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Design, Analysis & Optimization of V6 Engine Crankshaft Assembly

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ABSTRACT: In automobile industry most, important unit is internal combustion engine. The connecting rod and crank shaft are the main component. A connecting rod is a shaft which connects a piston to crank is a mechanical part able to perform a conversion between reciprocating motion and rotational motion. Crankshaft is to translate the linear reciprocating motion of a pistons into the rotational motion required by the automobile. optimization analysis of connecting rod and crankshaft is to study was to evaluate and compare the fatigue performance for automotive connecting rod and crankshafts. The present aim of the project is to study the effect of different material used for the piston, connecting rod and crankshaft assembly for an v6 petrol engine. In the initial design of v6 engine the working cycle of the crankshaft is 36,30,000 cycles and the heat flux of piston is 2.99 W/mm which is optimized by using different parameters like material, size and shape of the major parts using the analytical calculations. The validation of designed are done by FEA. These parts are modelled and assembled SOLIDWORKS software. The main objective of the project is to increase the working cycle of the crankshaft, reduce the heat flux on the piston and reduce the weight of the entire assembly. The paper comes up with the overall design of the crankshaft connecting rod mechanism and piston performed by considering various structural force analysis. Those results are compared with FEA results for conclusion.

Keywords: Solidworks, Piston, Crankshaft, Connecting rod, Thermal Flux, V6 Engine.

1. INTRODUCTION:

The internal combustion (IC) engine has been the dominant prime mover in our society since its invention in the last quarter of the 19th century Its purpose is to generate mechanical power from the chemical energy contained in the fuel and released through combustion of the fuel inside the engine. It is this specific point, that fuel is burned inside the work-producing part of the engine, that gives IC engines their name and distinguishes them from other types such as external combustion engines. The first commercially successful internal combustion engine was created by Étienne Lenoir around 1859[1] and the first modern internal combustion engine was created in 1876 by Nikolaus Otto (see Otto engine).There are two major cycles used in internal combustion engines: Otto and diesel. Engine working on Otto cycle is also called as spark ignition (S.I.) engine, since a spark is needed to ignite the fuel air mixture. The diesel cycle engine is also called as a compression cycle (CI) engine, since the fuel will auto ignite, when injected into the combustion chamber. The Otto and diesel cycles either operate on either a four or two stroke cycle.

Following are the types of IC engines-

1. In line
2. Horizontally opposed
3. Radial
4. V

V6 ENGINE :-

A V engine, or Vee engine is a common configuration for an internal combustion engine. The cylinders and pistons are aligned, in two separate planes or 'banks', so that they appear to be in a "V" when viewed along the axis of the crankshaft. A V6 engine is a V engine with six cylinders mounted on the crankshaft in two banks of three cylinders, usually set at a 60 or 90 degree angle to each other. The V6 is one of the most compact engine configurations, usually ranging from 2.0 L to 4.3 L

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displacement, and it is shorter than the inline 4. Because of its short length, the V6 fits well in the widely used transverse engine front-wheel drive layout.

The most popular vehicles which used v6 engines are Chevrolet Impala, the Dodge Charger, and the Hyundai Santa Fe SUV.

Main components of the engine

CYLINDER:

A cylinder is the central working part of a reciprocating engine or pump, the space in which a piston travels. Multiple cylinders are commonly arranged side by side in a bank, or engine block, which is typically cast from aluminum or cast iron before receiving precision machine work. A cylinder's displacement, or swept volume, can be calculated by multiplying its cross-sectional area by the distance of piston travels within the cylinder A piston is seated inside each cylinder by several metal piston rings [1] fitted around its outside surface in machined grooves; typically two for compressional sealing and one to seal the oil.

The cylinder block is an integrated structure comprising the cylinders of a reciprocating and often some or all of their associated surrounding structures coolant passages, intake and exhaust passages and ports, and crankcase.

PISTON:

A piston is a component of reciprocating engines, It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. Pistons are cast from aluminum alloys. For better strength and fatigue life, some racing pistons may be forged instead. Gas sealing is achieved by the use of piston rings. These are a number of narrow iron rings, fitted loosely into grooves in the piston, just below the crown. Two types of ring are used: the upper rings have solid faces and provide gas sealing; lower rings have narrow edges and a U-shaped profile, to act as oil scrapers.

