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DESIGN AND WEIGHT OPTIMIZATIONOF A CONNECTING ROD

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ABSTRACT

Connecting rod is one of the main key factors in improving the efficiency of internal combustion engines. Recently aluminium alloys are used for manufacturing of connecting rodas the weight of the material is less when compared to the carbon steel. To obtain a safe design, an analysis is carried out by comparing three materials named as aluminium 360, forged steel, and structural steel for a solid 3D model of connecting rod which is developed using CATIA V5 and analysis was carried out by using ANSYS – FEA analysis. This paper mainly highlights to improve the strength and efficiency of the engine by changing the materials and compare the results of three materials used for obtaining the safe design. In this paper, FEA analysis using ANSYS is opted toperform static, buckling and transient analysis, the key Identity factors are to check the variations in stress, strain, deformation, heat flux and weight optimization is also done by changing the geometry of the connecting rod for the fixed boundary conditions to analyse the change in stresses. Analysis is carried out for the three materials and the results obtained proved that, stress values obtained for forged steel is safe when compared with Aluminium alloy and structural steel. The analysis resulted that the forged steel falls under safe limits.

Key words:* *Connecting Rod, FEA, Forged Steel, Aluminium Alloy, Structural steel.

1. INTRODUCTION

Internal Combustion engine consists of cylinder, piston, connecting rod [1], crank and crank shaft. The connecting rod is very important part of an engine which transmit power of piston to crank pin. Connecting rod [2] has two ends one is pin end and other is crank end. Circular section is generally used for low speed engines.

2. 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. A connecting rod[2][3] 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.The schematic diagram of the connecting rod is shown in fig-2.1.

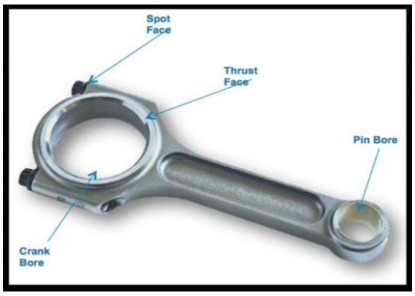

Fig-2 Schematic Diagram of Connecting Rod

2.1 PARAMETERS FOR CONNECTING ROD

Table2.1: Parameters for Connecting Rod

Description	Parameters
Engine type	4-stroke air cooled
Bore x Stroke	57 x 58.6 mm
Displacement	149.5 cc
Maximum Power	13.8 bhp @ 8500rpm
Compression Ratio	9.35: 1
Density of petrol Auto ignition temperature	737.22 kg/m^3 280°C (536°F) = 553K
Mass	Density x Volume = 737.22 x 10 $^{-9}$ X 149.5 = 0.110214 kg
Molecular weight of petrol	= 114.228 g/mole = 0.11423 kg/mole Where,P = Pressure, MPa.V = Volume, m = Mass, kg R specific = Specific gas constant T = Temperature, K
R specific = R/M	R specific = 8.3143 / 0.114228 = 72.76 Nm/kg K
P = mRT / V	P = (0.110214 x 72.757 x 553)/149.5 = 29.67 MPa
Therefore, from the above, calculation of analysis is done for maximum Pressure of 30 MPA and 15 MPA.	

