mathbf{=12mm}$



Stroke length (l) =**117.2mm**
Diameter of piston (D) =**57mm**
P =$\mathbf{15.5N/mm^2}$

Radius of crank(r) =**stroke length/2**

=**58.6/2**
=**29.3**

Maximum force on the piston due to pressure
$F_p = \pi/4 \times D^2 \times P$
$=\pi/4 \times (57)^2 \times 15.469$
=**39473.16N**

Maximum angular speed
$W_{max} = [2\pi N_{max}]/60$
$= [2\pi\times8500]/60A$

$=\pi r^2$

=**768 rad/sec**

Ratio of the length of connecting rod to the radius of crank
N = l / r
=112 / (29.3)
= **3.8**

Maximum Inertia force of reciprocating parts

F_i = Mr (W_{max}) 2 r (cosθ + COS2θn) (Or)
F_i = Mr (W_{max})2 r (1+1n)
= 0.11x (768)2 x (0.0293) x
(1+ (1/3.8))
F_i = **2376.26N**

Inner diameter of the small end
d1 **= Fg / $Pb_1 \times l_1$**
= 6277.167 /($12.5 \times 1.5d_1$)
= **17.94mm**

Where,
Design bearing pressure for small end
pb_1 =12.5 to 15.4N/mm^2
Length of the piston pin
l_1 = (1.5to 2) $d1_1$
Outer diameter of the small end
= $d_1+2t_b+2t_m$
= 17.94 + [2×2] + [2×5]
= **31.94mm**
Where,
Thickness of the bush (t_b) = 2 to 5 mm
Marginal thickness (t_m) = 5 to 15 mm

Inner diameter of the big end
d_2 = Fg / ($Pb_2 \times l_2$)
= $6277.167/10.8 \times 1.0d_1$
=**23.88mm**
Where,
Design bearing pressure for big end

pb_2 = 10.8 to 12.6N/mm^2

Length of the crank pin l_2 =(1.0 to 1.25) d_2
Root diameter of the bolt =$((2F_i) / (\pi \text{ x } S_t))^{0.5}$
=$(2\times6277.167)^{0.5}/ (\pi\times56.667)^{0.5}$
= **4mm**

Outer diameter of the big end = $d_2 + 2t_b + 2d_b + 2t_m$
=23.88+2×2+2×4+2×5
= 47.72mm
Where,
Thickness of the bush [t_b] = 2 to 5 mm
Marginal thickness [t_m] = 5 to 15 mm
Nominal diameter of bolt [d_b] = 1.2 x root diameter of the bolt
= 1.2×4

= **4.8mm**

3.2Specifications of connecting rod

S.NO	SPECIFICATIONS OF THE CONNECTING ROD	MEASUREMENTS(mm)	
		CARBON C40 STEEL	ALUMINIUM BORON SILICIDE
1	Thickness of the connecting rod (t)	3.2	3.56
2	Width of the section (B = 4t)	12.8	14.24
3	Height of the section(H = 5t)	16	17.8
4	Height at the big end H_2 = (1.1 to 1.125)H	17.6	19.58
5	Height at the small end H_1 = 0.9H to 0.75H	14.4	16.02
6	Inner diameter of the small end	17.94	
7	Outer diameter of the small end	31.94	
8	Inner diameter of the big end	23.88	
9	Outer diameter of the big end	47.72	

Table1 : Specifications of connecting rod

4.MODELLING OF CONNECTING ROD

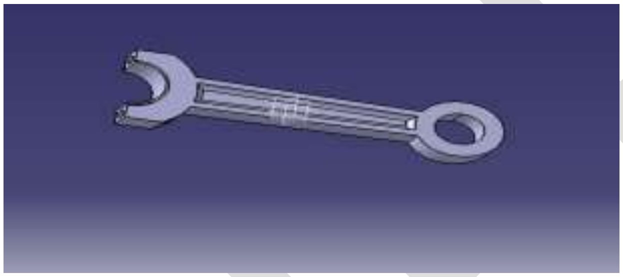


Fig 3:Connecting rod stem(steel)

Fig4 : Connecting rod Head(steel)

