Design & Static Structural Analysis of Connecting Rod For High Pressure Plunger Pump

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Abstract- *Connecting rod is one of the most important parts in pump assembly which transfers energy from plunger rod to crankshaft and convert the linear reciprocating motion of a plunger rod into the rotary motion of a crankshaft. The connecting rod primarily undergoes tensile and compressive loading under pump cyclic process. The forces acting on connecting rod are forces due to maximum fluid pressure and force due to inertia of connecting rod and reciprocating mass. From functionality point of view, connecting rods must have the highest possible rigidity at the lowest weight. This research addresses the computation of the strength characteristic of a connecting rod. This paper describes design, modelling and analysis of connecting rod. In this work connecting rod of EN9 material used for high pressure plunger pump. A parametric model of connecting rod is modeled using Solid Edge ST6 software. Analysis is carried out by using ANSYS 14.5 software.*

The main objective of this research is to study the static structural analysis of connecting rod.The loads on the connecting rod were obtained as a function of crank angle. Static structural analysis is carried out under two major stresses developed on connecting rod i.e. compressive stress and tensile stress, the best parameter equivalent vonmises stress is calculated theoretically as well as using finite element analysis for material at both ends of connecting rod and the comparison is made between theoretical results and results of FEA for material.

Keywords- Ansys 14.5, Connecting rod, EN9, FEA, Static analysis, Solid edge ST6.

I. INTRODUCTION

Connecting rods are widely used in variety of pumps, IC engines and industrial engines. The function of connecting rod is to transmit the thrust of the plunger rod to the crank shaft, and as a result the reciprocating motion of the plunger is translated into rotational motion of the crank shaft. It consists of a pin end, a shank section and crank end. In our case one end of the connecting rod is connected to the crank slider by the piston pin. The connecting rod consists of an eye at the small end to accommodate the piston pin, a long shank and a big end opening split into two parts to accommodate the crank pin. Crank slider is intermediate medium which connect the plunger rod and the connecting rod. The connecting rod is subjected to the force of gas pressure and the inertia force of the reciprocating part. A connecting rod must be capable of transmitting axial tension, axial compression, and bending stress caused by the thrust and pull of the piston and by centrifugal force. The influential component factors are able to change such as material, cross section conditions etc.

The materials used for the connecting rod are either medium carbon steel or alloy steel. Medium carbon steel is used for the connecting rod of industrial engines. The carbon steel having 0.35 % carbon has an ultimate tensile strength of 650 MPa when properly heat treated and the carbon steel with 0.45 % carbon has an ultimate tensile strength of 750 MPa. These steels are used for connecting rod of industrial engines. The connecting rod of a pump is made by the drop forging process and the outer surface is left unfinished.

They are not rigidly fixed at either end, so that the angle between the connecting rod and crank slider can change as the rod moves up and down and rotates around the crank shaft. The big end of connecting rod is under tremendous stress from the reciprocating load represented by the plunger or crank slider, actually stretching and being compressed with every rotation, and the load increases to the third power with increasing engine speed.

Therefore, it is important for engineers to properly determine the stresses present within the rod to ensure that even under its worst conditions. By being able to model the connecting rod and determining the forces present on it under all conditions it is possible to use programs such as ANSYS to determine the stresses developed within the connecting rod.

The material used for connecting rod has following properties,

Material selected	EN9
Young's Modulus	2.05×10^5MPa
Poisson's Ratio	0.260
Tensile Yield strength	700 N/mm^2
Density	7800 Kg/m^3
Yield stress	355 MPa

Table 1: Material properties of connecting rod

II. LITERATURE REVIEW

D. Gopinath, Ch.V.Sushma [1] et al, explores weight reduction opportunities for the production of forged steel, aluminium and titanium connecting rods. Performing a detailed load analysis and deals with static load stress analysis of the connecting rod for three materials and optimization for weight of forged steel connecting rod. Mathematical calculations finds the dimensions of the connecting rod for thickness at small or bigger end and forces acting on the connecting rod such as tensile and inertia forces. Geometrical model was developed using CATIA. Then the model is imported to the HYPERMESH which is a finite element pre-processor. The stresses were found in the existing connecting rod for the given loading conditions using Finite Element Analysis software ANSYS 11.0.