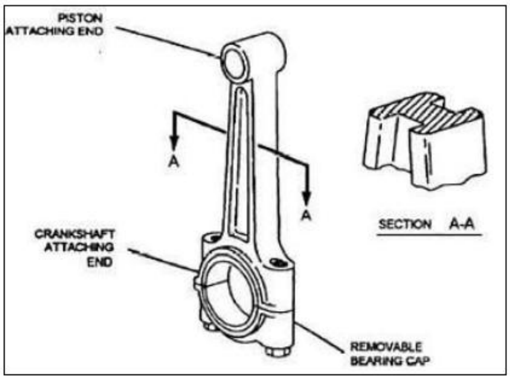

Fig 2.1 - Sectional View of Connecting Rod

2.2 Design Calculations of Connecting rod:

1. **Total Force acting F = FP-FI**

Where, Fp = force acting on the piston, FI= force of inertia

2. $F_P = \pi / 4\ d^2$ **x gas pressure** , $F_I = mw^2r\ (\cos\theta \pm \cos 2\theta n)$, m = mass of the reciprocating parts
w= 1.6 x 9.81 = 15.696 N , r = crank radius, = stroke of piston / 2 , r = 58.6/2= 29.3mm
Also, θ = Crank angle from dead centre , θ = 0 considering connecting rod is at TDC position ,n = length of connecting rod / crank radius ,g = acceleration due to gravity, 9.81m⁄s^2,v = crank velocity m/s ,
w =$2\pi n$ / 60 = 890.1179, V = r * w = 29.3×10^{-3}×890.1179 = 26.08 m/sec On substituting these,
FI = 9285.5481 Thus, **F = FP-FI ,** F = 39473.1543 – 9285.5481 **= 30187.6062 N**

Now, According to Rankine's – Gordon formula,

F =FcA / (1+aL) / kx , Let, A = Cross-section area of connecting rod, L = Length of the connecting rod,fc= Compressive yield stress, F = Buckling load, I_{xx}&I_{yy} = Moment of Inertia of section about the x-x and y – y axis resp. K_{xx}&K_{yy} = Radius of gyration of section about x – x and y – y axis resp.,t = 4.28 mm , Width B = 4 * t = 4×4.28 =17.12 mm , Height H = 5t = 21.40 mm

- **At the small end (H1) = 0.85H** = 0.85×21.40 = 18.19 mm
- **At the big end (H2) = 1.2H**

= 1.2×21.40 = 25.70 mm

- **Design of small end**

Load on piston pin (Fp) = projected area × bearing pressure = dp * lp * Pbp, dp = 51.29mm lp = 76.5mm

Outer diameter of small end = dp + 2tb + 2tm= 33.29 mm

- **Design of big end**

$F_p = d_c l_c P_b$, d_c = 53mm

3. Modelling of Connecting Rod

3.1 Introduction to CATIA

CATIA is a solid modelling tool that unites the 3D parametric features with 2D tools and also addresses every design-to-manufacturing process. Different modules used in CATIA are Sketcher, Part design, Assembly, Generative shape design.

3.1.2 Geometric modelling in CATIA V5

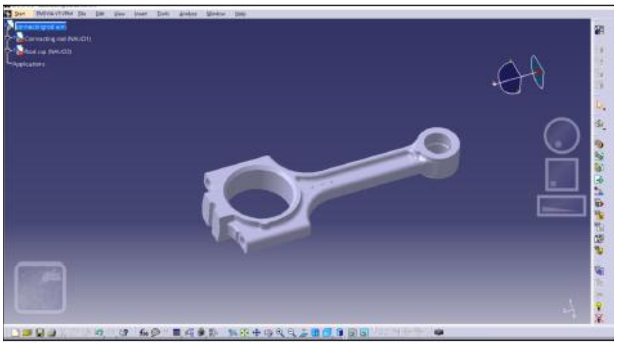

Fig: 3.1: Sketch of Connecting Rod

4. Introduction to FEA:

FEA consists of a computer model of a material or design that is stressed and analysed for specific results. It is used in new product design, and existing product refinement. In case of structural failure, FEA [11] may be used to help determine the design modifications to meet the new condition. There are generally two types of analysis that are used in industry: 2-D, and 3-D modelling. While 2-D modelling. A wide range of objective functions (variables within the system) are available for minimization or maximization, they are: 1. Mass, Volume, Temperature, 2. Strain energy, Stress, Strain, 3. Force, Displacement, Velocity, Acceleration.

In practice, a finite element analysis usually consists of three principal steps.

1) Pre-processing, 2) Analysis ,3) Post-processing

4.1 Analysis of connecting rod - INTRODUCTION TO ANSYS:

ANSYS is the standard FEA teaching tool, it provides a cost-effective way to explore the performance of products or processes in a virtual environment.

