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Static and Fatigue Analysis of Aluminum Silicon carbide Connecting rod for Comparative Study of Mechanical Parameters using FEA

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Abstract— **The objective of the present work is the static and Fatigue analysis of a connecting rod made of Aluminum Alloy reinforced with 10 percent Silicon carbide (Sic). In this paper the material (structural steel) of connecting rod is replaced with developed Aluminum silicon carbide material for connecting rod for the actual specification of TVS Jupiter vehicle. The model of connecting rod is created in CATIA V5 and imported in ANSYS 14 workbench for Static and Fatigue analysis. After analysis a comparison is made between an existing steel connecting rod and an aluminum silicon carbide connecting rod in terms of Von misses stress, equivalent strain total deformation, Fatigue life, Safety factor. All these parameters are also found analytically and compared with results of FEA.Both the results are within the range and the life for aluminum silicon carbide is found better in comparison of steel. The overall work is divided into three phases. First, concept and a review of existing material, Second, Modeling, static analysis and fatigue analysis, and third is a comparison of elastic strain, total deformation, maximum von misses stress value as well as fatigue life and fatigue safety factor in an aluminum alloy connecting rod is done with the connecting rod made of carbon steel .**

Keywords— ANSYS14. Workbench, Aluminum and Sic alloy, Connecting rod, CATIA V5, Finite Element analysis, von misses stress.

I.INTRODUCTION

Connecting rod is an intermediate link between the piston and crank link inside of an internal combustion engine. It connects the piston to the crankshaft and is responsible for transferring power from the piston to the crankshaft. Connecting rod should be lighter and lighter, and also they should provide comfort and safety to passengers, It leads to increase in weight of the vehicle. This problem necessitates the invention of alternative material which satisfies the design, power, safety and comfort requirement.

Every vehicle that uses an internal combustion engine requires at least one connecting rod depending upon the number of cylinders in the engine.. The main components of a connecting rod are big shank, a small end and a big end.

Due to its large volume of production, it is only logical that optimization of the connecting rod for its weight or volume will result in large-scale savings. It can also achieve the objective of reducing the weight of the engine component, thus reducing inertia loads, reducing engine weight and improving engine performance and fuel economy.

The connecting rod undergoes a complex motion, which experiences compressive, buckling loads that induce bending stresses.. It undergoes high cyclic loads, which range from high compressive loads due to combustion to high tensile loads due to inertia. Therefore, durability of this component is of critical significance. Due to these factors, the connecting rod has been the topic of research for different aspects such as , materials, performance , fatigue life, safety factor etc.

II.SPECIFICATION OF THE PROBLEM

A. Problem Definition

As Connecting rod undergoes repetitive loads during it service life, fatigue performance and durability of this component has to be considered in the Design Process. The stresses and weight for steel(c45) are more and life can be improved, hence it necessitates to find the alternative material at given loading conditions In this paper the material (structural steel) of connecting rod replaced with developed Aluminum alloy. The model of connecting rod was created in CATIA V5 and imported in ansys 14.5 workbench for static and fatigue analysis. After analysis a comparison is made between an existing steel connecting rod for the TVS Jupiter of given dimensions for Vonmises stress, equivalent strain and total deformation.

B.ObjectivesOf The Work

The objective of the present work is the static and fatigue analyses of a connecting rod made of Aluminum Alloy reinforced with Silicon carbide (SiC) to compare the stress distribution ,deformation and fatigue life with structural steel to check whether a steel connecting rod can be replaced with a developed composite connecting rod.

III.LITERRAURE REVIEW

Amir HussainIdrisi, VikasDev Singh, VipulSaxena et al, (1) has developed the metal matrix composite materials by combining the desirable attributes of metals and Ceramics. Here Aluminium5083 used as the matrix material in which SiC added as the reinforced material. This work was focused on the study of behavior of Aluminum 5083 with SiC as reinforcement produced by stir casting method and ultrasonic

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assisted stir casting method. Different percentages of reinforced particles were mixed and different specimens were made. Tensile and compressive tests were employed to obtain the mechanical properties and trend was compared between the samples developed by stir casting method and ultrasonic assisted stir casting method. The results show that the mechanical properties i.e., tensile and compressive properties improved.

Amir Hussain Idrisi and Shailendra Deva et al, (2) focused on the comparative study of behavior of Aluminum 5083 with SiC as reinforcement produced by stir casting method and ultrasonic assisted stir casting method. Hardness and Density tests were employed to obtain the mechanical properties of specimens by adding different percentages of SiC and trend was compared between the samples developed by stir casting method and ultrasonic assisted stir casting method.

