DESIGN AND ANALYSIS OF CONNECTING ROD USING COMPOSITE MATERIAL

A PROJECT REPORT

Submitted by

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In

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BONAFIDE CERTIFICATE

Certificate that this project report **DESIGN AND ANALYSIS OF CONNECTING ROD USING COMPOSITE MATERIAL** is the bonafide work of

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INTERNAL EXAMINER	**EXTERNAL EXMAINER**

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DESIGN AND ANALYSIS OF CONNECTING ROD USING COMPOSITE MATERIALS

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Abstract— **The Connecting rod is the intermediate member between the piston and crankshaft. It converting the reciprocating motion of the piston to rotary motion of the crank. Also it faces a lot of tensile & compressive loads during its lifetime and also it withstand more temperature during its operation. Generally connecting rod is manufactured using carbon steel. In applications, aluminum alloys are mostly used. In this work, the existing connecting rod (Aluminium360) can be replaced by new composite materials (i.e. aluminum based composite material reinforced with Boron carbide & Silicon carbide). Pro-e software is used to generate the 3-D model of connecting rod & ANSYS is used to analyze the connecting rod.**

***Keywords*— Connecting rod, Composites, aluminium, Boron Carbide, Silicon Carbide, Design of connecting rod, Pro-e, ANSYS, Analysis of composite connecting rod.**

I. INTRODUCTION

A connecting rod is a rigid member which connects a piston to a crank or crankshaft in a reciprocating engine. Together with the crank, it forms a simple mechanism that converts reciprocating motion into rotating motion. A connecting rod may also convert rotating motion into reciprocating motion, its original use. Earlier mechanisms, such as the chain, could only impart pulling motion. Being rigid, a connecting rod may transmit either push or pull, allowing the rod to rotate the crank through both halves of a revolution. In a few two-stroke engines the connecting rod is only required to push. Today, the connecting rod is best known through its use in internal combustion piston engines, such as automobile engines. These are of a distinctly different design from earlier forms of connecting rod used in steam engines and steam locomotives. The combination of axial stress and the bending stress acting on the rod in operation. The axial stresses are product due to cylinder gas pressure and the inertia force arising on account of reciprocating motion. Whereas bending stresses are caused due to the centrifugal effects. To provide the maximum rigidity with minimum weight, the cross section of the connecting rod is made as I-section end of the rod is a solid eye or a split eye this end holding the piston pin. Three different connecting rods, of which the left and the aluminum center, the connecting rod to the right (for endothermic engine) in steel, the left connecting rod (for endothermic engine) has the modular head and the foot equipped with a bushing, the central rod has the oil drip rod equipped with parts. In modern automotive internal combustion engine, the connecting rods are most usually made of steel for production engines, but can be made of T6-2024 and T651-7075 Aluminium alloy (for lightness and the ability to absorb high impact at the expense of durability) or titanium (for a combination of lightness with strength, at higher cost) for high-performance engines, or of cast iron for applications such as motor scooters. They are not rigidly fixed at either end, so that the angle between the connecting rod and the piston can change as the rod moves up and down and rotates around the crankshaft. Connecting rods, especially in racing engines, may be called "billet" rods, if they are machined out of a solid billet of metal, rather than being cast or forged. The small end attaches to the piston pin, gudgeon pin or wrist pin, which is currently most often press fit into the connecting rod but can swivel in the piston, a "floating wrist pin" design. The big end connects to the crankpin (bearing journal) on the crank throw, in most engines running on replaceable bearing shells accessible via the *connecting rod bolts* which hold the bearing "cap" onto the big end. Typically there is a pinhole bored through the bearing on the big end of the connecting rod so that pressurized lubricating motor oil squirts out onto the thrust side of the cylinder wall to lubricate the travel of the pistons and piston rings. Most small two-stroke engines and some single cylinder four-stroke engines avoid the need for a pumped lubrication system by using a rolling-element bearing instead, however this requires the crankshaft to be pressed apart and then back together in order to replace a connecting rod.

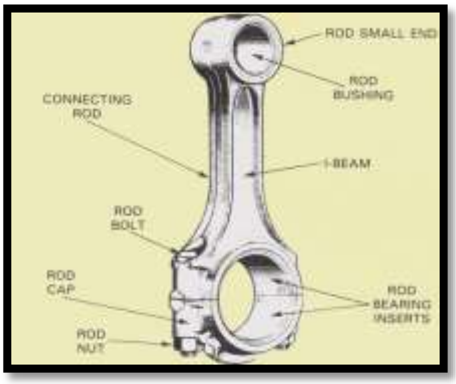


Fig. 1 Schematic diagram of connecting rod

K.Sudershan kumar, [1] described modeling and analysis of Connecting rod. In his project carbon steel connecting rod is replaced by aluminum boron carbide connecting rod. Aluminium boron carbide is found to have working factory of safety is nearer to theoretical factory of safety, to increase the stiffness by 48.55%andtoreducestress by 10.35%.

Vivek. C. Pathade, [2] he dealt with the stress analysis of connecting rod by finite element method using pro-e wild fire 4.0 and ansys work bench 11.0 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.

Pushpendra Kumar Sharma, [3] performed the 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 crack able forged steel (C70). And the software gives a view of stress distribution in the whole connecting rod which gives the information that which parts are to be hardened or given attention during manufacturing stage.

