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DESIGN AND ANALYSIS OF CONNECTING ROD BY USING FEA AND MATERIAL SUBSTITUTION

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ABSTRACT

The objective of the present work is the static and Fatigue analysis of a connecting rod made of Alloy Steel (40Ni1Cr1Mo15) and Aluminum Alloy. Nowadays Steel and aluminum materials are most commonly used to design the connecting rod. In this project the material (structural steel) of connecting rod is replaced with developed Alloy Steel for connecting rod of specification of AVENGER 150. The model of connecting rod is created in CATIA V5 R18 and imported in ANSYS 15 workbench for Static and Fatigue analysis. After analysis a comparison is made between an existing steel connecting rod and new material connecting rod viz., Alloy Steel (40Ni1Cr1Mo15) and Aluminum Alloy in terms of Von misses stress, equivalent strain and total deformation, Fatigue life, Safety factor.

The overall project will be 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 in static analysis as well as fatigue life and fatigue safety factor in an Alloy Steel connecting rod is done with the connecting rod made of steel from the results obtained.

Keywords –ANSYS15, Workbench, Alloy Steel, Aluminum Alloy, CATIA V5 R18, Connecting rod, Finite Element analysis, Materials, von misses stress.

I. INTRODUCTION

Connecting rod is a high volume production from automobile and a major 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, automotive should be lighter and lighter, should consume less fuel and at the same time they should provide comfort and safety to passengers, that unfortunately leads to increase in weight of the vehicle. This tendency in vehicle construction led the invention and implementation of quite new materials which are light and meet design requirements.

There are different types of materials and production methods used in the creation of connecting rods. The most common types of material for connecting rods are steel and aluminum. The most common types of manufacturing processes are casting, forging and powdered metallurgy.

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.

Fig.1.1-connecting rod

From the literature review, for automotive application especially connecting rods are made by many materials. The Alloy Steel and Aluminum alloy of light metals opens up the possibility of application of these materials in areas where weight reduction and good strength has first priority. Increase in yield strength and tensile strength at room temperature and above while maintaining the minimum ductility or rather toughness, increase in creep resistance at higher temperatures compared to that of conventional alloys, increase in fatigue strength, especially at higher temperatures, improvement of thermal shock resistance, improvement of corrosion resistance, increasing Young's modulus, reduction of thermal elongation etc.

1.1 Problem Statement

In this project he material (C45) of connecting rod replaced with developed Alloy Steel and Aluminum alloy. The model of connecting rod was created in CATIAV5 and imported in ANSYS 15 workbench for static analysis and Fatigue analysis. After analysis the comparison is made between an existing steel connecting rod and an aluminum alloy connecting rod viz., Alloy Steel (40ni1cr1mo15) and Aluminum alloy in terms of Vonmise's stress, equivalent strain, total deformation and life and safety factor.

1.2 Goal and Objective

The objective of the present work is the static and fatigue analyses of a connecting rod made of Alloy Steel (40Ni1Cr1Mo15) and Aluminum Alloy to compare the stress distribution, deformation and fatigue life and safety factor with structural steel. This work checks whether a steel connecting rod can be replaced with a developed Alloy Steel connecting rod.

1.3 Scope of work

Optimization of weight can be done by using Alloy Steel (40Ni1Cr1Mo15) and Aluminum Alloy and results can be obtained for the weight reduction, stiffness in comparison with Carbon Steel and some other Alloy Steel and Aluminum alloy which has been recently used for analysis by different authors for their research work and these lighter weight connecting rods can be checked with their suitability to perform under the actual working conditions in various engines.