4.1.1 Generic Steps to solving any Problem in ANSYS:

To define the problem analytically, basic steps need to follow a) solution domain b) the physical model c) boundary conditions d) physical properties. Solve the problem and present the results. In numerical methods [8], the main difference is an extra step called mesh generation Define Material Properties, Generate Mesh, Apply Loads, and Obtain Solution, finally present the Results.

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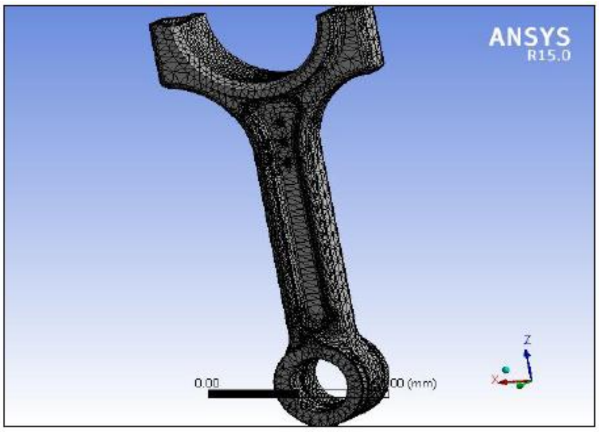


Fig: 4.1 Mesh Generation

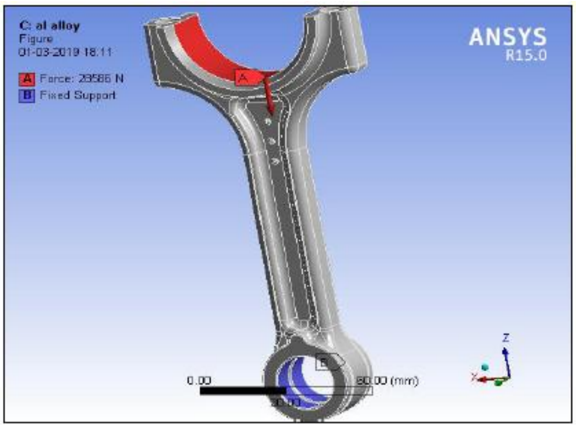


Fig: 4.1.2 Applied load and fixed support

	Statistics
Nodes	117280
Elements	69129

4.2 Specific Capabilities of ANSYS:

- Structural , Static Analysis, Thermal Analysis

4.2.1 Structural: Structural analysis is probably the most common application of the finite element method as it implies bridges and buildings

4.2.2 Static Analysis: It is used to determine displacements, stresses, etc. under static loading conditions.

4.2.3 Thermal Analysis: ANSYS is capable of both steady state and transient analysis of any solid with thermal boundary conditions [3,4]. The last step of a transient thermal analysis; performed after all transient effects have diminished.

ANSYS can be used to determine temperatures [5], thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

- Convection, Radiation Heat flow rates , Heat fluxes (heat flow per unit area) , Heat generation rates (heat flow per unit volume) ,Constant temperature boundaries

Transient calculations are time dependent and ANSYS [9, 10] can both solve distributions as well as create video for time incremental displays of models.

4.3 Properties of materials

4.3.1 Al alloy

Table-4.3 Composition of Al alloy.

Aluminium	Balanced
Copper	6
Magnesium	0.4-0.6
Iron	13
Tin	0.15
Nickel	0.50
Zinc	0.50
Manganese	0.35
Silicon	9.0-10.0

Table–4.3.1Physical and Mechanical properties of Aluminium (Al) alloy

Physical properties of Al alloy		**Mechanical properties of Al alloy**	
Material	Al	Material	Al
Alloy	AL360	Alloy (g/cc)	AL360
Density	2.63	Tensile Strength Mpa	317
Melting Pt. (C)	577	Yield Strength Mpa	170
Thermal conductivity(W/m-K)	113	Shear Strength Mpa	180
Coefficient of thermal Expansion(μm/m-K)	21	HardnessBrinel(HB)	75
Electrical conductivity	29	Elongation%in50mm	35