CONNECTING ROD:

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.[1] 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.

CRANKSHAFT:

The crankshaft, sometimes casually called the crank, is the part of an engine which changes the up and down motion of the pistons into rotation. To convert the motion, the crankshaft has one or more offset shafts. The pistons are connected to the crankshaft by these shafts. When the piston moves up and down, it pushes the offset shaft. This in turn rotates the crankshaft. The pistons cause a pulsing affect in the rotation. A crankshaft usually connects to a flywheel. The flywheel smooth's out the rotation. Sometimes there is a torsion or vibration damper on the other end of the crankshaft. This helps reduce vibrations of the crankshaft. Large engines usually have several cylinders. This helps to reduce pulsations from individual firing strokes. For some engines it is necessary to provide counterweights. The counterweight is used to offset the piston and improve balance. While counterweights add a lot of weight to the crankshaft, it provides a smoother running engine. This allows higher RPMs to be reached and more power produced.

2. LITERATURE REVIEW:

Solanki et al. presented a literature review on crankshaft design ang optimization. The materials, manufacturing process, failure analysis, design consideration etc. were reviewed. The design of the crankshaft considers the dynamic loading and the optimization can lead to a shaft diameter satisfying the requirements of the automobile specifications with cost and size effectiveness[1].

Leela Krishna Vegi, Venu Gopal Vegi states in this thesis describes designing and Analysis of connecting rod. Currently existing connecting rod is manufactured by using Carbon steel. In this drawing is drafted from the calculations. A parametric model of Connecting rod is modelled using CATIA V5 R19 software and to that model, analysis is carried out by using ANSYS 13.0

Software. Finite element analysis of connecting rod is done by considering the materials, viz. Forged steel. 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[2].

S. Satishkumar states in this thesis that two materials such as aluminium and cast iron are compared using fatigue test and thermo mechanical test. Outcomes are Equivalent stress is same for both the materials. The weight is less of aluminium compared to cast iron. Life of aluminium is greater than cast-iron. Also no. of cycles for aluminium (8500 x10 3) is more than the existing CI (6255 x 103)[3].

S. Srikanth Reddy, Dr. B. Sudheer Prem Kumar states in this thesis that the main emphasis is placed on the study of thermal behaviour of functionally graded coatings obtained by means of using ANSYS. The analysis is carried out to reduce the stress concentration on the upper end of the piston. By changing the dimension and applying coating of Aluminum and Zirconium alloy on aluminum piston surface, the maximum stress has changed from 85 Mpa. to 55 Mpa. And biggest deformation has been reduced from 0.051762 mm to 0.025884 mm[4].

Pravardhan S. Shenoy states in this thesis that load analysis was performed which comprised of the crank radius, piston diameter, the piston assembly mass, and the pressure-crank angle Diagram, using analytical techniques and computer-based mechanism simulation tools Optimization was performed to reduce weight and manufacturing cost. Cost was Reduced by changing the material of the current forged steel connecting rod to crack able forged steel (C-70)[5].

R.j Deshbhratar states in this thesis that the maximum Deformation appears at the centre of the crankshaft surface. The crankshaft deformation was mainly bending deformation under low frequency. The result provides a theoretical basis to optimize the design and fatigue life calculation[6].

3. METHODOLOGY:

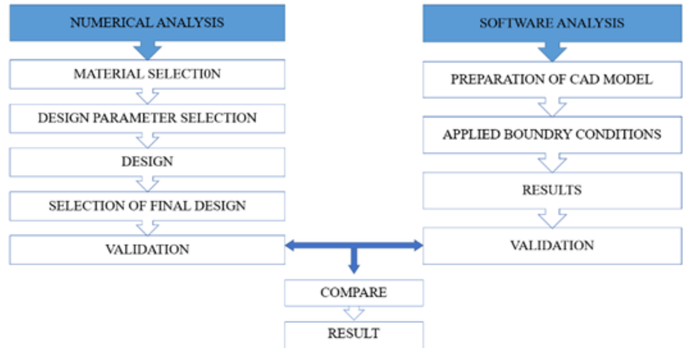


Fig.1: Block diagram

4. NUMERICAL CALCULATIONS:

GIVEN DATA

- Bore x stroke (mm) = 138 x 138 mm
- Displacement – 1670 cm3
- Maximum power = 102KN @5364rpm
- Maximum torque = 178 @3400 rpm
- Compression ratio = 9.35/1
- Density of petrol = 0.00000073722 kg/mm3
- Temperature = 69 °F