II. DESIGN OF CONNECTING ROD

2.1Material properties

Table 2.1.1 Material Properties

Material Properties	C45	Alloy Steel	Aluminum Alloy
Young's Modulus(MPa)	$2.05*10^5$	$2.05*10^5$	$70*10^3$
Poisson's Ratio	0.3	0.29	0.33
Density (Kg/m^3)	7850	7850	2670
Compressive Yield strength (MPa)	500-650	770-900	360

2.2 Pressure calculation:

Consider a 149.01cc engine of **AVENGER 150**

Engine type; Single cylinder oil cooled 4-stroke, spark ignition engine

Bore × Stroke (mm) = 58mm×56.4mm

Displacement = 149.01CC

Maximum Power = 14.3 bhp at 9000rpm

Maximum Torque = 12.5Nm at 6500rpm

Compression Ratio = 9.5/1

Density of petrol at 288.855 K - 737.22*10-9 kg/mm^3

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

$R_{specific}$ = Specific gas constant, T = Temperature

But, mass = density * volume

m = $737.22 * 10^{-9} * \frac{\pi}{4} * d^2 * l$

m= $737.22 * 10^{-9} * \frac{\pi}{4} * 58^2 * 56.4$

m = 0.1098 kg

We have,

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PV=m.Rspecific.T

Where, P = Pressure

V = Volume

m = Mass

$R_{specific}$ = Specific gas constant

T = Temperature

$R_{specific} = R/M$

$R_{specific} = 8.3143/0.114228$

$R_{specific} = 72.78$

$P = m.\ R_{specific}.\ T/V$

$$P = 0.1098 * 72.786 * \frac{288.85}{\frac{\pi * 58^2 * 56.4}{4} * 10^{-3}}$$

P = 15.49 MPa

P ~ 16 MPA.

2.3 Design calculation of connecting rod:

In general,

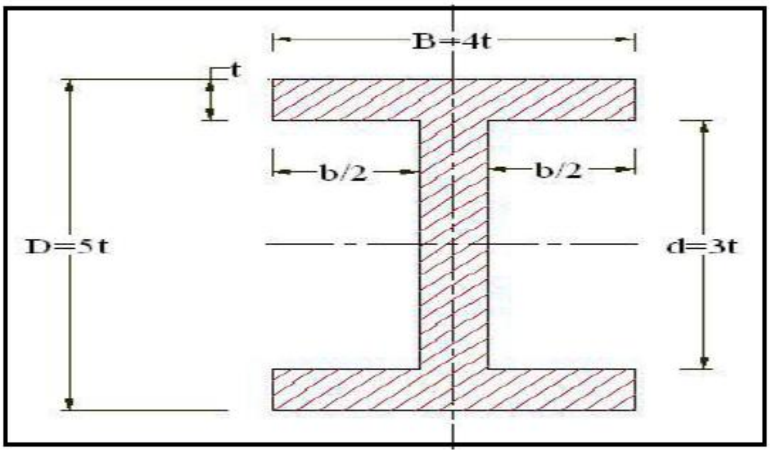

Fig 2. 3.1: Standard Dimensions of I Section

From standards,

i) Thickness of flange and web of the section = t

ii) Width of the section B = 4t

iii) Height of the section H = 5t

iv) Area of the section A = $11t^2$

v) Moment of inertia about x axis $I_{xx} = 34.91t^4$

vi) Moment of inertia about y axis $I_{yy} = 10.91t^4$

Radius of gyration of the section about xx axis is

$A * (K_{xx})^2 = I_{xx}$

$11t^2*(K_{xx})^2 = 34.91t^4$

$K_{xx} = 1.78t$

Therefore $I_{xx}/I_{yy} = 3.2$

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

L = 112.8 mm

Maximum Gas Force=$\frac{\pi}{4} * 58^2 * 15.49$ =40925.81 N

Buckling Load

W_B =Maximum Gas Force * F.O.S.