Ram Bansal, [4] in his paper a dynamic simulation was conducted on a connecting rod made of aluminum alloy using FEA. In this analysis of connecting rod were performed under dynamic load for stress analysis and optimization. Dynamic load analysis was performed to determine the in service loading of the connecting rod and FEA was conducted to find the stress at critical locations.

Folgar [5] (1987) developed a Metal matrix composite Connecting Rod with the aid of FEA, and loads obtained from kinematic analysis. Fatigue was not addressed at the design stage.

S.Venkatesh [6] “Design and Analysis of Connecting Rod with Modified Materials and FEA Analysis‖ The main objective is to reduce the weight of connecting rod by replacing steel with aluminium fly ash composite material without losing any of its strength and hardness. Experimental results are obtained from the compressive and tensile tests of connecting rods. Spectrometer test is also performed and the results are found out. It is found that by using aluminium fly ash composite material weight is greatly reduced up to 50% without losing any of its strength and hardness. Finally aluminium and steel connecting rods are analyzed with the help of Ansys and the FEA results are compared with the experimental results both the results are give equal value.

II. 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 I-section 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 axis.

According to Rankine formulae Wcr about x-axis

$$= \frac{[\sigma_c \times A]}{1+a[\frac{L}{Kxx}]^2} = \frac{[\sigma_c \times A]}{1+a[\frac{l}{Kxx}]^2}$$

[* for both ends hinged L = l]

Wcr about y-axis

$$= \frac{[\sigma_c \times A]}{1+a[\frac{L}{Kyy}]^2} = \frac{[\sigma_c \times A]}{1+a[\frac{l}{2Kyy}]^2}$$

[*for both ends fixed L = l/2]

$$= \frac{[\sigma_c \times A]}{1+a[\frac{l}{Kxx}]^2} = \frac{[\sigma_c \times A]}{1+a[\frac{l}{2Kyy}]^2}$$

In order to have a connecting rod equally strong in buckling about both the axis, the buckling loads most are equal. i.e.

[or]

$$[\frac{l}{Kxx}]^2 = [\frac{l}{2Kyy}]^2$$

$K^2_{xx} = 4K^2_{yy}$ [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

$$= 2[4t \times t] + 3t \times t = 11t^2$$

section Moment of

$$= 2[4t \times t] + 3t \times t = 11t^2$$

inertia about x-axis

$$I_{xx} = \frac{1}{12}[4t\{5t\}^3 - 3t\{3t\}^3] = \frac{419}{12}[t^4]$$

Moment of inertia

about x-axis

And moment of inertia about y-axis

$$I_{yy} = \frac{2\times1}{12} \times t \times \{4t\}^3 + \frac{1}{12}\{3t\}t^3 = \frac{131}{12}[t^4]$$

$$I_{xx}/I_{yy} = [419/12]x[12/131]$$

$$= 3.2$$

There are two beam sections for designing connecting rod, i.e. I- section & H-section connecting rod.

III. FORCES ACTING ON THE CONNECTING ROD

1. All The combined effect (or joint effect) of,
    a) The pressure on the piston, combined with the inertia of the Reciprocating parts.
    b) The friction of the piston rings, piston, piston rod and the cross head.
2. The longitudinal component of the inertia of the rod.

3. The transverse component of the inertia of the rod.
4. The friction of the two end bearings.

Different forces:

1. Axial forces resulting from gas pressure and inertia of piston assembly modified by the side thrust arising in consequence of the connecting rod crank angle. The maximum axial load is compressive (at TDC).
2. Tensile stresses occur after firing, due to piston inertia.
3. Bending stress also occurs after firing.
4. Transverse forces Known as whip are caused by inertia effects of the rod mass. Fortunately axial & transverse forces do not occur at the same time.

IV. THEORETICAL CALCULATION OF CONNECTING ROD

A. *Pressure Calculation*

A 150cc Engine
Specification Engine
type air cooled 4-
stroke Bore x Stroke
(mm) = 57x58.6
Displacement = 149.5
cc
Maximum power = 13.8 bhp
at 8500 rpm Maximum
torque = 13.4 Nm at 6000
rpm Compression ratio =
9.35/1

*****Density of petrol at 288.85k – 737.22*10-9 kg/mm^2
*****Molecular weight M – 114.228 g/mole
*****Ideal gas constant R – 8.3143 J/mole.K

From gas equation,

PV= m RT

Where, P = Pressure
V = Volume
m = Mass
□□□□□□□□□ = Specific gas constant
T = Temperature

But,
Mass = Density * Volume
m =

737.22E-9 *
150E3
m = 0.11 kg

$\square_{\square\square\square\square\square\square\square\square} = R/M$

$\square_{\square\square\square\square\square\square\square\square} = 8.3143/0.0114228$

$\square_{\square\square\square\square\square\square\square\square} = 72.76$

P = mRT/ V
P = 0.11* 72.786
*288.85 /150E3 P =
15.4177 Mpa
P ≈ 16 Mpa

B. *Design Calculation of Connecting Rod*

Thickness of flange and web of the section = t Width of section B = 4t

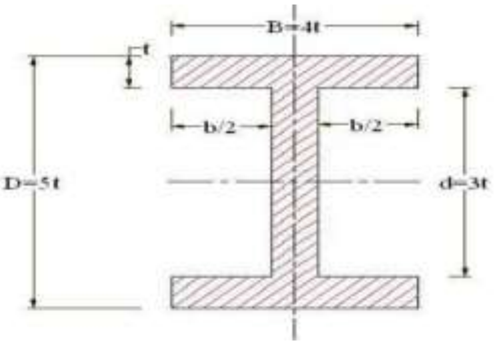


Fig. 2 Standard dimension‘s of I-section

Height of the section H = 5t
Area of section A = 2(4t × t) +3t × t
A = 11□^{2}

M.O.I of section about x-axis:

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

$$= \frac{419}{12}[t^4]$$

= 34.91□^{4}

M.O.I of section about y-axis:

$$I_{yy} = \frac{2\times1}{12} \times t \times \{4t\}^3 + \frac{1}{12}\{3t\}t^3$$

$$= \frac{131}{12}[t^4]$$

= 10.91□^{4}

□□□ □□□ = 3.2

So, in this case of this section (I-section) proportions shown above will be satisfactory. The most suitable section for the connecting rod is I–section with proper proportions.
Length of the connecting rod (L) = 2
times of the stroke L = 117.2 mm
Bucking load, F =
□□ Total acting
load F = □□ -□□
Where,

□□ = force acting on piston
□□ = force by inertia

□□ = π□$^{□}$/ 4 * gas pressure

□□ = 39473.1543 N

$$F_i = \frac{1000\,wr\,v^2}{gr} * cos\theta \pm \frac{\cos 2\theta}{n^l}$$

□□ = Weight of the reciprocating parts
□□ = 1.6 * 9.81

□□ = 15.696 N

Where, r = crank radius
r = stroke of
piston / 2 r =
58.6 / 2
r = 29.3 mm
Ɵ = crank angle from the dead centre
Ɵ = 0 considering that connecting rod is at the TDC position
$\square^{\square}$ = length of the connecting rod / crank radius

□□ = 117.2 / 29.3

□□ = 4

g = acceleration due to gravity = 9.81 v = crank velocity, m/s

w = □□□ / □□

w = □□×□□□ / □□ = 890.1179 N
□□

□□

v = wr = 890.1179 × 29.3□−□ = 26.08 m/s On substituting above values in □□ Equation, We get,□ = 9285.5481 N
Therefore,
F = □□ - □□

F = 39473.1543 - 9285.5481 F = 30187.6062 N = □□

For Aluminium6061-1.5%□□C- 1.5%SiC

Buckling load,

$$W_B = \frac{(\sigma_C \times A)}{(1+a\ (L/Kxx)2}$$

Where,
□□ = compressive yield stress = 390 Mpa
□□ = □□□ / □ □

□□□ = 1.78 t a = □□ /□□E a = 0.0028

By substituting □ , A, a, L, □□□ on buckling load □□ then We get,

$$W_B = \frac{(\sigma_C \times A)}{(1+a\ (L/Kxx)2}$$

30187.6062 = 326.48□□
□□ = 92.4

t = 3.1 mm

Width of section, B = 4t

B = 4× 3.1

B = 12.4 mm

Height of the section, H = 5t

H = 5× 3.1

H = 15.5 mm

Area of the section, A = 11$□^{□}$

A = 11 × $□.\ □^{□}$

A = 105.71 $□□^{□}$

Height at the big end (crank end) = $□_{□}$ = 1.1H to 1.25H

$□_{□}$ = 1.1 ×15.5

$□_{□}$ = 17.05

mm Height at the small end (piston end) =

$□_{□}$ = 0.9 H to 0.75H

$□_{□}$ = 0.9 × 15.5

$□_{□}$ = 13.95 mm

Small end (Piston end):

Inner diameter of small end $□_{□}$ = $□_{□}$ / ($□□_{□}$×$□_{□}$)

[□ = □□ = 9285.5481 N]

=

□□ □□□□.□ □□□

□□.□×
□.□□□

□□$^{□}$ = 495.23

□□ = 22.25 mm

Where,

Design bearing pressure for small end □□□ = 12.5 to 15.4 N/□□$^{□}$ Length of the piston pin □□ = (1.5 to 2) □□

Outer diameter of the small end □′□ = □□+ 2□□ + 2□□

□′□ = 22.25 + [2×2] + [2×5]

□′□= 36.25 mm

Where,

Thickness of the bush (□) = 2 to 5 mm Marginal thickness (□□) = 5 to 15 mm

Big end (Crank end)

Inner diameter of big end □□ = □□ / (□□ × □□)

□□ = □□□□.□□□□ / □□.□×□ □□

□□ = 29.32 mm

Where,

Design bearing pressure for big end □□□ = 10.8 to 12.6 N/□□$^{□}$ Length of the crank pin □□ = (1 to 1.25) □□

Root diameter of bolt = (□□□ / □×□□) ^2

= 4 mm

Outer diameter of big end □′ = □□ + 2□□ + 2□□ +2 □□

□′□ = 29.32 + [2×2] + [2×4.8] + [2×5]