K. Sudershan Kumar, Dr. K. Tirupathi Reddy, Syed Altaf Hussain et al,(3) conducted Finite element analysis of connecting rod by considering two materials ,viz.. Aluminum Reinforced with Boron Carbide and Aluminum 360. 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, aluminum boron carbide and aluminum 360, Aluminum boron carbide is found to have working factor of safety is nearer to theoretical factor of safety, 33.17% to reduce the weight, to increase the stiffness by 48.55% and to reduce the stress by10.35% and most stiffer.

Priyanka D. Toliya, Ravi C. Trivedi, Prof. Nikhil J. Chotai et al, (4) has 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.

Mr. Dharun Lingam, Mr..Arun Lingam et al.(5)has performed analysis on both the standard steel and composite connecting rods. Both are modeled and analyzed using Pro-E Wildfire 4.0 and ansys workbench 11.0 software respectively. A comparative study was undertaken to predict the structural behavior of connecting rods using three dimensional finite element stress and fatigue analysis model, and to determine the most cost effective modeling and analysis approach. The finite element results verify that the performance is same as that of standard steel connecting rod. The stress and fatigue analysis of the composite connecting rods is found to be better than that of the standard connecting rod Design and Fatigue Analysis on Metal Matrix Composite Connecting Rod Using FEA.

S B Chikalthankar, V M Nandedkar, Surendra Prasad Baratam et al (6) have performed Fatigue Numerical Analysis for Connecting Rod shows the complete connecting rod Finite Element Analysis (FEA) methodology. It was also performed a fatigue study based on Stress Life (SxN) theory, considering the Modified Goodman diagram. The analysis emphasized that the highest stresses were observed in the small end region and fatigue factors calculated for most critical nodes at three different positions at the small end.

Mr. H. B. Rahmani, 2 Mr. Neeraj Kumar, 3 Mr. P. M. Kasundra (7) has performed detailed load analysis on connecting rod, followed by finite element method in Ansys-13 medium. In this regard, In order to calculate stress in Different part of connecting rod, the total forces exerted connecting rod were calculated and then it was modeled, meshed and loaded in Ansys software. The maximum stresses in different parts of connecting rod were determined by Analysis.

Tony George Thomas, S. Srikari, M. L. J Suman et al.(8)have analytically calculated loads acting on the small end of connecting rod were used to carry out the static analysis using ANSYS. A stress concentration was observed near the transition between small end and shank. A piston-crank-connecting rod assembly was simulated for one complete cycle (0.02 seconds) using ADAMS to obtain the loads acting on small end of connecting rod. This force vs. time graph was converted into an equivalent stress vs. time graph. This stress vs. time graph was used as loading graph for fe-safe. The fatigue life calculated using fe-safe is 6.94×10^{6} cycles and these results were validated with the help of Palmgren-Minerlinear damage rule. The fatigue life of connecting rod can be further enhanced by incorporating manufacturing process effects in the analysis stage. Fatigue life was estimated by incorporating the shot peening process effects. An in-plane residual stress for the selected surface elements were applied for obtaining the beneficial effect of shot peening. There was an increment of 72% in fatigue life cycles). They concluded from the analysis that shot peening can significantly increase the fatigue life of a connecting rod component.

IV.THEORETICAL CALCULATION OF CONNECTING ROD

1. Pressure calculation:

Consider a 109.7cc engine (TVS Jupiter)
Engine type air cooled 4-stroke
Bore × Stroke (mm) = 53.5 x48.8
Displacement = 109.7CC
Maximum Power = 7.882bhp at 7 500rpm
Maximum Torque = 8 Nm at 5500rpm
Compression Ratio = 9.5/1
Density of petrol at 288.855 K - 737.22*10-9 kg/mm3
Molecular weight M - 114.228 g/mole
Ideal gas constant R – 8.3143 J/mol.k
From gas equation,
PV=m.Rspecific.T
Where, P = Pressure
V = Volume
m = Mass
Rspecific = Specific gas constant

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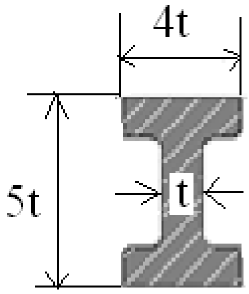
T = Temperature
But,
mass = density * volume
m =737.22E-9*3.14(53.5/2)2x 48.8
m = 0.0808 kg
Rspecific = R/M
Rspecific = 8.3143/0.114228
Rspecific = 72.78
P = m.Rspecific.T/V
P = 0.11*72.786*288.85/150E3
P = 15.4177 MPa
P ~ 16 MPA.