Consider, F.O.S. = 4

W_B = 40925.81*4

W_B = 163703.24 N

$$W_B = \frac{\sigma_c * A}{1+a\left(\frac{L}{K_{XX}}\right)^2}$$

Where,

σ_c=Compressive Yield Strength=650MPA

$K_{XX} = \frac{I_{XX}}{A}$= 1.78t

a=$\frac{\sigma_c}{\pi^2 * E} = \frac{650}{\pi^2 * 2.05 * 10^5}$

=0.000178

By Substituting The Values Of σ_c, K_{XX}, A, a, L In Eq we get,

$$W_B = \frac{\sigma_c * A}{1+a\left(\frac{L}{K_{XX}}\right)^2}$$

$$= \frac{650 * 11t^2}{1+0.000178\left(\frac{112.8}{1.78t}\right)^2}$$

t=4.85mm≅4.9mm

Width of Section, B= 4t = 19.6mm

Height of Section, H=5t = 24.5mm

Cross section Area, A=$11t^2$ =264.11mm^2

Height of Big End, H_2= (1.1 to 1.25) H =26.95mm≅27mm

Height of Small End, H_1= (0.75to 0.9) H =18.38mm≅18.4mm

Stroke Length, l =56.4mm

Diameter of Piston (D) =58mm

P_{gas}=15.49 N/mm^2

Radius of crank (r) =$\frac{stroke\ length}{2}$ =28.2 mm

Max force on the piston due to pressure

$F_1 = \frac{\pi}{4} * 58^2 * 15.49$

F_1 =40925.81 N

Max Angular Speed,

$W_{max} = \frac{2\pi * N}{60}$

W_{max} =942.478 rad/sec

Ratio of length of connecting rod to radius of crank

N= $\frac{l}{r} = \frac{112.8}{28.2} = 4$

Max Inertia Force of Reciprocating parts,

$F_{im} = m_r \times W_{max}{}^2 \times r\,(cos\theta + \frac{\cos 2\theta}{n})$

$= 0.1098 \times 942.478^2 \times 28.2\,(1 + \frac{1}{4})$

F_{im} =3437.9844 N

Inner Dia. of Small End,

$$d_1 = \frac{F_g}{P_{b1} * l_1}$$

$d_1 = 36.45mm$

Where,

Design bearing Pressure for Small End P_{b1} =12.5 to 15.4 N/mm^2

Length of the piston pin $(l_1) = (1.5 to\ 2)d_1$

Outer Dia. of Small End,

$d_2 = d_1 + 2t_b + 2t_m$

$d_2 = 50.45mm$

Where,

Thickness of Bush $t_p = 2\ to\ 5\ mm$

Marginal thickness $t_m = 5\ to\ 15mm$

Inner Dia. of Big End,

$$d_2 = \frac{F_g}{P_{b2} * l_2}$$

$$d_2 = \frac{40925.8}{12.6 * 1.25d_2}$$

$d_2 = 50.97mm$

Where,

Design Bearing Pressure for Big End P_{b2} =10.8 to 12.6 Nmm^2

Length of Crank Pin, l_2 = (1 to 1.25)d_2

Root Diameter of Bolt= $\left(\frac{2*F_{im}}{\pi*s_t}\right)^{\frac{1}{2}}$

$$= \left(\frac{2*3437.98}{\pi*56.4}\right)^{\frac{1}{2}} = 2.495 \text{ mm}$$

Outer Diameter of the big end= $d_2+2t_b+2d_b+2t_m$

=50.97+2*2+2*2.994+2*5

= 70.958 mm

Table 2.1.1 specification of connecting rod

Sr.No	Parameters (mm)	C45	Alloy steel	Al-alloy
1	Thickness of connecting rod(t)	4.90	4.265	6.582
2	Width of section(B=4t)	19.60	17.06	26.328
3	Height of the section(H=5t)	24.50	21.325	32.91
4	Height of the Big end(1.1 to 1.25)H	27.00	23.4575	36.201
5	Height of the Small end(0.75 to 0.9)H	18.38	16.00	24.68
6	Inner Dia. of Small End	36.46	36.46	36.46
7	Outer Dia. of Small End	50.46	50.46	50.46
8	Inner Dia. of Big End	50.97	50.97	50.97
9	Outer Dia. of Big End	70.96	70.96	70.96