4.3.2 Forged Steel

Table-4.3.2 Chemical and Mechanical properties of Forged steel

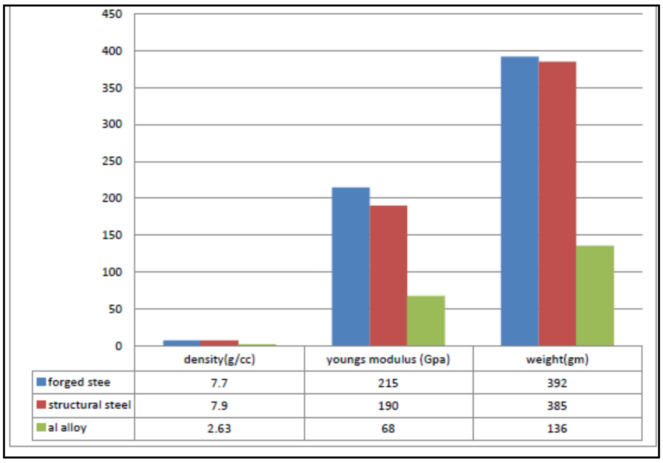
Chemical properties of Forged steel		**Mechanical properties of Forged steel**	
Carbon	0.612-0.68%	Density(g/cc)	7.7
Sulphur	0.02-0.04%	Average hardness (HRB)	101
Manganese	0.5-1.20%	Modulus of elasticity (Gpa)	221
Phosphorous	0.04%	Yield strength (Mpa)	625
Chromium	0.90-1.20%	Ultimate strength (Mpa)	625
		%reduction in area RA	58
		Poisson ratio	0.29

4.3.3 Structural steel

Table-4.3.3 Chemical and Mechanical properties of Structural steel

Chemical properties of Forged steel		**Mechanical properties of Forged steel**	
Manganese	1.6 %	Density(g/cc)	780
Silicon	0.5 %	Average hardness(HRB)	300
Phosphorous	0.025 %	Modulus of elasticity(Gpa)	200
Carbon	0.12 %	Yield strength(Mpa)	250
		Ultimate strength(Mpa)	250
		Poisson ratio	0.26

FEM analysis was carried out by considering three materials Al alloy, forged steel and structural steel.Comparison of density, young's modulus, weight for three materials [7,8] as shown in the graphical representation. (4.3.1)



Graph 4.3.1: Comparison of density, young's modulus, weight for aluminium, forged steel and structural steel.

From the above graph4.3.1 structural steel has maximum density and forged steel has maximum young's modulus and al alloy has minimum young's modulus and forged steel has maximum weight and al alloy has minimum weight

5. Analysis of connecting rod by using three different materials

I. Static analysis

5.1 Connecting rod – Equivalent stress, strain analysis, Total deformation and life of aluminium alloy

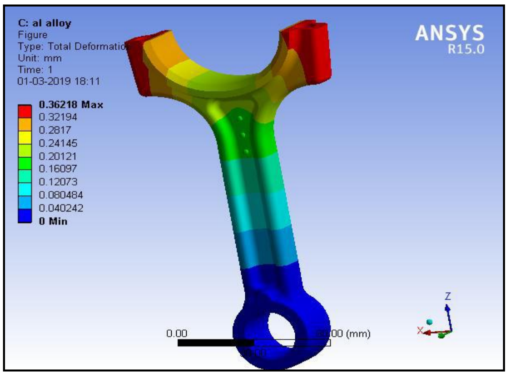


Fig: 5.1 Total deformation analysisof aluminium alloy

Table: 5.1 – Minimum and Maximum Values of Equivalent stress, strain analysis, total deformation and life of al alloy

	Min	Max
Total deformation	0	0.36218 mm
Equivalent strain	$1.4665*10^{-6}$ mm/mm	$3.7062*10^{-3}$ mm/mm
stress Equivalent	0.070732 Mpa	263 Mpa
Life	2563.7 cycles	1*108 cycles