2. Design calculation of connecting rod:



In general From standards,
Thickness of flange and web of the section = t
Width of the section B = 4t
Height of the section H = 5t
Area of the section A = $11t^2$
Moment of inertia about x axis Ixx= $34.91t^4$
Moment of inertia about y axis Iyy= $10.91t^4$
Therefore Ixx/Iyy = 3.2
So, in the case of this section (assumed section) proportions shown above will be satisfactory.
Length of the connecting rod (L) = 2 times the stroke
L = 97.6 mm
Total Force acting F = Fp-Fi
Where Fp = force acting on piston
Fi = force by inertia
Fp = (πd2/4) * gas pressure
Fp = 34811.49 N
Fi =
$1000wrv^2/gr{*}cos\theta \pm \cos 2\theta/nl$
Wr = weight of reciprocating parts
Wr = 1.6 * 9.81 = 15.696 N
r = crank radius
r = stroke of piston / 2
r = 58.6/2 = 29.3
θ = Crank angle from the dead center
θ = 0 considering that connecting rod is at the TDC position
n1 = length of connecting rod / crank radius
n1 = 97.6/24.4 = 4
g = acceleration due to gravity, 9.81
v = crank velocity m/s
w = $2\pi n/60$
w = $2\pi 7500/60$ = 785.398 r/s
v = rw= 19.1637 m/s
on substituting
Fi = 6020.4491 N

Therefore
F = 39473.1543 – 9285.5481
F = 28791.04 N
According to Rankine's – Gordon formula,
$F = fcA/+(1/kxx)$
A = C/s area of connecting rod,
L = Length of connecting rod
fc = Compressive yield stress,
F = Buckling load
Ixx and Iyy = Radius of gyration of the section about x – x and y – y axis respectively
and
Kxx and Kyy = Radius of gyration of the section about x – x and y – y axis respectively.

For aluminum Silicon Carbide
On substituting to Rankine's formula
$30187.6 = 363*11t^2/1+0.002(117.2/1.78t)^2$
t = 5.8695
There fore
Width B = 4t = 23.47 mm
Height H = 5t = 29.34 mm
Area A = 11t = 378.969 mm2
Height at the piston end H1 = 0.75H – 0.9 H
H1 = 0.75*23.66 = 22 mm
Height at the crank end H2 = 1.1H – 1.25H
H2 = 1.1*23.66 = 32.2858mm

2.Bending stress (whipping stress calculation)

i)For carbon steel
m1=.29 kg
Mmax= $m_1w^2rl^2/9$ x1.732
=0.29 $x758^2x0.029x(.097)^2/(9x1.732)$
= 291.6 Nm= 291.6x10^3Nmm
Mmax= σ_b x Z
$\sigma_{b=}$ Mmax/Z
where Z= Section Modulus= Ixx/y=$419t^4/12$ x 2/5t=13.97 t^3
z =13.97 x5.86^3=2811.18
$\sigma_{b=}$ Mmax/Z= 291.6 x 10^3/2811.18
σ_b =103.75 MPa< 360/2.5=144 MPa
Design is safe.

ii)For Al SiC
m1=.1 kg =1N/m
Mmax= $m_1w^2rl^2/9$ x1.732
=1 $x758^2x0.029x(.097)^2/(9x1.732)$
z =13.97 x5.86^3=2811.18 mm^3
$\sigma_{b=}$ Mmax/Z= 103.6 x 10^3/2811.18

σ_b =36.88 MPa<430/2.5 =172 MPa .

Design is safe.
For the calculation of deformation, Connecting rod is being considered as simply supported beam carrying uniformly varying load changing from zero at one end to w= m_1w^2r at other end,
Hence the formula for deflection is 0.006522 $wl^4/3EI$
Deformation for steel

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$Ymax = 0.006522x\ 0.29x758^2x\ 0.029x.097^4/3\ x\ 2x\ 10^{11}x419\ (.00586)^4$

$=9.4\ x\ 10^{-5}$ mm

Deformation for Al SiC

$Ymax = 0.006522x\ 0.1x758^2x\ 0.029x.097^4/3\ x\ 2.05x\ 10^{11}x419\ (.00586)^4$

$=9.17$ **x**10^{-5} mm

A.FEA of Steel and composite material.