III. MODELING OF THE CONNECTING ROD USING CATIA V5 R18

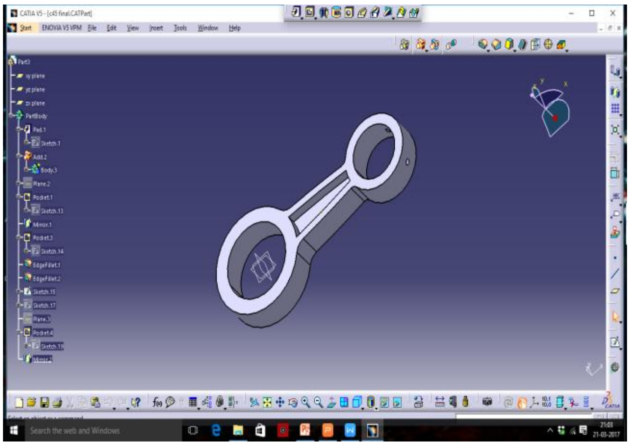

Fig.3.1. Model of C45

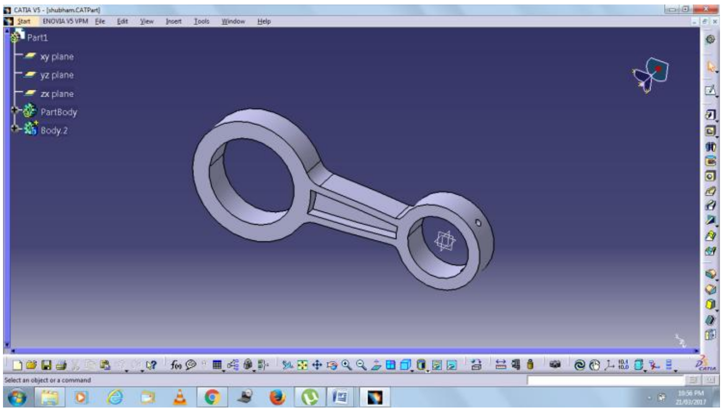

Fig.3.2Model of alloy steel

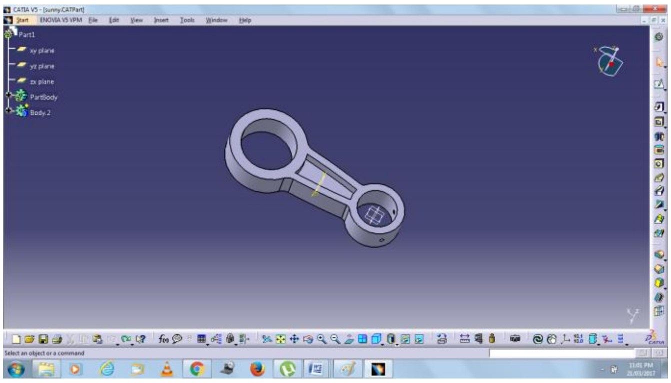

Fig.3.3 Model of aluminum alloy

IV. FINITE ELEMENT ANALYSIS USING ANSYS

For the analysis of the connecting rod we have designed our model in CATIA V5 R18 and then save it as IGES format for exporting the part into ANSYS 15Workbench environment.

4.1 Meshing

CATIA and ANSYS workbench software are used for the Finite Element Analysis of the connecting rod. At first the connecting rod is designed in the CATIA software and then the file is saved as IGES format and imported in the ANSYS workbench software.

The reason for choosing this huge number of element was to make our part very complex which enables us to gain more authentic results based on the high technique of fatigue life calculation.