□′□ = 52.92 mm

Where,

Thickness of the bush (□□) = 2 to 5 mm Marginal thickness (□) = 5 to 15 mm

Nominal diameter of the bolt (□□) = 1.2 × root diameter of bolt

□□ = 1.2 × 4

□ □ = 4.8 mm

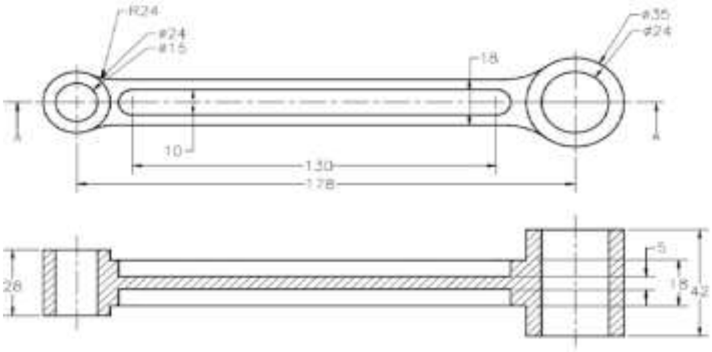


Fig. 3 General Dimensions of Connecting rod

C. *Specifications of connecting rod (aluminium 6061-1.5% B_4 C-1.5 SiC)*

TABLE I

S. No	Parameters (mm)
1.	Thickness of the connecting rod (t) = 3.1 mm
2.	Width of the section (B) = 12.4 mm
3.	Height of the section (H) = 15.5 mm
4.	Height at the big end (H_2) = 17.05 mm
5.	Height at the small end (H_1) = 13.95 mm
6.	Inner diameter of the small end = 22.25 mm
7.	Outer diameter of the small end = 36.25 mm
8.	Inner diameter of the big end = 29.32 mm
9.	Outer diameter of big end = 52.92 mm

D. *Material properties used for analysis*

TABLE II

S. No	Parameters	Old material (Al360)	New materials (Al6061-1.5%B_4C-1.5%SiC)
1.	Ultimate tensile strength (Mpa)	303Mpa	422Mpa
2.	Yield strength (Mpa)	170Mpa	390Mpa
3.	Young _s modulus	60Gpa	293.63Gpa
4.	Poisson‘s ratio	0.33	0.33
5.	Density (g/ cm^3)	2.6 g/cm^3	2.7 g/ cm^3