A 3D model of a connecting is used for analysis in ANSYS14 workbench. The loading conditions are assumed to be static. Analysis is done with pressure loads applied at the piston end and at the fixed crank end..

B. Material Properties

Property	Steel C45	Al-SiCp(10% SiCp)
Young's modulus, MPa	$2.05x10^5$	$2\ x10^5$
Poisson ratio	0.29	0.3
Yield Strength, MPa	360	430
Density, kg/m^3	7850	2900

C. Solid Modelling of Steel and composite material

Catia V5 is used for Modelling of connecting rod.

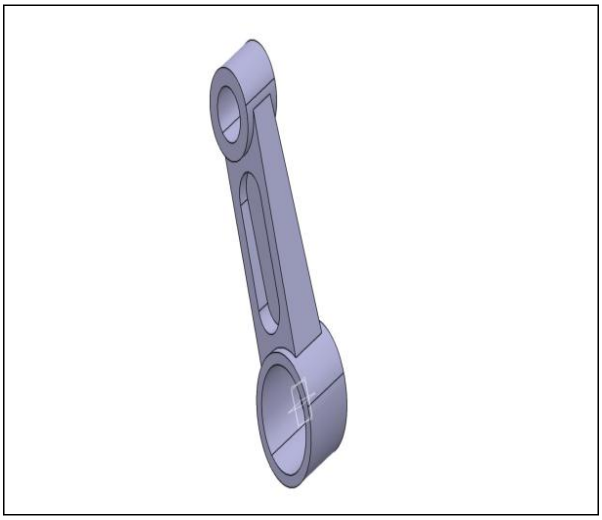

Fig 1-Solid Modelling of Connecting rod

D.FEM Analysis

The element selected is 10 tetrahedral. Finite element analysis is carried out on carbon steel connecting rod as well as on aluminum alloy reinforced with SiC particles. The material properties for Al alloy composite were taken from the reference papers. From the analysis the equivalent stress (Von-mises stress), equivalent strain and total deformation are determined.No.of nodes and elements generated are 88912 and 41058 Respectively