Fig 5: Connecting rod bolt

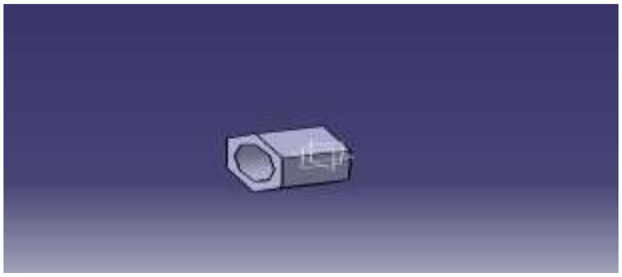


Fig 6: Connecting rod nut

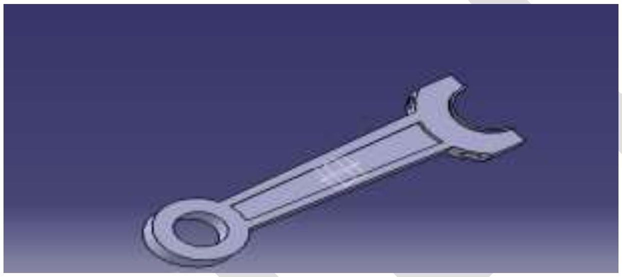


Fig7 : Connecting rod stem (Al $b_4$si)

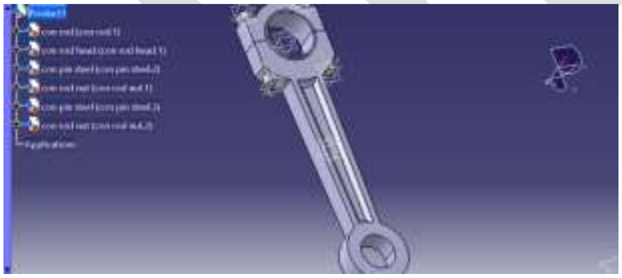


Fig 8: Connecting rod assembly

5.RESULTS AND DISCUSSIONS

5.1 Analysis of connecting rod

For the finite element analysis 15.5 Mpa of pressure is used. The analysis is carried out using ANSYS software.The pressure is applied at the small end of connecting rod keeping big end fixed. The maximum and minimum vonmisses stress, strain,displacement and frequency are noted from the ANSYS

S.No	**Material**	**Deformation (mm)**	**Von misses Stress (Mpa)**		**Elastic Strain**
			Max	**Min**	
1	**Carbon steel**	**0.01495**	**79.399**	**$7.79e^{-5}$**	**$3.97e^{-4}$**
2	**Aluminium Boron silicide**	**0.0155**	**61.383**	**$3.9e^{-4}$**	**$3.507e^{-4}$**

Table 2 :Deformation,Von-mises stress and Elastic strain for different materials

5.2 Material properties used for analysis

S.NO	PARAMETERS	CARBON STEEL (C40)	ALUMINIUM BORON SILICIDE
1	Ultimate tensile strength(Mpa)	620	452
2	Yield strength(Mpa)	415	363
3	Endurance strength(Mpa)	310	226
4	Youngs modulus(Gpa)	200	70
5	Poisson ratio	0.33	0.33
6	Density(g/cm^3)	7.85	2.661

Table 3: Material properties of carbon c40 steel and Aluminium boron silicide

5.3 Analysis of carbon steel connecting rod

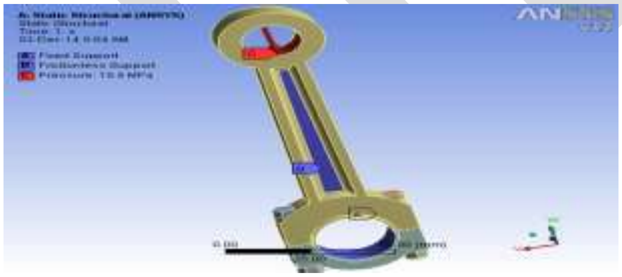


Fig 9: supports and pressure applied

Fixed support applied at big (crank) end and frictionless support applied at small(piston) end.Pressure of 15.5Mpa applied downwards at piston end