5.1.2. Connecting rod – Equivalent stress, strain analysis, and Total deformation of Forged Steel

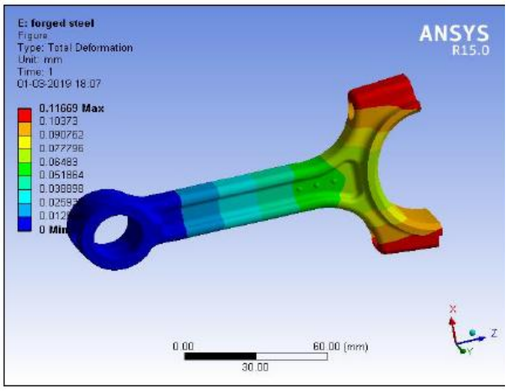


Fig: 5.1.2 - Total Deformationof Forged Steel

Table: 5.1.2 Minimum and Maximum values of Equivalent stress,strainand Total deformation of Forged Steel

	Min	Max
Equivalent strain	2.8775*10−7	1.1898*10−3
Total deformation	0.0mm	0.1169mm
Equivalent stress	0.11669Mpa	262.81Mpa

5.1.3 Connecting rod – Equivalent stress, strain analysis, and Total deformation and life of structural steel

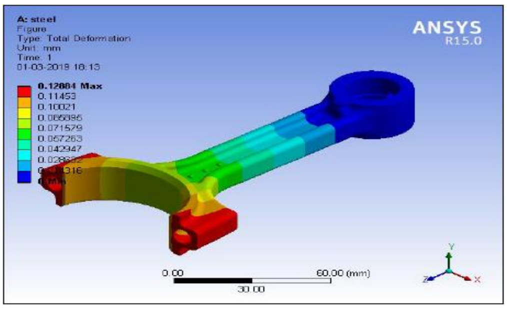
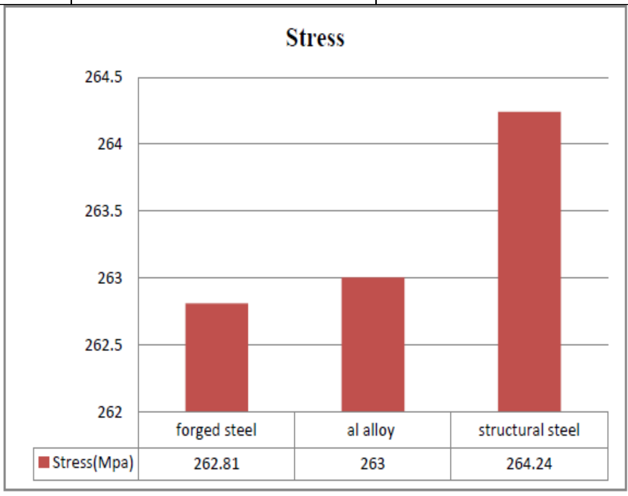
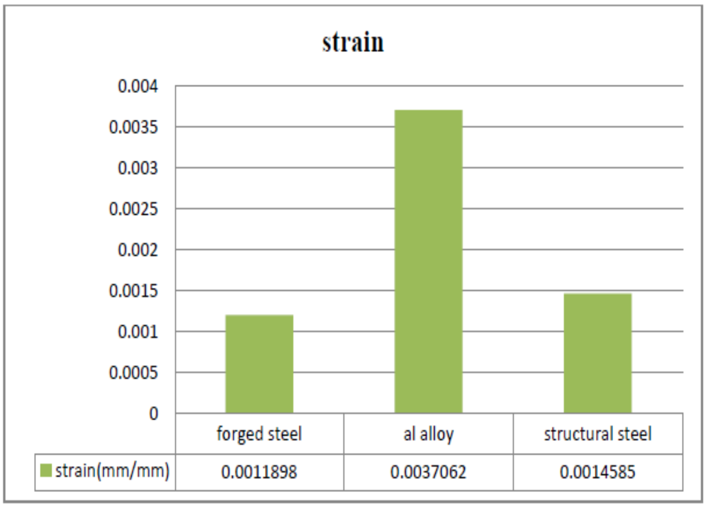