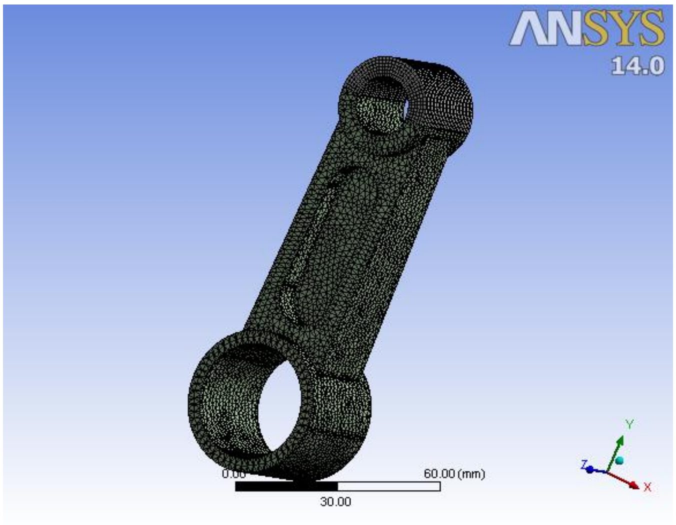

Fig.2Meshed Model of Connecting rod

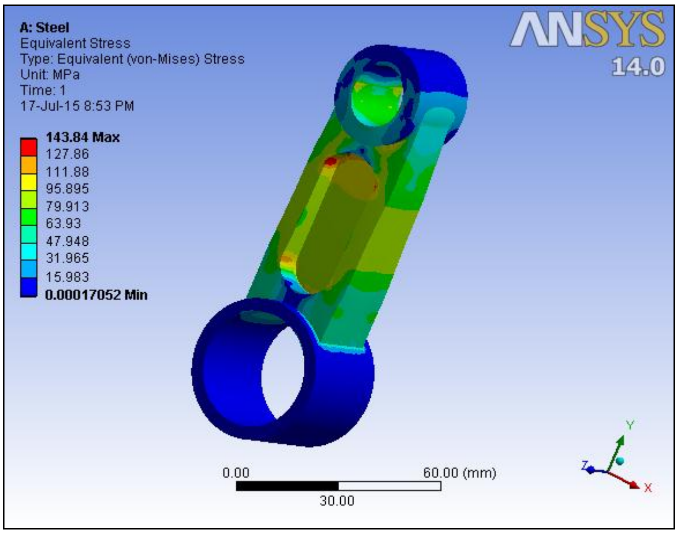

Fig. 3.VonMises Stress of Structural steel connecting rod

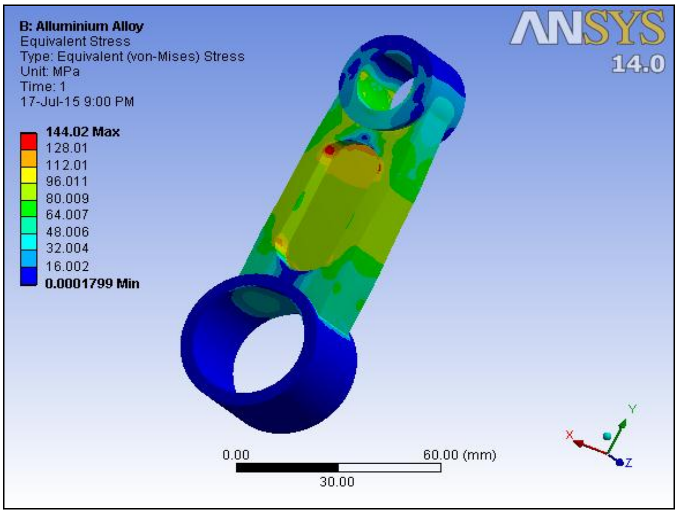

Fig. .4Von Mise's Stress of Al 5083 alloy Composite Connecting rod

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Fig. 3 and Fig.4 shows Min Equivalent stress as .00017052 MPa and maximum 143.84MPa and minimum equivalent stress as .00001799Pa and maximum 144.02MPa for a connecting rod made of Structural steel and Al alloy composite respectively.

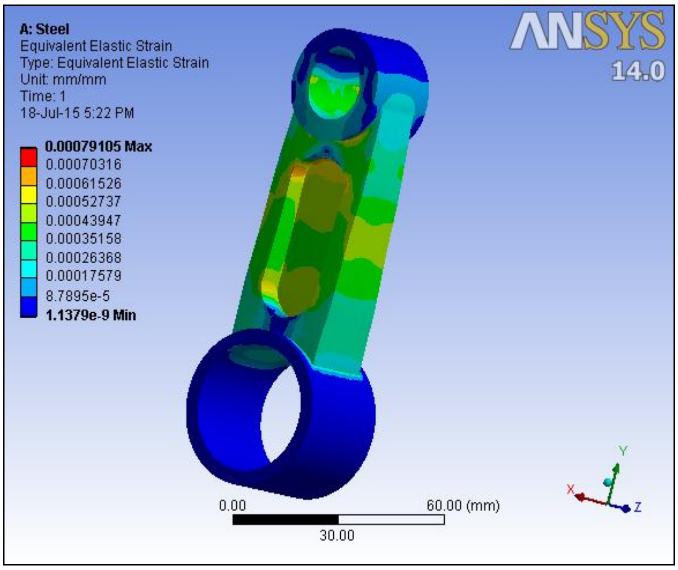

Fig. 5 Equivalent elastic strain of Structural steel connecting rod

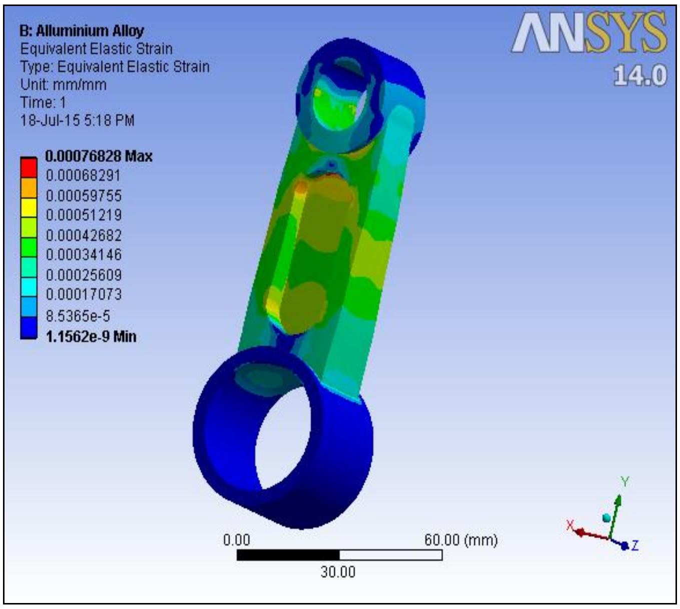

Fig. 6 Equivalent elastic strain of Al 5083 alloy Composite Connecting Rod

Fig. 6 and Fig. 7 shows Min Equivalent elastic strain as 1.137 8X 10^{-9} mm/mm and1.156 X 10^{-9} mm/mm and max Equivalent elastic strain as .00079mm/mm and 0.00076 mm/mm for a connecting rod made of Structural steel and Al alloy composite respectively.