CALCULATIONS

1. **Petrol Density** = 737.2 Kg/m3
2. **Temperature** = 6p°F = 20.55°C = 290.55°K
3. **Mass** = ρ * volume = 0.0007372*167
   = 0.1231124 kg
4. **Maximum Gas Pressure**

According to ideal gas equation

PV = mRT

P = mRT/V

P = (0.1231124*8.3143*290.55)/(0.0001670*0.11422)

P = 15.72 MPa

5. **Mean effective pressure**

Pm = (2π*T)/Displacement

Pm = (2*π*178*100)/167

Pm = 6.69 MPa

For 6 cylinders

Pm = 6*6.69

Pm = 40.18 MPa

6. **Indicated Power**

IP=(P*L*A*n*N)/60

IP=(P*L*A*n*N)/60

IP=(40.18*138*π* 〖138〗^2*6*5364)/(60*4*2)

IP = 3703.4 KW

7. Brake Power

BP = (2*π*N*T)/60

BP = (2*π*5364*178*6)/60

BP = 599.35 KW

8. Mechanical Efficiency

= BP/IP= 3700/599.351=6.68%

DESIGN OF PISTON :-

- **Material:-** Alloy Steel
- Tc =260o C to 290o C
- Te =185o C to 215o C

Calculations:-

1. Thickness of Piston Head (th):-

=D√((3*Pmax)/(16*permissible tensile stress))

=138√((3*15.72)/(16*730))

=10.12≈11mm

2. Thickness of Piston Rings:-

a) Radial thickness of piston ring(t1):-

b=D√((3*Pw)/(allowable tensile stress))

b =138 √((3*0.035)/100)

b =2.57 mm

b) Axial thickness of piston ring (t2):-

t2= D/(10*n)=138/(10*3)

=4.6 mm

c) Width of top land (b1):-

=1.2* th=1.2*10.12= 12.1529 mm

d) Distance between two consecutive rings (b2):-

=1*t2 =4.6 mm

e) Gap between free ends (g):-

=4*b =4*2.57 =10.28 mm

3. Piston Barrel:-

a) Thickness of piston barrel at the top end (t3):-

=0.03*D+q+4.5

=0.03*138+(t1+0.4) +4.5

=0.03*138+(2.57+0.4) +4.5

=11.616mm

b) Thickness of piston barrel at bottom end (t4):-

=0.35*t3

=0.3*11.616

=3.483 mm

4. Length of Piston Skirt:-

Pb*D*ls=μ*((π*D^2)/4)*Pmax

1.5*138*ls=0.1((π* 〖138〗^2)/4)*15.72

Ls=113.574 mm

5. Length of Piston:-

=Top land + length of ring section + length of piston skirt

=12.159+4.6+113.574

=130.3276 mm

6. Piston pin:-

Pb*l*do*l1=Pmax*(πD^2)/4

23*do*62.1 =15.72*π/4*1382

do=95.1265 mm

di=0.6*do

=0.6*95.1265

di =57.075 mm

7. Force on piston:-

=(π*D^2)/4× Pmax

=14957.122 × 15.72

=235125.9676 N

8. Max Bending Moment(M):-

=(P*D)/8

=(235125.9676*138)/8

=4055.47 Nm

DESIGN CALCULATIONS OF CONNECTING ROD :-

1. Empirical Relations

b=4t

h=5t

A=11t2

kxx =1.78t

2. Cross section of connecting rod

Pc = P/(cosØ)

Pc =(235125.9676)/(cosØ)= (235125.9676)/1 = 235516.49

Pcr =Pc*(fs)

Pcr =235516.49*0.5

Pcr =117758.245

Pcr = (σc*A)/(1+a 〖(l/kxx)〗^2)