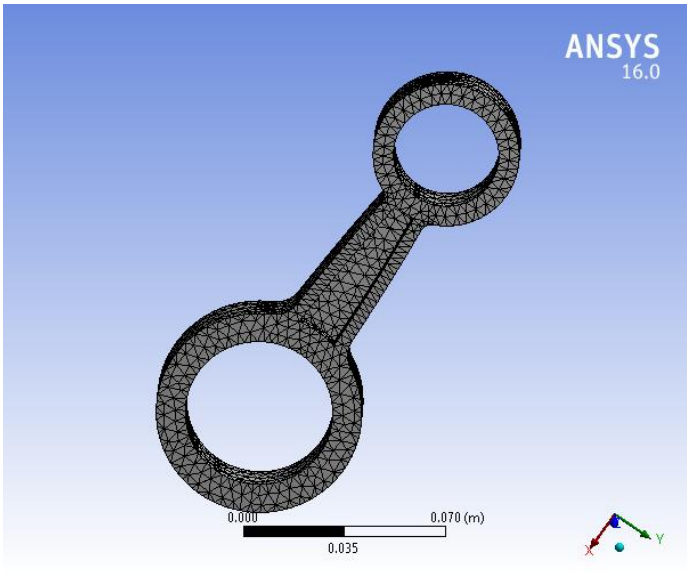

Fig.4.1.1 meshing of model

4.2 Loading conditions and constrains.

We are considering that the loading condition is static. Here one case is analyzed where the force is acting on the big end and the other end i.e. small end remains fixed. For all practical purpose, the force acting on the connecting rod is taken to be equal to the maximum force which is acting on the piston due to the pressure exerted by the gas (16 MPa)

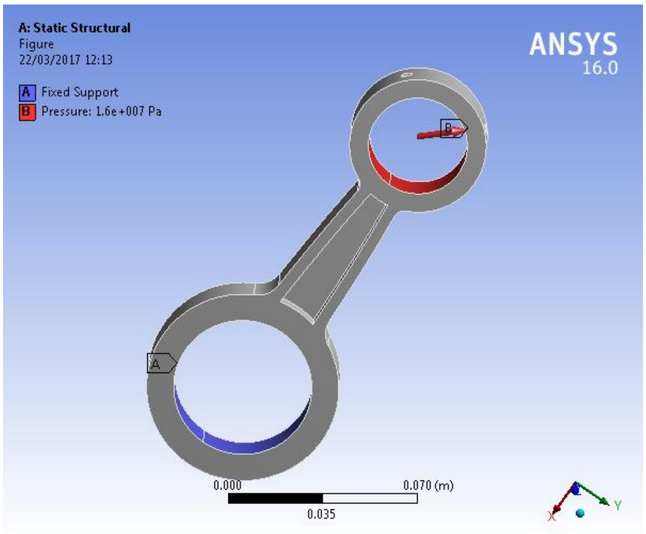

Fig.4.2.1 loading conditions and constrains.

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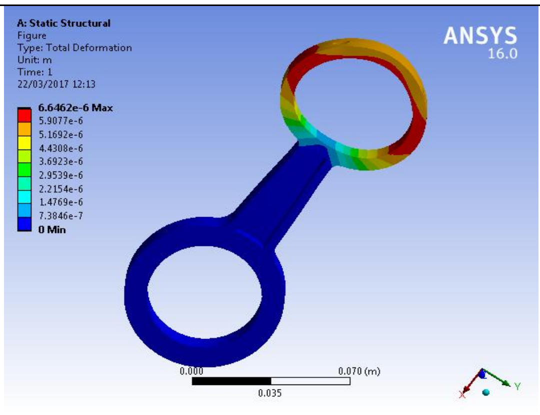
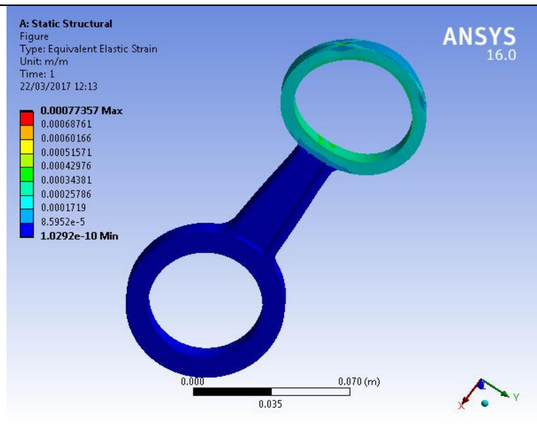
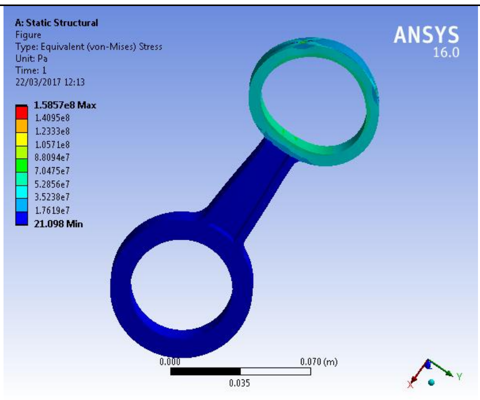
4.3 Analysis of connecting rod