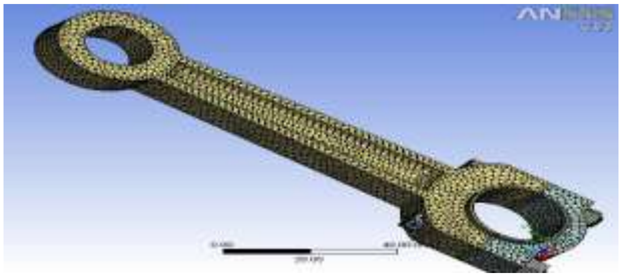


Fig10: Meshed model of connecting rod

Type	Tetrahedral
Nodes	65530
No of elements	35507

Table 4 : Nodes and Element type of meshed model of connecting rod

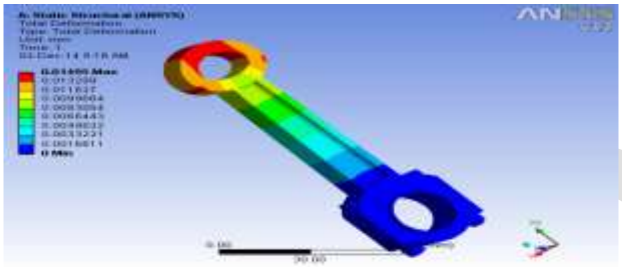


Fig 11 : Deformed model of connecting rod

High deformation occurs at piston end of 0.01495 mm and slowly reduces to get minimum at crank end

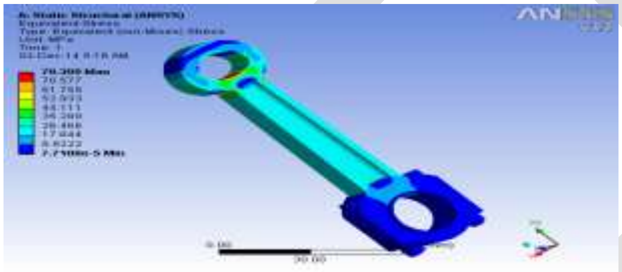


Fig12: Von misses stress on connecting rod

High von-misses stress occurs at piston end of 79.399 Mpa and slowly reduces to get minimum 7.7108e^{-5} crank end

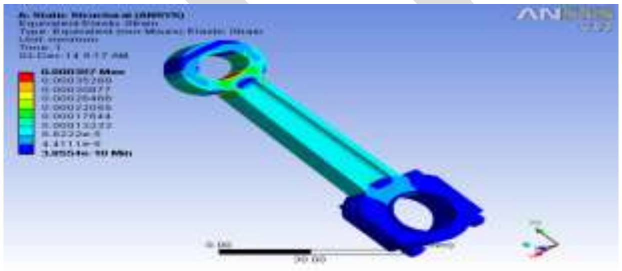


Fig 13:Elastic strain on connecting rod

High strain occurs at piston end of 0.000397 and slowly reduces to get minimum 3.8554e^{-10}at crank end

5.4 Analysis of Aluminium boron silicide connecting rod

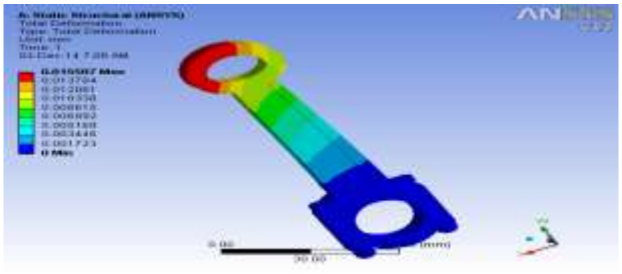


Fig 14: Deformation of connecting rod

High deformation occurs at piston end of 0.0155 mm and slowly reduces to get minimum at crank end

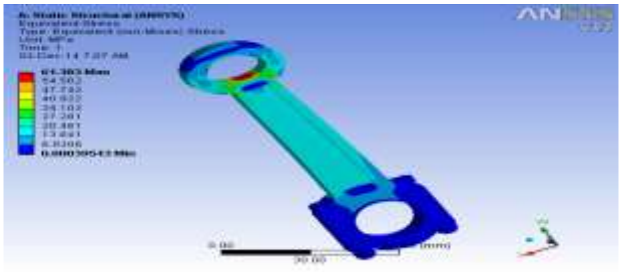


Fig 15: Von misses stress on connecting rod

High von-misses stress occurs at piston end of 61.383 Mpa and slowly reduces to get minimum $3.9543e^{-4}$ crank end