Pcr =(330*11t^2)/(1+1.330* 〖10〗^(-4) 〖((2*79.5)/(1.7816*t))〗^2)

Pcr =(330*t^2)/((t^2+1.059)/1)

38420.68 = (330*11t^4)/((t^2+1.059)/1)

384206.8t4-384206.8 = 330*11t4

3630t4 – 384206.8t2 – 406875.02 = 0

t2=(384206.8±√(〖(384206.8)〗^2+4(3630)(406875.02)))/(2*3630)

t2 = (384206.8±3918197.1)/7260 =592.61

t =24.34≈25 mm

H=5*t= 125 mm

B=4*t = 100 mm

A = 11*t*t = 6875 mm2

At small end H1=0.75H to 0.91H

H1=75 mm

At big end H2 = 1.1H to 1.25 H

H2 = 110 mm

3. Buckling load

=Force on piston * FOS

=235099.7382*5

=1175498.691 N

4. Diameter of small end

=√(P_(max*A)/(bearing pressure*2))

=√((15.72*14949.54)/(12*2))

=98.9542 mm

5. Diameter of big end

=length of crankpin * dc

=1.5*√(P_(max*A)/(bearing pressure*1.25))

=1.5*125.193

=187.7895 mm

<u>DESIGN CALCULATION OF CRANKSHAFT</u>:-

1. Force on Crankpin

Fp = π/4 * D2 *P= π/4 * 1382 * 15.72=235099.7382 N

2. Reactions

H1 = H2 =117549.8691 N

3. Distance Between two bearings

=2*D

=2*138 /2

=138 mm

4. Design of crank web

Thickness of Crank web

t = 0.22 * D to 0.32 * D

t = 0.22 *138

t = 30.36 mm

Width of Crank web

w = 1.125 * dc +12.5

w = 1.125 * 125.193 + 12.7

w = 153.54 mm

5. Maximum Bending moment on Crank shaft

Mb = [b_2-l_c/2-t/2]* H1

Mb = [138-187.79/2-30.36/2]* 117549.8691

Mb =3400149.27 Nmm

6. Section Modulus

Z =1/6 * w * t2 =1/6 * 153.54 * 30.362

Z = 23587.40667 mm

7. Bending Stress

σ_b = M/Z

σ_b = (3400149.27)/(23587.40667)