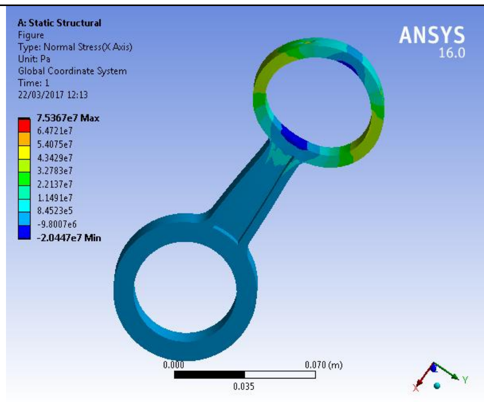
Total Deformation



Equivalent elastic strain

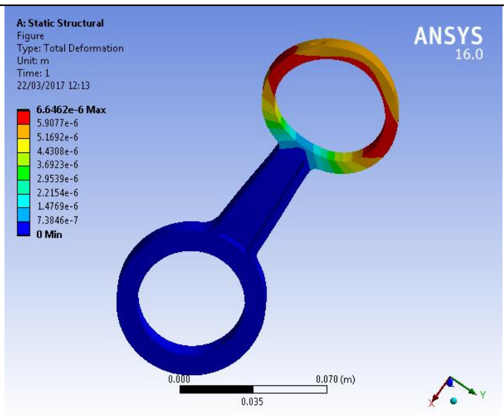


Equivalent (von-mises) Stress

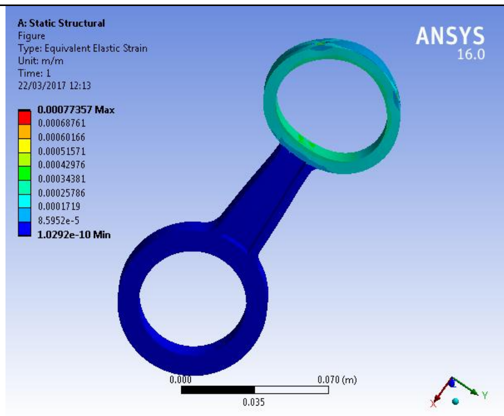


Normal Stress

Fig.4.3.1 Analysis of C45 material



Total Deformation



Equivalent elastic strain

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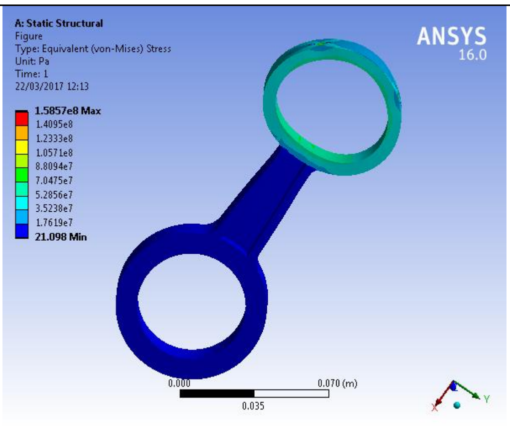
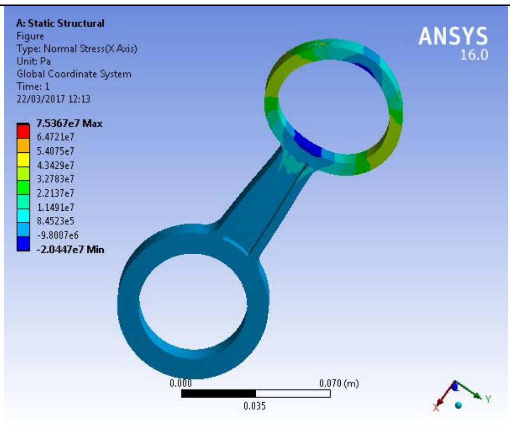
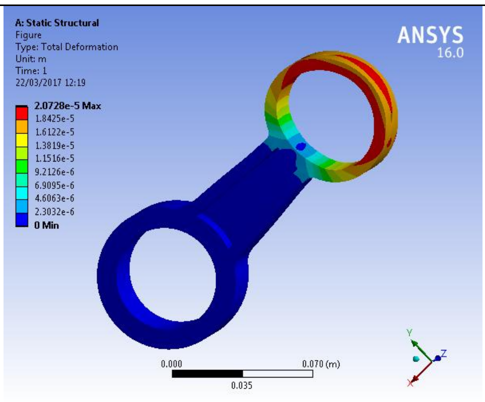


Equivalent (von-mises) Stress

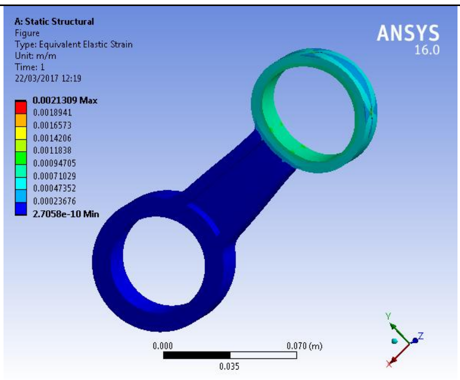


Normal Stress

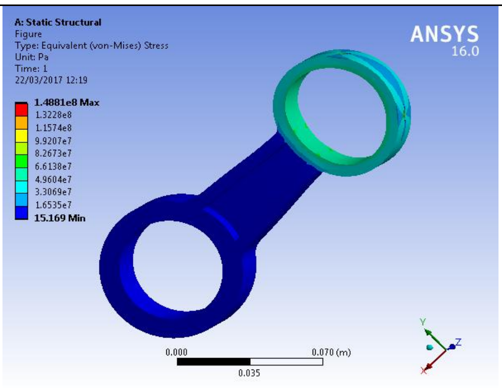