V. FEA OF CONNECTING ROD

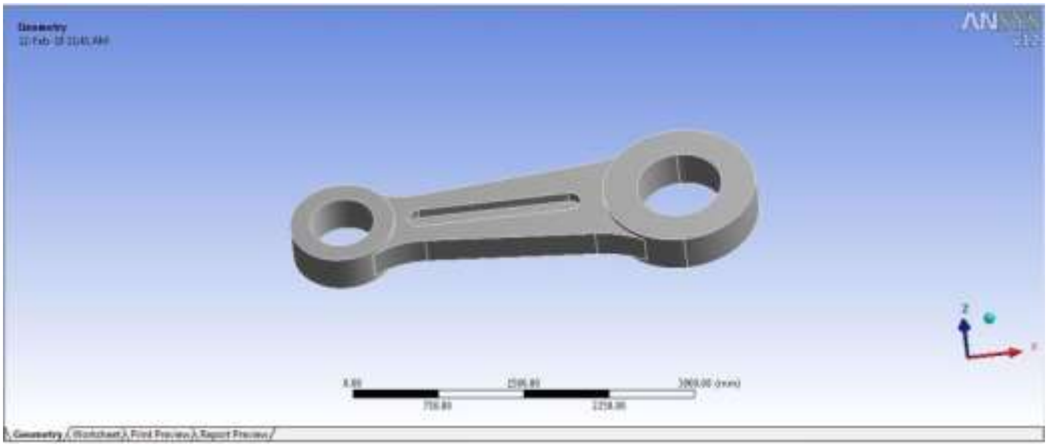


Fig. 4 Model of connecting rod

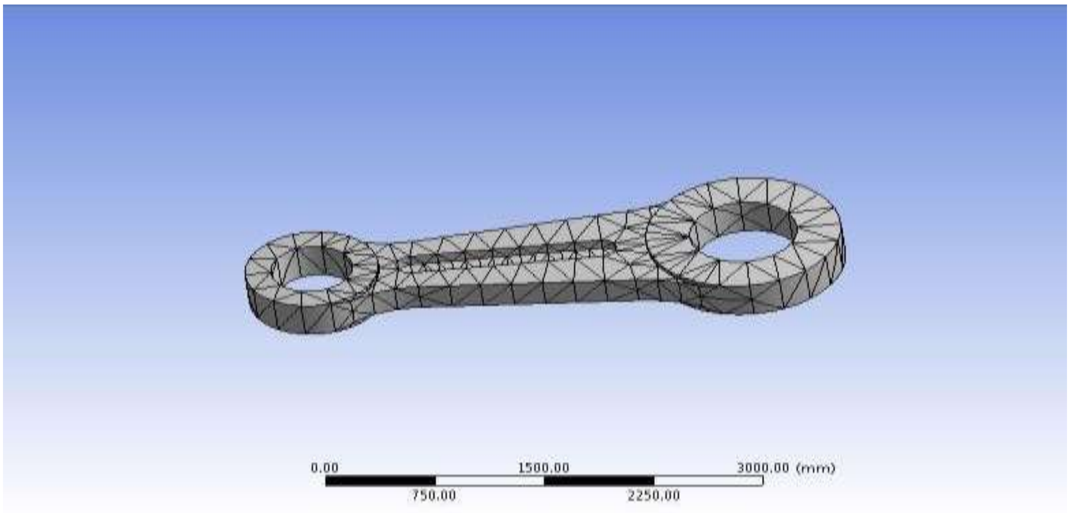


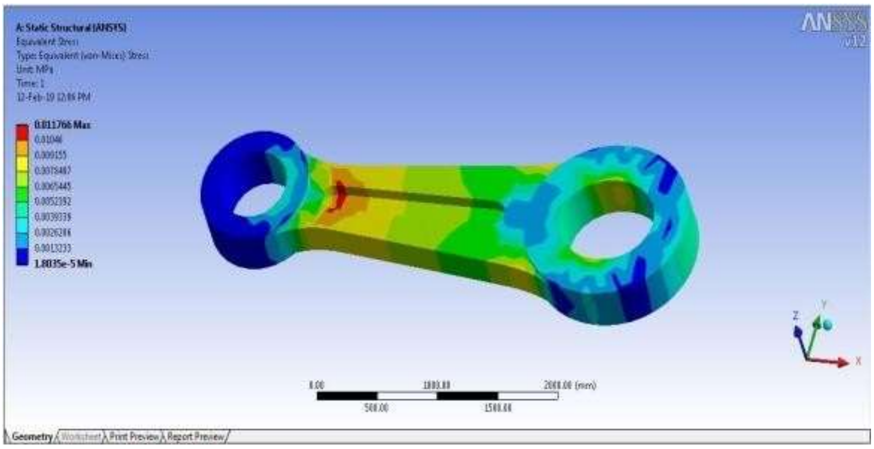
Fig. 5 Meshed Model of connecting rod

VI. RESULTS AND DISCUSSION

Analysis

For finite element analysis 16 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 von-misses stress, strain and displacement are noted from the ANSYS.

1. *EQUIVALENT STRESS:*



A: Static Structural (ANSYS)
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
12-Feb-19 12:86 PM