σ_b = 144.15 N/mm2

8. Compressive Stress

σ_c = H1/(w*t) = (117549.8691)/(30.36*153.54) = 25.2169 N/mm2

9. Total Stress

σ_t = σ_c + σ_b= 144.15 + 25.2169

σ_t = 169.368 N/mm2

10. Diameter of Shaft:

=Thickness of crank web/0.6

=30.36*/0.6

=50.6

11. Diameter of Crank pin

=√(Fp/12.6) =√(235099.7382/12.6)=136.597 mm

5. SOFTWARE ANALYSIS:

CAD models of main parts of V6 engine are as follows,

Fig.2: CAD Model of Crankshaft

Fig.3: CAD Model of Connecting Rod

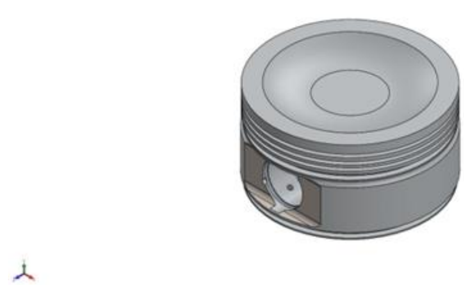


Fig.3: CAD Model of Piston

Finite Element Analysis of main components of V6 engine as follows,

1. **PISTON:**

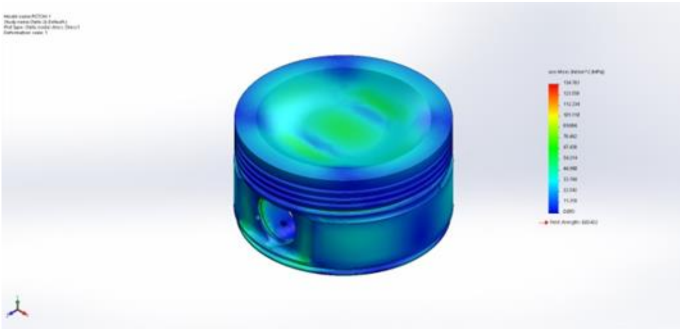


Fig.4: Finite stress Analysis of Piston

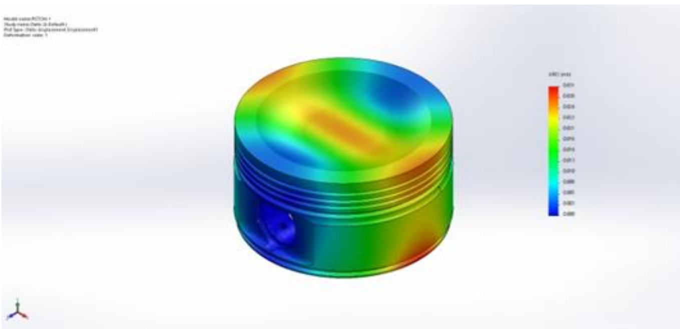