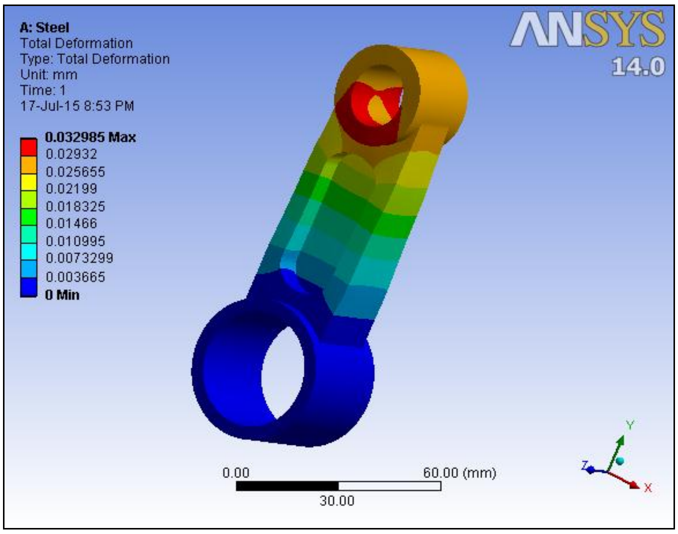

Fig.7 Total Deformation of Structure steel Connecting

Fig. 7 and Fig. 8 shows Min Total deformation as 0 for both and max Total deformation as 0.032185 mm and 0.032199 mm for a connecting rod made of Structural steel and Al alloy composite respectively.

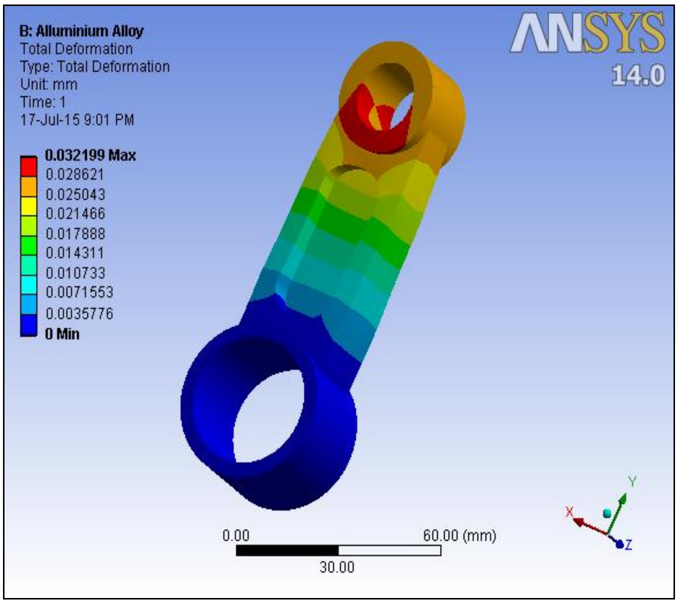

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Fig.8 Total Deformation of Al 5083 Composite Connecting rod

V.FATIGUE LIFE PREDICTION

The Stress Life (SxN) theory was employed to evaluate the connecting rod fatigue life.

i)Calculation for factor of safety of connecting rod

As yield stress is considered as criteria of design, calculations are done based on Soderbeg's equation.

f.s = factor of safety

σm = mean stress

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σy = yield stress

σv = variable stress

σe = endurance stress

1/f.s= σm/σy +σv/σe

For Steel C 45

σmax = 143.84 σmin = 0.00017052

σm = σmax + σmin/2 =71.92

σy = 360 Mpa

σv = σmax−σmin/2 = 71.73

σe = 0.6×360=216

$1/f.s$ = 0.531= 1.88

Factor of safety [F.S] = 1.88

ii)Calculation for Weight and Stiffness
For carbon Steel (c45):