Fig. 6 Equivalent Stress for Al6061-1.5% B4C-1.5% SiC

2. *EQUIVALENT STRAIN*

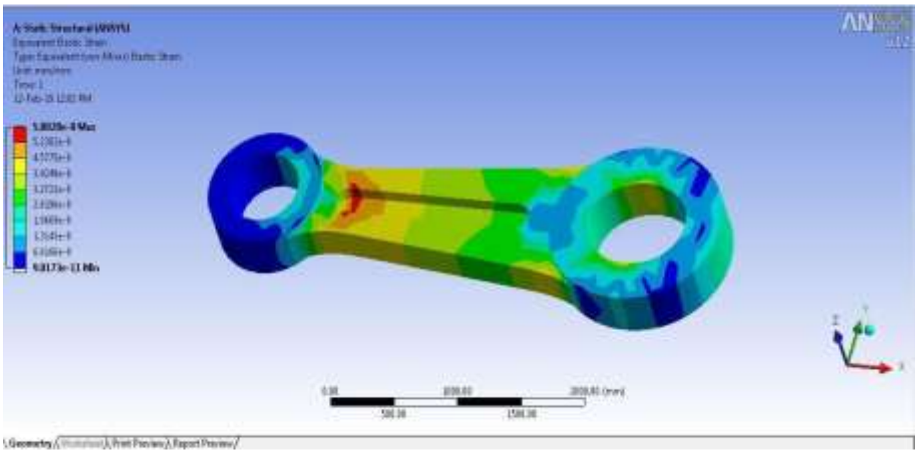


Fig. 7 Equivalent Strain for Al6061-1.5% B4C-1.5% SiC

3. *NORMAL STRESS (X-AXIS):*

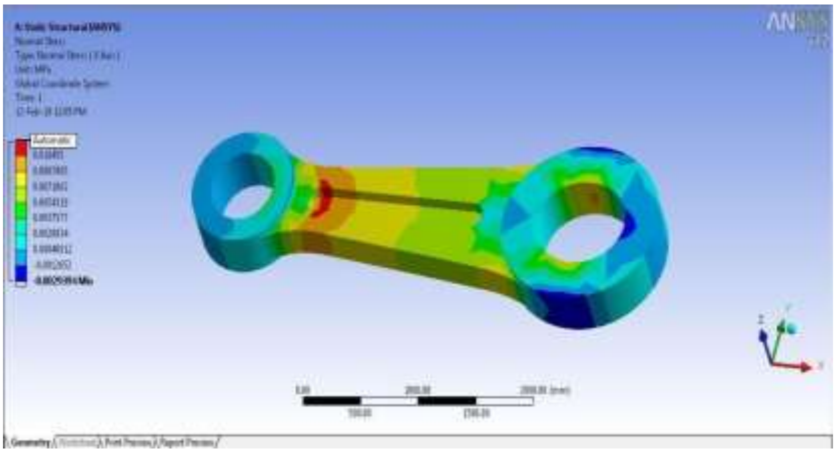


Fig. 8 Normal Stress for Al6061-1.5% B4C-1.5% SiC

4. *NORMAL STRESS (Y-AXIS):*

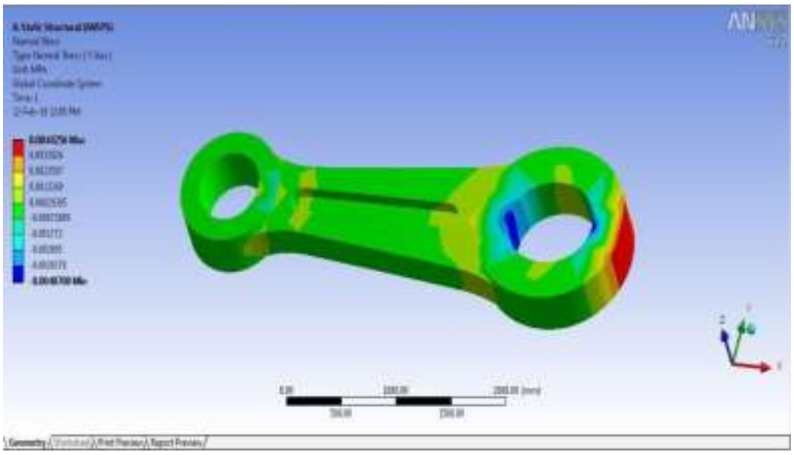


Fig. 9 Normal Stress (y-axis) for Al6061-1.5% B4C-1.5% SiC

5. *NORMAL STRESS (Z-AXIS):*

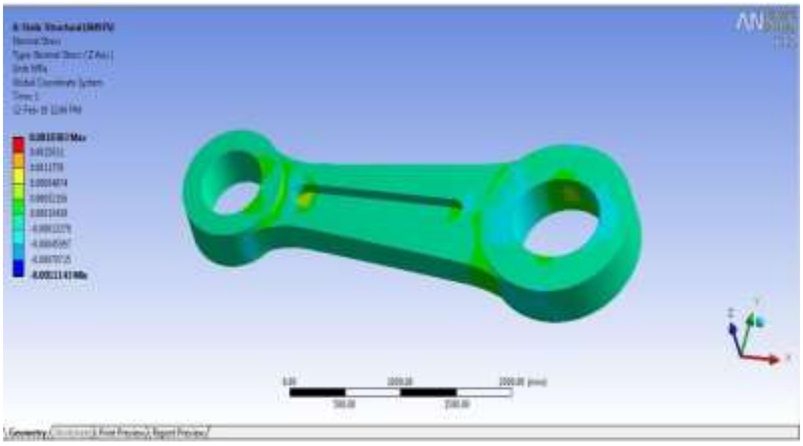


Fig. 10 Normal stress (z-axis) for Al6061-1.5% B4C-1.5% SiC

6. *SHEAR STRESS (XY-PLANE):*

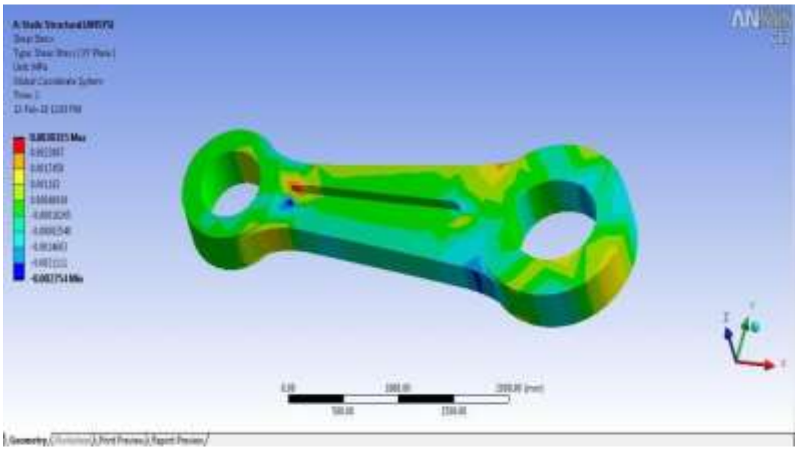


Fig. 11 Shear stress (xy-plane) for Al6061-1.5% B4C-1.5% SiC

7. *SHEAR STRESS (YZ-PLANE):*

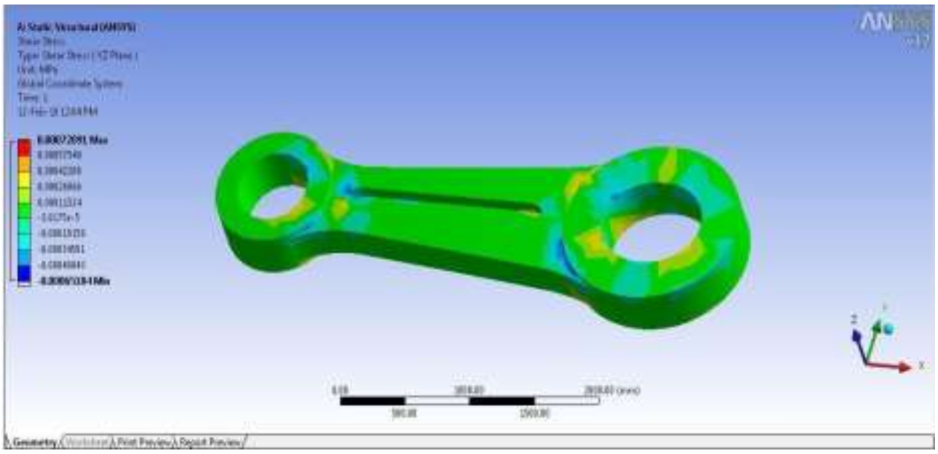


Fig. 12 Shear stress (yz-plane) for Al6061-1.5% B4C-1.5% SiC

8. *SHEAR STRESS (ZX-PLANE):*

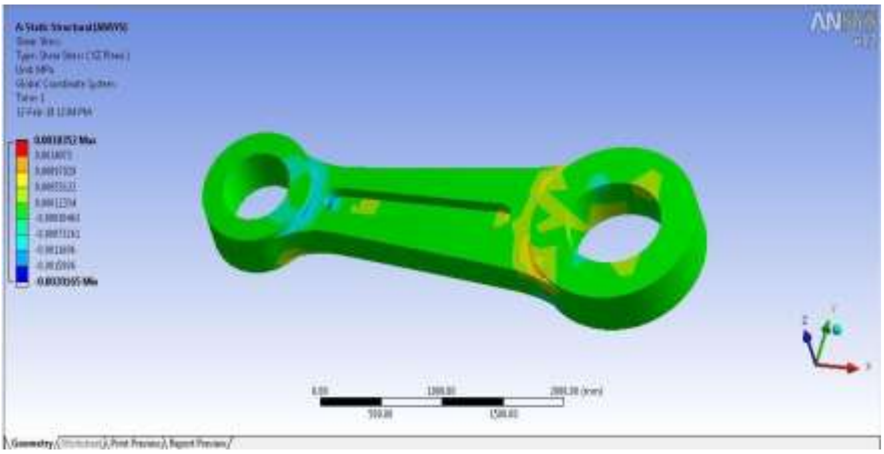


Fig. 13 Shear stress (yz-plane) for Al6061-1.5% B4C-1.5% SiC

9. *TOTAL DEFORMATION:*

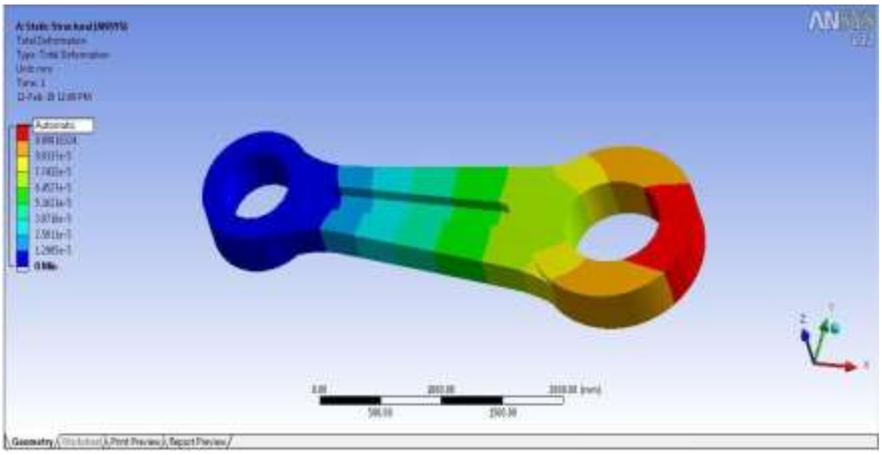


Fig. 14 Total Deformation for Al6061-1.5% B4C-1.5% SiC

10. *DIRECTIONAL DEFORMATION (X-AXIS):*

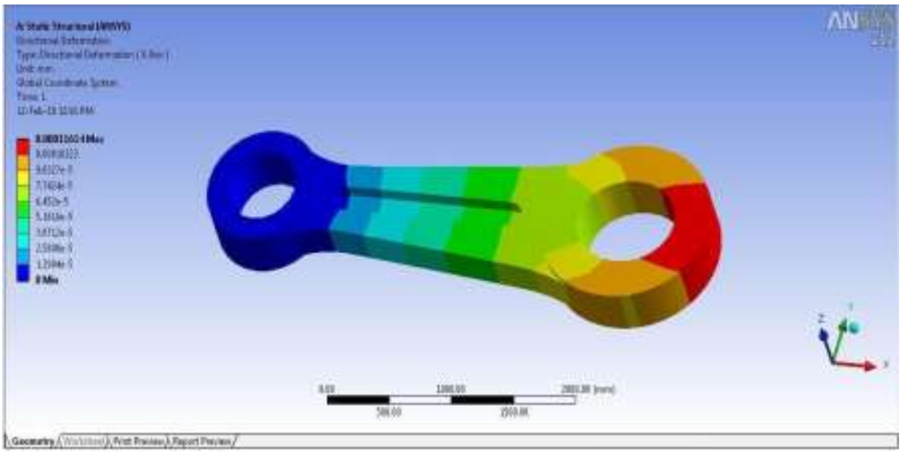


Fig. 15 Directional deformation (x-axis) for Al6061-1.5% B4C-1.5% SiC

11. *DIRECTIONAL DEFORMATION (Y-AXIS):*