Fig.5: Finite Displacement Analysis of Piston

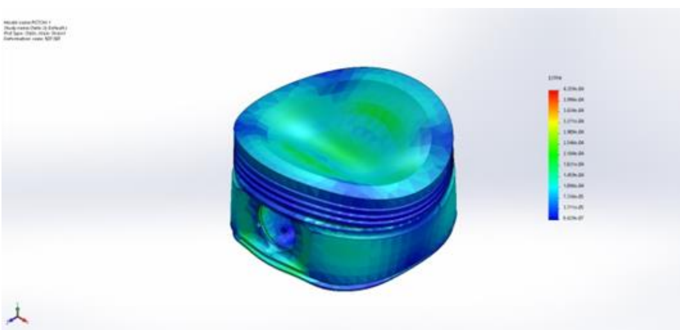


Fig.6: Finite Strain Analysis of Piston

2. **CONNECTING ROD :**

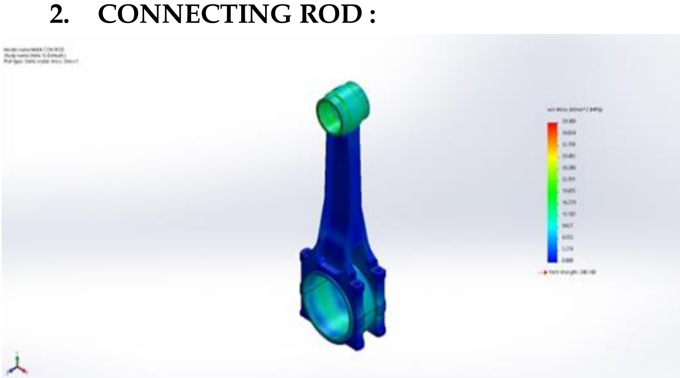


Fig.7: Finite stress Analysis of Connecting Rod

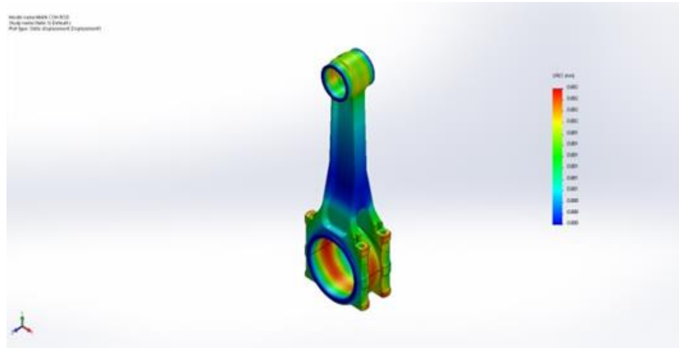


Fig.8: Finite displacement Analysis of Connecting Rod

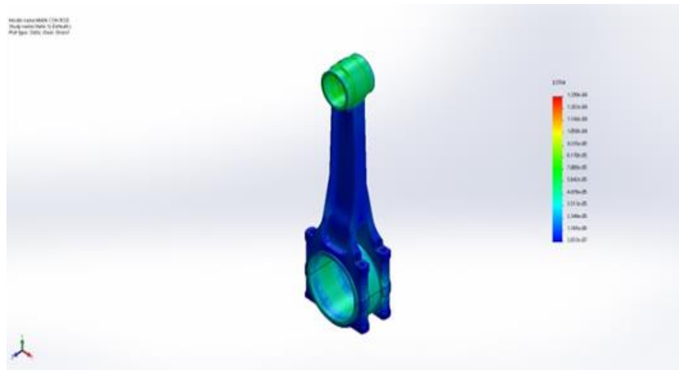


Fig.9: Finite strain Analysis of Connecting Rod

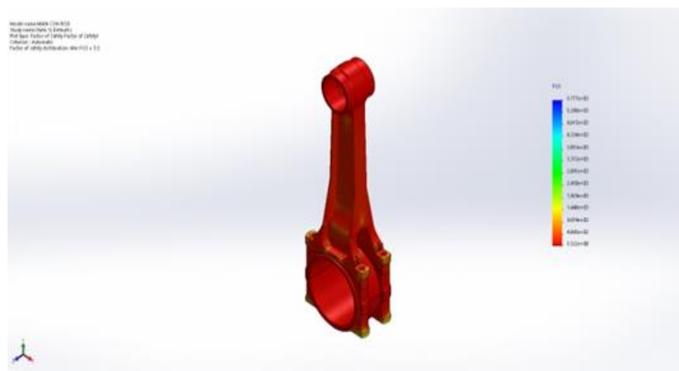


Fig.10: FOS Analysis of Connecting Rod

3. **CRANKSHAFT :**

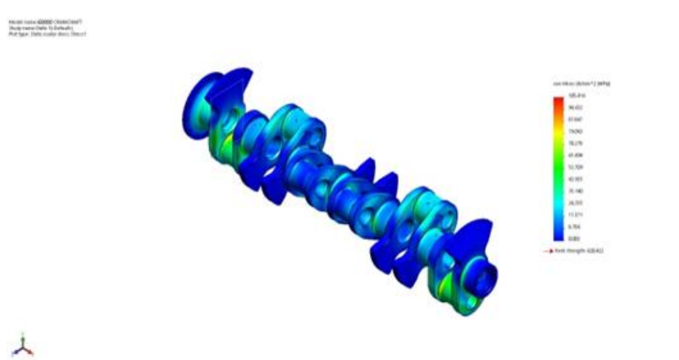


Fig.11: Finite stress Analysis of Crankshaft

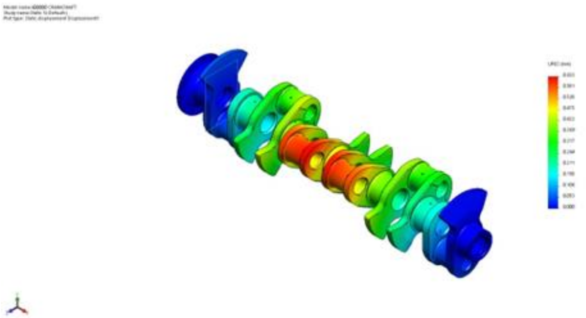


Fig.12: Finite displacement Analysis of Crankshaft

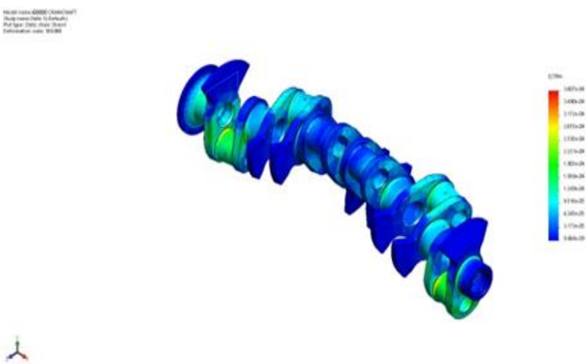