Density of steel = 7.850 x 10^{-6} kg/mm^3

Volume = Area x length=378.6x 97.6=37829.8mm^3

Deformation = 0.032985 mm

Weight of forged steel = volume ×density

= 37829.8x 7.85 x10^{-6}

= 0.29 kg

= 0.29×9.81 = **2.91 N**

Stiffness = weight/deformation

= 0.29/0.032985=8.79 kg/mm=87.9 N/mm

iii) Fatigue calculation

Result for fatigue of connecting rod:

N=1000(sf/0.9σu) $^{3/\log}$ $(\sigma e'/0.9\times\sigma u)$

Where,

N = No. of cycles

σe = Endurance Limit

σu = Ultimate Tensile Stress

$\sigma e'$ = Endurance limit for variable axial stress

ka = Load correction factor for reversed axial load = 0.8

ksr = Surface finish factor = 1.2

ksz = Size factor = 1

$\sigma e'$ = σe×ka×ksr×ksz

$sf = f.s.$σv/ $(1-f.s.\sigma m/\ )$

For Carbon Steel

σu=750 Mpa

$\sigma e'$= σe×ka×ksr×ksz

= 216×0.8×1.2×1

= 207.36Mpa

sf = f.s.σv /$(1-f.s.\sigma m/\sigma u)$

= 1.88x 71.73/(1-1.88x 71.92/750)

= 164.5 MPa

N=1000(sf/0.9σu) $^{3/\log}$ $(\sigma e'/0.9\times\sigma u)$

= 1000(164.5/ 0.9×750) $^{3/\log}$ (207.36/ 0.9×750)

= 1.3 x 10^6cycles

iv)Calculation for factor of safety of connecting rod
For Al SiC (10% SiC)

σmax = 144.02 σmin = 0.0001799

σm = σmax + σmin/2 =72.01

σy = Mpa

σv = σmax−σmin/2 = 71.99

σe = 0.6×430=258 Mpa

$1/f.s$ =.446

Factor of safety [F.S] = 2.25

v)Calculation for Weight and Stiffness
For Al SiC

Density of Al SiC = 2.9 x 10^{-6} kg/mm^3

Volume = Area x length=378.6x 97.6=37829.8mm^3

Deformation = 0.032199 mm

Weight of steel = volume ×density

= 37829.8x 2.9x10^{-6}

= 0.109kg

= 0.29×9.81 = **1 N**

Stiffness = weight/deformation

= 0.109/0.032199 =3.385 kg/mm=33.85 N/mm

vi)Fatigue calculation

Result for fatigue of connecting rod:

N=1000(sf/0.9σu) $^{3/\log}$ $(\sigma e'/0.9\times\sigma u)$

For Al SiC

σu= σe x2 =516 MPa

$\sigma e'$= σe×ka×ksr×ksz

= 258×0.8×1.2×1

= 247.68Mpa

sf = f.s.σv /$(1-f.s.\sigma m/\sigma u)$

= 2.25x 71.99/(1-2.25x 72.01/516)