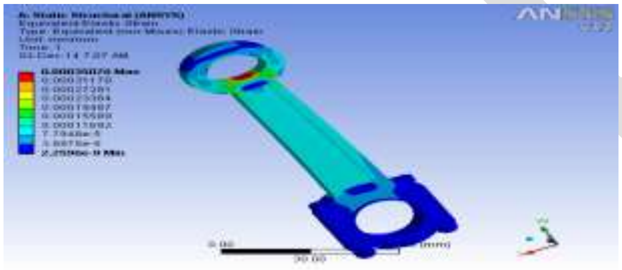


Fig 16: Elastic strain on connecting rod

High strain occurs at piston end of 0.00035076 and slowly reduces to get minimum $2.2596e^{-9}$ at crank end

5.5 Calculation for factor of safety of connecting rod

f.s = factor of safety

σ_m = mean stress

σ_y = yield stress

σ_v = variable stress

σ_e = endurance stress

$(1 / f.s) = (\sigma_m / \sigma_y) + (\sigma_v / \sigma_e)$

For Carbon Steel (C40)

σ_{max} = 79.399 Mpa $\sigma_{min} = 7.7108\times10^{-5}$ Mpa

$\sigma_m = (\sigma_{max} + \sigma_{min})/2 = 39.699$

σ_y= 415 Mpa

$\sigma_v = (\sigma_{max} - \sigma_{min})/2 = 39.699$

σ_e= 310

1 / F.S = 0.223

= 4.469

Factor of safety [F.S]= 4.469

$N = 1000\,(S_f/0.92\sigma_u)^{3/\log(\sigma_e'/0.9\sigma u)}$

$= 7046.303\times10^{3}$ cycles

Where, $S_f = \frac{f'.x\sigma v}{1 - f.s\sigma m/\sigma u}$

= 248.51 Mpa

For Aluminium boron silicide

σ_{max} = 61.38 Mpa $\sigma_{min} = 3.981e^{-4}$ Mpa

$\sigma_m = (\sigma_{max} + \sigma_{min})/2 = 30.69$

σ_y= 415 Mpa

$\sigma_v = (\sigma_{max} - \sigma_{min})/2 = 30.69$

σ_e= 310

1 / F.S = 0.220

= 4.538

Factor of safety [F.S]= 4.538

$N = 1000(S_f/0.92\sigma_u)^{3/\log(\sigma_e'/0.9\sigma u)}$

$= 2095\times10^{4}$ cycles

Where, $S_f = \frac{f'.x\sigma v}{1 - f.s\sigma m/\sigma u}$

= 201.31 Mpa

5.6 Calculation for Weight

For Carbon Steel:

Density of carbon steel $= 7.7\times10^{-6}$ kg/mm3

Volume = 41050 mm3

Deformation = 0.01495 mm

Weight of forged steel = volume ×density

= $41050 \times 7.7 \times 10^{-6}$

= 0.31kg

For Aluminium boron silicide

Density of carbon steel = 2.637×10^{-3} kg/mm3

Volume = 57472.72 mm^3

Deformation = 0.0155 mm

Weight of forged steel = volume ×density

= $57472.72 \times 2.637 \times 10^{-3}$

= 0.151 kg

S.NO	MATERIAL	FATIGUE LIFE (N)	WEIGHT kg
1	Carbon steel	7046.36×10^3 cycles	0.31
2	Aluminium boron silicide	2095×10^4 cycles	0.151

Table 5: Comparison of Fatigue Life and Weight between Carbon steel and Aluminium boron silicide

6.CONCLUSION

ANSYS Equivalent stress for the both the materials are almost same. For the Aluminium boron silicide metal matrix composite material factor of safety (from Soderberg's) is increased compared to existing carbon steel. Weight can be reduced by changing the material of existing carbon steel connecting rod into Aluminium boron silicide metal matrix composite connecting rod.And also no. of cycles for for Aluminium boron silicide (2095×10^4)is more than the existing carbon steel connecting rod (7046.36×10^3). When compared to both of the materials, Carbon steel is cheaper than the existing connecting rod material

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