Fig.13: Finite strain Analysis of Crankshaft

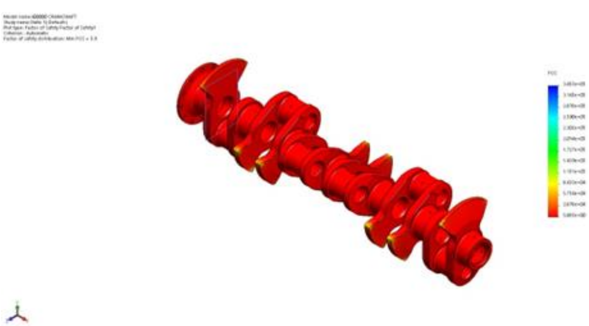


Fig.14: FOS Analysis of Crankshaft

6. RESULTS:

a) Piston:-

Materials	Displacement	Stress	Strain
Grey cast iron	0.197 mm	269.617 (MPa)	2.742e-03
Alloy Steel	0.031 mm	134.783 (MPa)	4.359e-04
7075-T6	0.274 mm	403.902 (MPa)	3.968e-03

b) Connecting rod:-

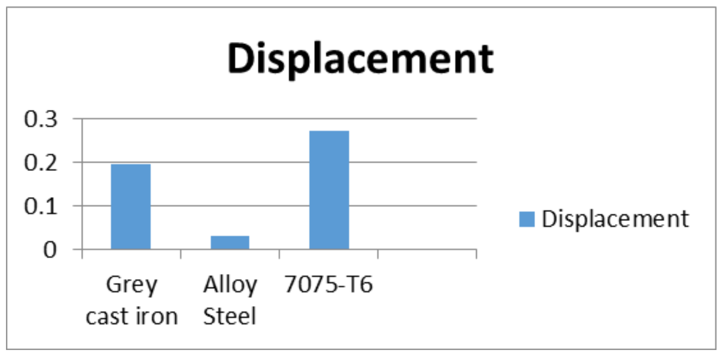
Materials	Displacement	Stress	Strain	FOS
Grey cast Iron	0.010 mm	60.450 (MPa)	6.220e-04	2.4
AISI-316	0.003 mm	48.392 (MPa)	1.706e-04	3.2
Cast carbon steel	0.002 mm	39.309 (MPa)	1.399e-04	5.5

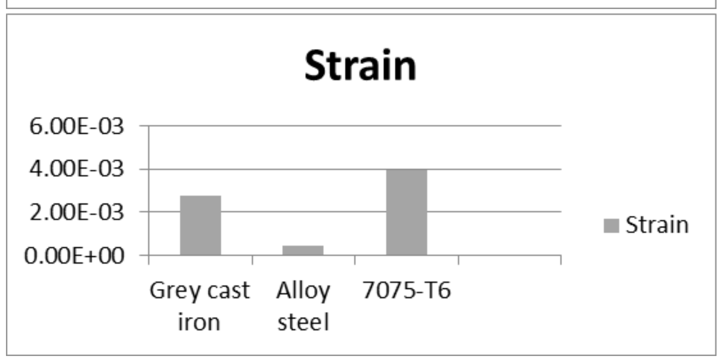
c) Crankshaft :-

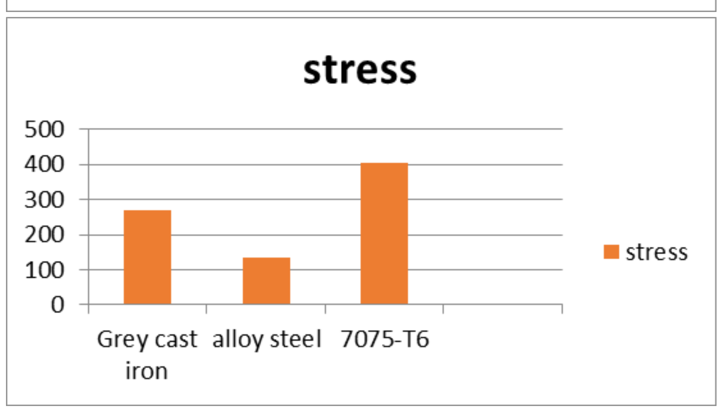
Material	Displacement	Stress	Strain	FOS
Forged Steel	0.633 mm	105.416 (MPa)	3.807e-04	5.9