Fig4.3.2 Analysis of Alloy steel



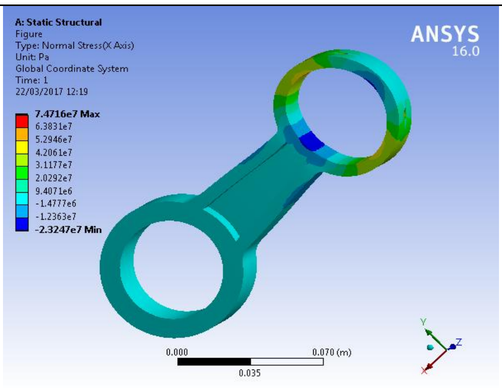
Total Deformation



Equivalent elastic strain



Equivalent (von-mises) Stress



Normal Stress

Fig.4.3.3 Analysis of aluminum alloy

V. RESULTS

5.1 Bending (whipping) stress calculation

For Carbon Steel (C45)

M_1=11t^2*ρ=11*(4.9*10^{-3})*7850 = 2.0732kg/m^2

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$M_{max} = \frac{M_1 * W^2 * r * l}{9 * 1.732} = \frac{2.0732 * 942.478^2 * 28.2 * 10^{-3} * 112.8}{9 * \sqrt{3}}$ = 375.79*10^3 Nm

M_{max}=σ_b*z

Z= section modulus = $\frac{I_{xx}}{y}$ =$\frac{419 * t^4}{12}$*$\frac{2}{5t}$ =13.97t^3