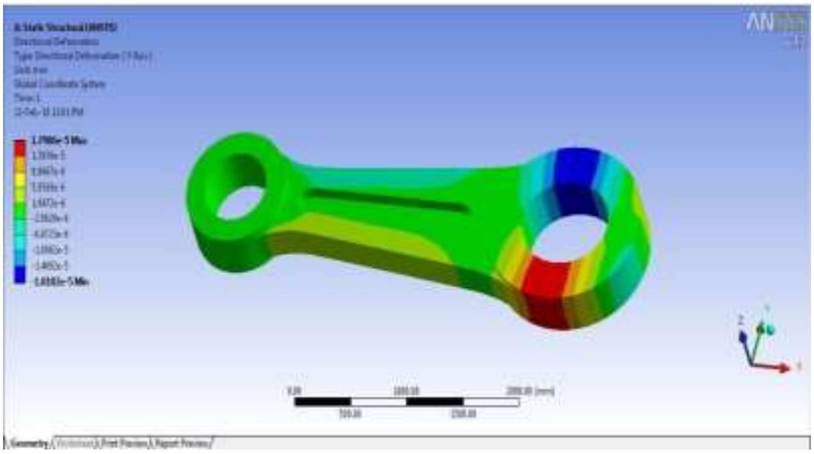


Fig. 16 Directional deformation (y-axis) for Al6061-1.5% B4C-1.5% SiC

12. *DIRECTIONAL DEFORMATION (Z-AXIS):*

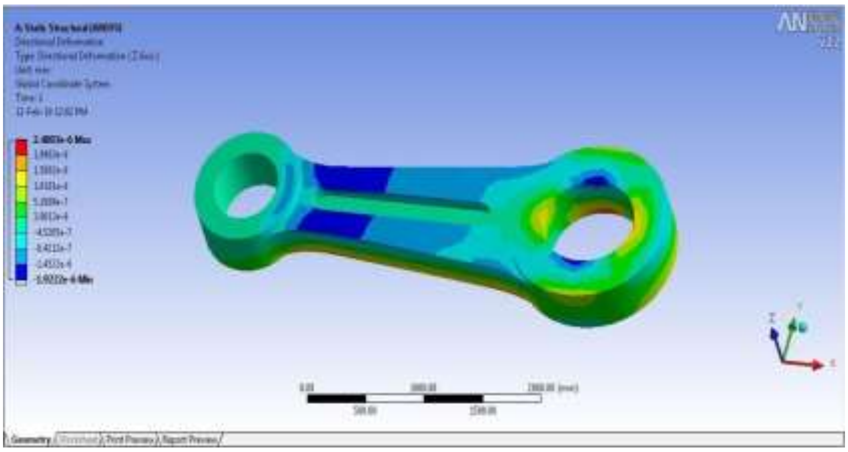


Fig. 17 Directional deformation (z-axis) for Al6061-1.5% B4C-1.5% SiC

TABLE III

STRESSES AND DEFORMATION OF (AL6061-1.5%□4C-1.5%SIC)

S. No	Types	MAX (Mpa)	MIN (Mpa)
1.	Equivalent stress	0.011766	1.8035□$^{-5}$
2.	Normal stress (x-axis)	0.010455	-0.0029394
3.	Normal stress (y-axis)	0.0044256	-0.0048708
4.	Normal stress (z-axis)	0.0018303	-0.0011143

5.	Shear stress (xy plane)	0.0030315	-0.002754
6.	Shear stress (yz plane)	0.00072891	-0.00065184
7.	Shear stress (zx plane)	0.0018352	-0.0020165
8.	Total deformation	0.00010324	0
9.	Directional deformation (x-axis)	0.00011614	0
10.	Directional deformation (y-axis)	$1.7986\square^{-5}$	$-1.8102\square^{-5}$

11.	Directional deformation (z-axis)	$2.4883□^{-6}$	$-1.9222□^{-6}$

TABLE IV

STRAIN OF (AL6061-1.5%□4C-1.5%SIC)

S. No	**Types**	**MAX (mm)**	**MIN (mm)**
1.	Equivalent strain	$5.8828□^{-8}$	$9.0173□^{-11}$

VOLUME, WEIGHT AND STIFFNESS OF THE CONNECTING ROD

a) For aluminium 360

The volume of the connecting rod used is 100829.348□□^{3}. Therefore mass of the connecting rod for respective materials are:

Weight = Volume*
Density Weight =
57472.72836 * 2.6$□^{-3}$