Fig: 5.1.3 - Total deformationof Structural Steel

Table: 5.1.3 Minimum and Maximum values of Equivalent stress,strainand Total deformation of Structural Steel

	Min	Max
Total deformation (mm)	0 mm	0.12884
Equivalent strain	4.0137*10−7	0.0014585
Equivalent stress Mpa	0.075321	264.24
Directional deformation about y-axis (mm)	-0.0020423	0.0020617
Life (cycles)	9740.3cycles	10^6





Graph-5.1 Stress vs Forged steel, Al Alloy, Structural steel materials

Graph-5.2 Strain vs Forged steel, Al Alloy, Structural steel materials

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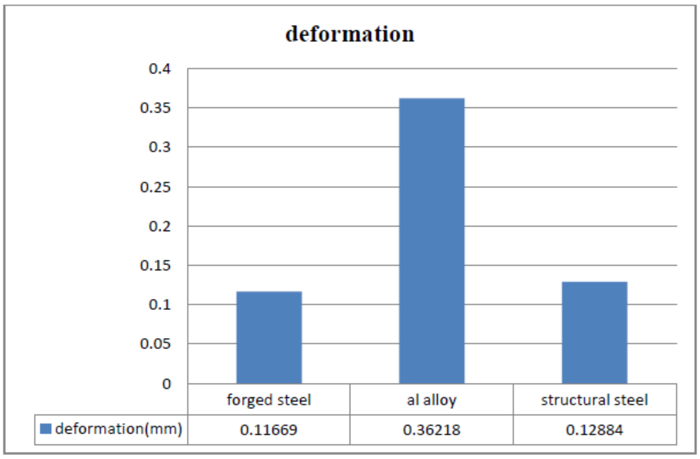

Graph-5.3 Deformation vs Forged Steel, Al Alloy, Structural steel materials

From the above graphs**5.1, 5.2 & 5.3,** structural steel has the maximum von missies' stress about (264.24Mpa) and forged steel has minimum von missies' stress (262.81Mpa). Al alloy has maximum von missies' strain (0.0037mm/mm) and forged steel has minimum von missies' strain (0.001189mm/mm).al alloy has the maximum deformation (0.36218mm) and forged steel has minimum deformation (0.11669mm)

II. Transient Thermal analysis

5.2 ANSYS is capable of both steady state and transient analysis of any solid with thermal boundary conditions. Steady-state thermal analyses calculate the effects of steady thermal loads on a system or component. ANSYS can be used to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time.
Such loads include the following;

- Convection , Radiation, Heat flow rates ,Heat fluxes (heat flow per unit area) ,Heat generation rates (heat flow per unit volume) , Constant temperature boundaries

5.2.1 For Structural Steel

	Minimum (W/m^2)	Maximum(W/m^2)
Total Heat Flux	6.342×10^{-6}	1.492×10^{7}
Directional Heat Flux	-9.9766×10^{6}	9.2416×10^{6}

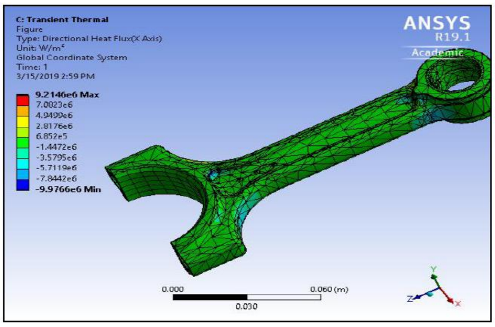

Fig-5.2.1 Heat flux for Structural Steel Table-5.2.1 Minimum and Maximum values of Total Heat Flux for Structural Steel

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5.2.2 For Forged Steel

Table-5.2.2 Minimum and Maximum values of Total Heat Flux for Forged Steel

	Minimum	**Maximum**
Total Heat Flux	$3.6161 * 10^{-5}$	$2.2014 * 10^{7}$
Directional Heat Flux	-1.5552×10^{7}	1.436 * 107