7. DISCUSSIONS:

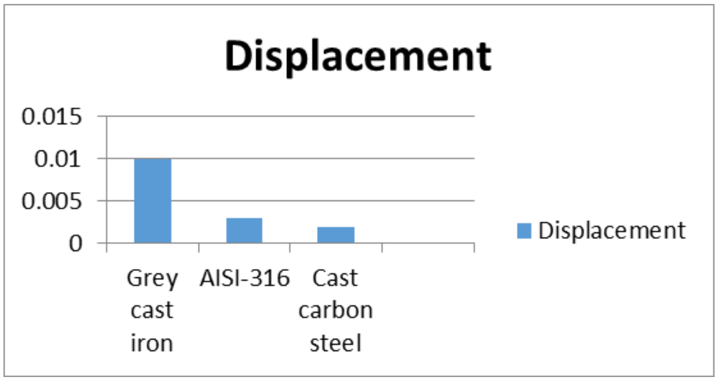
Piston:

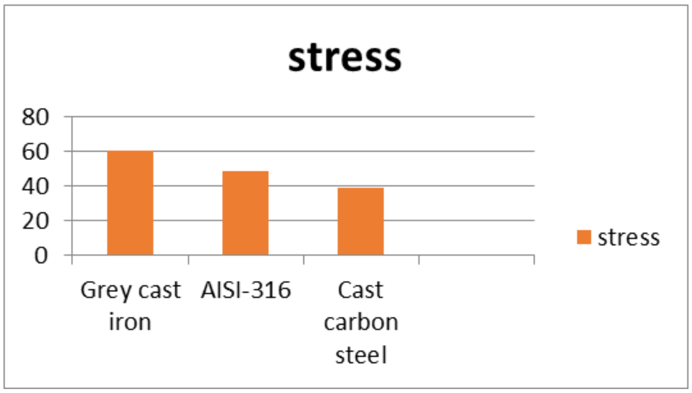


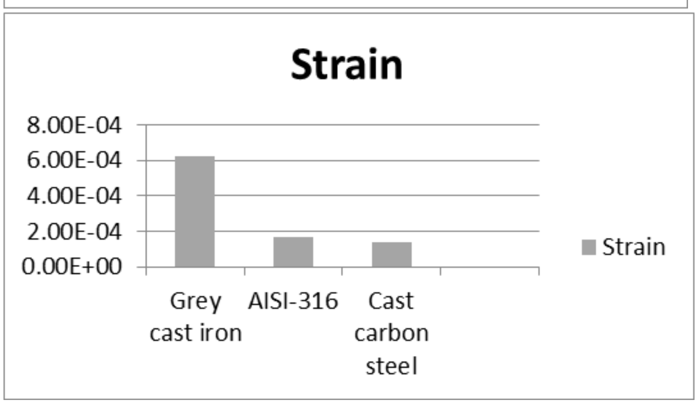


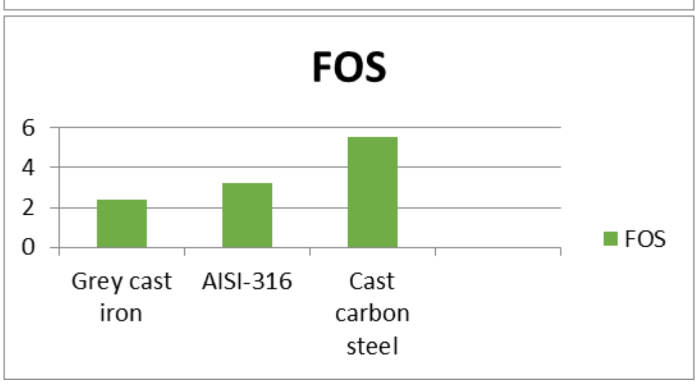


Connecting rod









8. CONCLUSIONS:

After analysis on different material and conditions , we get the final required data

1. **Piston:-**

   Material: Alloy steel

   Max stress: 134.78 Mpa

   Max strain: 0.0004359

   Max Displacement: 0.031 mm

2. **Connecting rod:-**

   Material:-Cast Carbon steel

   Max. stress: 39.309 Mpa

   Max. strain: 0.0001706

   Max .Displacement: 0.002 mm

   Max. FOS : 5.5

3. **Crankshaft :-**

Material : Forged steel

   Max. Stress : 105.42 MPa

   Max Strain : 0.00038

   Max Displacement: 0.633 mm

   Max FOS : 5.9

7. ACKNOWLEDGMENT:

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