Z= 13.97*4.9^3 Z=1643.55

σ_b=$\frac{M_{max}}{z}$

σ_b=$\frac{375.79 * 10^3}{1643.55}$ σ_b=228.70N/mm^2

5.2 Calculation for factor of safety, weight, stiffness, life for connecting rod

5.2.1 Safety Factor for Steel C45

σ_{max} = 154.52Mpaσ_{min} = 1.7188*10^{-5}

σ_m = $\frac{\sigma_{max} + \sigma_{min}}{2}$=77.26Mpa

σ_y = 650 Mpa

σ_v= $\frac{\sigma_{max} - \sigma_{min}}{2}$= 77.259Mpa

σ_e = 0.5×650=325

$\frac{1}{fs}$ =$\frac{\sigma_m}{\sigma_y}$ + $\frac{\sigma_v}{\sigma_e}$ =0.3565

fs = 2.80

Factor of safety [F.S] = 2.80

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

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

Volume = Area x length=264.11* 112.8 =29791.608 mm^3

Deformation = 6.67*10^{-3} mm

Weight of forged steel = volume ×density

= 29791.608*7.85 *10^{-6}

= 0.2338 kg = 2.29 N

Stiffness = $\frac{\text{weight}}{\text{deformation}}$= $\frac{2.29}{6.67 * 10-3}$=343.29 kg/mm

Fatigue calculation of life For Carbon Steel

Result for fatigue of connecting rod:

N=1000$(\frac{sf}{0.9\sigma_u})^{\frac{3}{log}}(\frac{\sigma_e'}{0.9\sigma_u})$

Where,

N = No. of cycles

σ_e = Endurance Limit

σ_u = Ultimate Tensile Stress

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$\sigma_e{}'$ = 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

$\sigma_e{}' = \sigma_e * k_a * k_{sr} * k_{sz}$

$sf = \frac{f.s.\sigma_v}{(1-f.s.\sigma_m)}$

σ_u=610Mpa

$\sigma_e{}' = \sigma_e * k_a * k_{sr} * k_{sz}$

= 325×0.8×1.2×1 = 312Mpa

sf=$\frac{f.s.\sigma_v}{\left(1-f.s.\frac{\sigma_m}{\sigma_u}\right)} = \frac{2.80*77.259}{\left(1-2.80*\frac{77.25}{610}\right)}$= 335.19MPa`

N=1000$\left(\frac{sf}{0.9\sigma_u}\right)^{\frac{3}{\log}}\left(\frac{\sigma_e{}'}{0.9\sigma_u}\right)$

= 4.16 x 10^5cycles

Table5.1Results

Parameter	C45	Alloy steel	Aluminum Alloy
Mass m_1	2.0732kg/m^2	1.57 kg/m^2	1.2723 kg/m^2
BENDING (WHIPPING) STRESS (σ_b)	228.70N/mm^2	262.63N/mm^2	57.83 N/mm^2
Factor of safety [F.S]	2.8	3.783	1.612
Weight	0.2338 kg	0.1777kg	0.14352 kg
Stiffness	343.29 kg/mm	261.51 kg/mm	67.54 kg/mm
Result for fatigue of connecting rod (No. of cycles)	4.16 x 10^5cycles	2.41 x 10^5cycles	1.3 x 10^6cycles
Maximum von-mises stress	154.52	158.057	148.81
Deformation (mm)	$6.66 * 10^{-3}$	$6.64 * 10^{-3}$	$2.0728 * 10^{-2}$

6. CONCLUSION

By checking and comparing the results of materials in above tables, the finalized results are shown below.It explains about the various stresses to be considered while designing the connecting rod and different materials used and comparing the result of all material.

Also most of the researchers used the Catia software for the modeling and ANSYS software for analysis. These can be used for designing the any connecting rod in Automobile. Connecting rod can be designed for weight and cost reduction also to increase the life time

Aluminum alloy are lighter and fatigue failure life also more than both materials i.e. C45 and Alloy Steel.

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