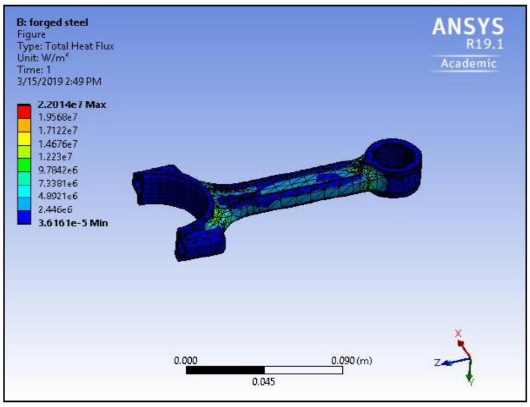
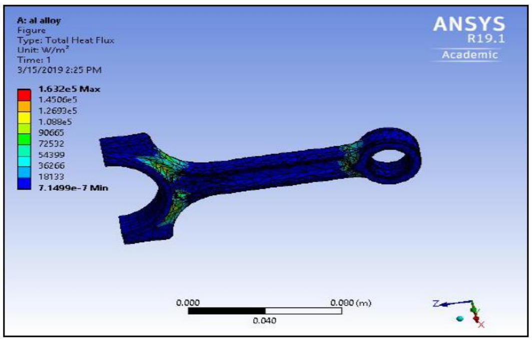


Fig: 5.2.2 -Heat flux for Structural Steel

5.2.3 For Al Alloy



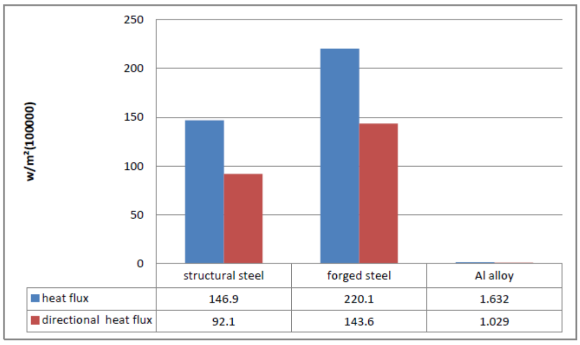


Fig: 7.3.5 - Total heat flux for Al Alloy

Graph: 5.2 – Heat Flux and Directional Heat Flux for three different Materials.

6. Weight optimization

The finite element analysis (FEA) is a computing technique that is used to obtain approximate solutions to boundary value problems. It uses a numerical method called finite element method (FEM). Solid models (CAD) of connecting rod are created in CATIA. These solid models of connecting rod are imported in ANSYS workbench. Static structural analysis connecting rod is carried out in ANSYS CAE software package

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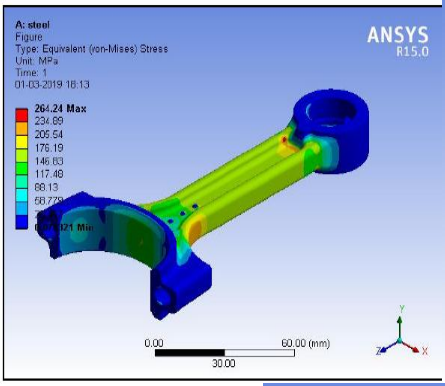
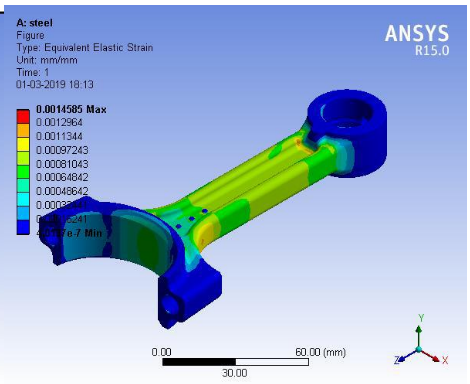
Table: 6- Properties of the Material