= 236.11MPa

N=1000(sf/0.9σu) $^{3/\log}$ $(\sigma e'/0.9\times\sigma u)$

$= 1000(236.11/ 0.9\times516)^{3/\log} (247.68/ 0.9x516)$

$= 1.83x\ 10^{6}$cycles

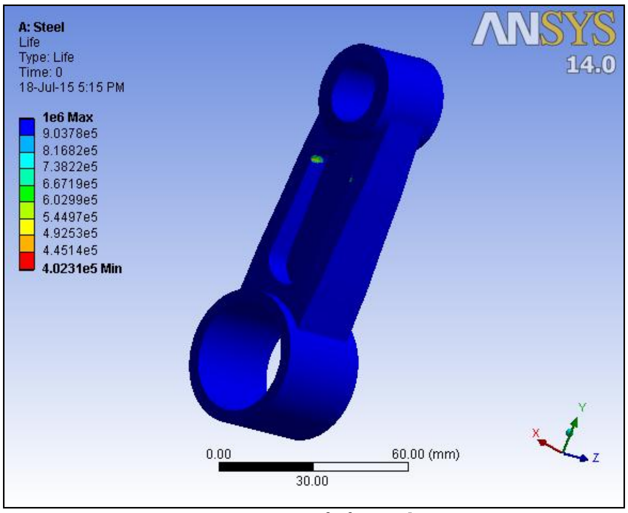

Fig.9 Life for steel

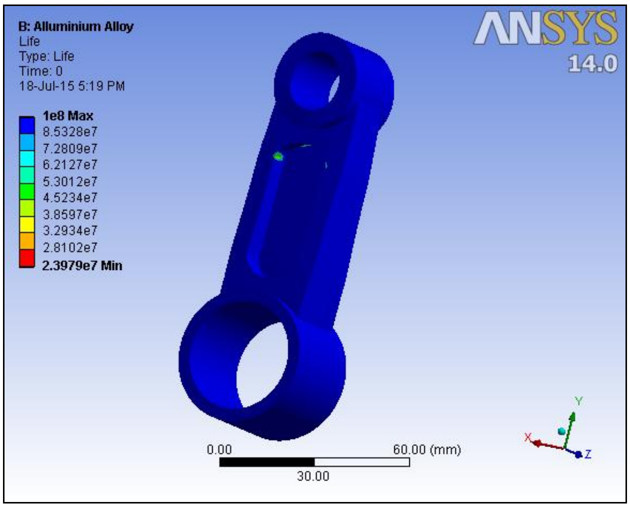

Fig.10 Life for Al sic

After calculating the alternate and mean stresses, we can plot the Soderberg diagram. With the alternate and mean stresses, and using the Modified Goodman diagram for the connecting rod material, it is possible to evaluate the fatigue factors.

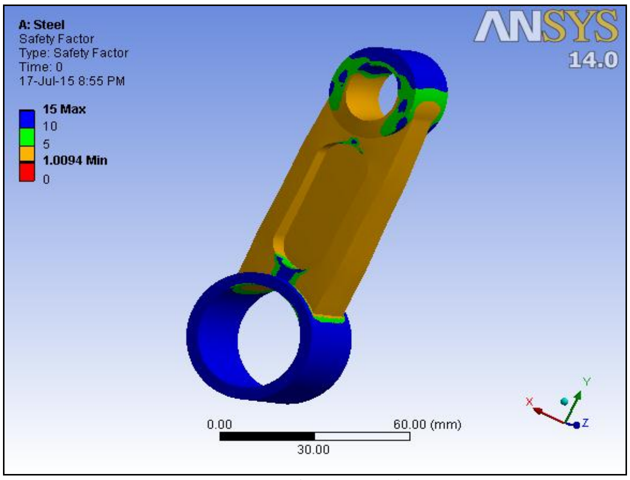

Fig.11 Safety Factor for Steel

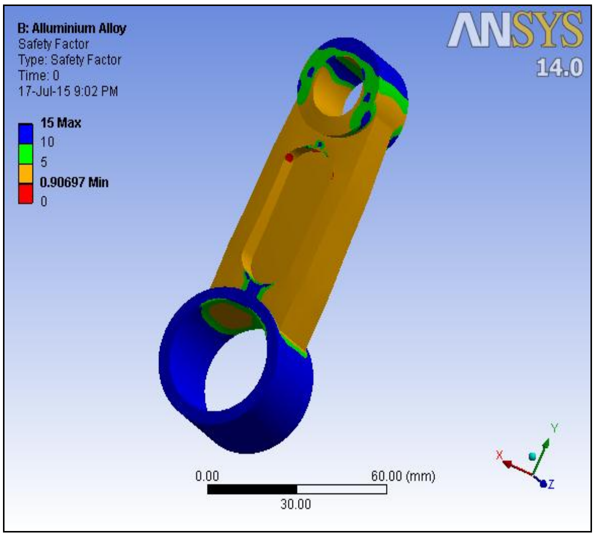

Fig12.safety factor for Al Sic

VI .RESULT

Parameter	C45	Al SiC
Von Mises stress(Mpa)Ansys	143.44	144.02
Total deformation (mm)(ansys)	.03285	.032199
Equivalent strain	.00079	.00076
Safety factor(Ansys)	1.0094 to15	0.9 to 15
Life (Cyckes)(ansys)	$1x10^{6}$	$1x10^{8}$
Bending stress (analytical)	103	36.88
Life (analytical)	$1x10^{6}$	$1.8\ x10^{6}$
Safety factor (analytical)	1.88	2.15

VII. CONCLUSION

The aluminum composite connecting rod has light weight about 1/3 of steel . Equivalent elastic strain , total deformation, and stresses are approximately equal in Al alloy composite connecting rod and structural steel connecting rod but it comes under the permissible tolerance limit. The maximum life value is more in an aluminum alloy connecting rod as compared to the connecting rod made of steel. Thus a steel connecting rod can be re placed with a developed Al alloy connecting rod.

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