Weight =
268.1811grams
Weight = 0.268kg
Weight = 0.268*9.81 = 2.62908N

b) For aluminium 6061-1.5%□4 C- 1.5%SiC

The volume of the connecting rod used is 57472.72836□□^{3}. Therefore mass of the connecting rod for respective materials are:

Weight = Volume*
Density Weight =
57472.72836 * 2.7$□^{-3}$
Weight = 155.176367
grams Weight =
0.15517kg
Weight = 0.15517*9.81 = 1.52055N

Therefore there is net difference of 127.145807 grams in the new connecting rod for the same volume, i.e., is 45.035% reduction in weight.

Stiffness of the connecting rod

a) For aluminium 360

Weight of the connecting rod =

268.1811grams = 2.62908N Deformation
= 0.0010324
Stiffness = Weight /
Deformation Stiffness
= 2.62908 / 0.0010324
Stiffness =
2546.5711N/mm

b) For aluminium 6061-1.5%□4 C-1.5%SiC
Weight of the connecting rod = 155.176367
Deformation =
0.0001324 Stiffness =
Weight / Deformation
Stiffness = 1.52055 /
0.00010324 Stiffness =
14728.303N/mm

VII. CONCLUSIONS

1. The Weight can be reduced by changing the material of the current Al360 connecting rod to hybrid al6061-1.5%□4 c- 1.5% SiC.
2. The optimized connecting rod is 45.035% lighter than the current Al360 connecting rod.
3. The new optimized connecting rod is comparatively much stiffer than the Al360.

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