Material	Volume (m3)	Density (kg/m3)	Weight (kg)
Steel	5.034 e -005	7860	0.395

6.1 Weight of Material before Optimization





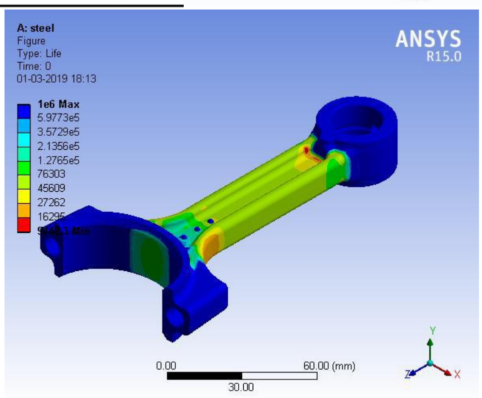


Fig: 6.1 - Von Misses stress of Steel **Fig: 6.2Elastic Strain of Steel** **Fig: 6.3 – Life of Steel**

From the above figures it is found that maximum stress and maximum strain are concentrated at the shank of connecting rod. Fatigue damage is defined as the designed life divided by available life.

The maximum and minimum values of the resulting parameter are shown in the below table

Table: 6.1 Resultant Parameters of Steel

Stress	230.89 Mpa
Strain	0.0012964 mm / mm
Deformation	0.1288 mm
Life	1 x 10^6 Cycles

Weight can be optimized by considering same boundary conditions and loading conditions under static loading and by changing geometry of existing connecting rod. Fatigue strength which is most important driving factor. In the optimization of connecting rod, is Improve significantly.

7. Results of optimized connecting rod

Table 7.1: Optimized Values of Connecting Rod

Existingwt.(kg)	**Optimized wt.(kg)**	**Reduced wt.(kg)**	**Stiffeners (wt. / deform)**
0.395	0.313	0.082	2911 (g/mm)

Material	**Steel**
Volume	3.994 e-005 m^3
Density	7860 kg/m^3
Weight	0.313 kg
Stress	225.65 Mpa
Strain	0.001274 mm / mm
Deformation	0.1075 mm
Life	1 x 10^6 Cycles

8. Conclusion

A connecting rod used in the internal combustion engine is designed by using 3D parametric software CATIA V5 to validate the static structural, transient analysis and weight optimization. Analysis is carried out by varying materialsas aluminium 360, forged steel, and structural steel.

Seen from the above analysis it is observed that stresses of all the materials are almost comparable and also in safe limit, i.e., well below the yield stress. In the static analysis the stress is found maximum at the small end of the connecting rod. Steel connecting rod is having more weight than Aluminium, structural steel connecting rod.

Minimum stresses among all loading conditions, were found at crank end cap as well as at piston end. Hence, the material can be reduced from those portions, thereby reducing material cost. Dynamic analysis of connecting rod is needed for further optimization of material. Finite element analysis, need to be performed for dynamic load conditions once again, gives accurate results than the existing.Hence the connecting rod can be designed and optimized under a load range

The existing connecting rod can be replaced by optimization with a new connecting rod made of lighter in weight by changing geometry (approximately 21%) . The section modulus of the connecting rod should be high enough to prevent high bending stresses due to inertia forces . Equivalent von misses stress, equivalent von misses' strain are minimum in connecting rod of forged steel. . It is observed that stress, strain and total deformation is minimum in forged steel connecting rod. Hence, for the longer life of connecting rod, forged alloy can be used for production.

Aluminium alloy connecting rod is having less weight and more deformation than forged and structural steel. So, aluminium connecting rod show more shaky behaviour

- Weight of connecting rod is reduced, thereby reduces the inertia force by comparing the results of three different materials used for connecting rod analysis it is found that equivalent von misses stress for all the materials is approximately same.

- From the fig: 5.2.2,total heat flux, and directional heat flux for forged steel is 2.261 x 10^7w/m^2 is higher than al alloy and structural steel

Hence it is concluded that, among thethree materialsforged steel is best suited when compared with the structural steel and Aluminium alloy materials, also by performing the structural analysis the results obtained were in safe limits.

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