Akbar khan [2] et al, performed design, modelling and static structural analysis of connecting rod. Existing steel 16MnCr5 replaced by steel alloy SAE 8620 and Aluminium alloy 360 and gives the opportunity to reduce the weight and cost of the connecting rod so that static structural analysis is carried out fewer than two major stresses occurs on connecting rod.

Sushant, Victor Gambhir [3] et al, designed a connecting rod for two wheeler by analytical method. Geometrical model was modelled in Pro-E wildfire 5.0. Structural system of connecting rod has been analysed using FEA. With the use of FEA von mises stress, shear stress, strain and bending stress were calculated for a particular loading conditions using FEA software ANSYS WORKBENCH 14.0. The same work was done on the same design for two different materials. There is reduction in mass, shear stress, bending stress, von mises stress, and elastic strain by using material Aluminium 7068.

Gurunath Shinde, Vinayak Yadav [4] et al, measured dimensions from connecting rod and CAD model is developed in Pro-E 2.0 and ANSYS software is used for static analysis of connecting rod. The main advantage of using simulation is to save time and cost involved in analysis. Material Properties, static load, boundary conditions etc. aregiven. The loads on the connecting rod were obtained as a function of crank angle.

Asadi [5] et al, developed detailed load analysis under service loading conditions was performed for connecting rod and The conclusions can be drawn from this study as follows the maximum pressure stress was obtained between pin end and rod linkage and the maximum tensile stress was obtained in lower half of pin end. The crank and piston pin ends are assumed to have a sinusoidal distributed loading over the contact surface area, under tensile loading. This is based on experimental results.

K. Sudershan Kumar [6] et al, described modelling and analysis of Connecting rod. In his project carbon steel connecting rod is replaced by aluminium 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% and to reduce stress by 10.35%.

2.1 Objective

The main objective of this research is to study the static structural analysis of plunger pump connecting rod. Theoretical design of connecting rod is carried out using Rankin formula by considering the cross section and modelling of the connecting rod is done using Solid edge ST6 and finite element analysis is done in Ansys 14.5 software, comparisons of the results are made in between the von misses stresses occurs in material.

III. DESIGN OF CONNECTING ROD

The connecting rod does this important task of converting reciprocating motion of the plunger rod into rotary motion of the crankshaft. It consists of an upper forked section which fits on the crank slider bearings while the lower part fits on the crankpin bearing. For the analysis of high pressure plunger pump connecting rod the most critical area is considered and accordingly the model of connecting rod is formed. The different dimensions of the pump and connecting rod are given below,

Plunger pump	
No. of Plunger rod	1
Speed of Plunger pump	83 rpm
Maximum Pressure	350 bar
Design Pressure	415 bar
Length of connecting rod	225 mm
Plunger rod diameter	20 mm
Stroke	45 mm
Factor of safety	3

Table 2: Plunger pump specification

3.1Theoretical Calculation 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 strut and the Rankine formula is used. A connecting rod, subjected to an axial load W may buckle with X-axis as neutral axis (i.e. in the plane of motion of the connecting rod) or Y-axis as neutral axis (i.e. in the plane perpendicular to the plane of motion). 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 about both the axes.

Let,

A = Cross-sectional area of the connecting rod

l = Length of the connecting rod,

σ_c = Compressive yield stress,

W_B = Buckling load,

Ixx and Iyy = Moment of inertia of the section about X-axis and Y-axis respectively.

Kxx and Kyy = Radius of gyration of the section about X-axis and Y-axis respectively.

Rankin formula = (Ixx=4Iyy).

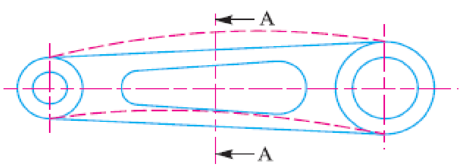

Figure 1: Buckling mode in connecting rod.

3.2 Design Calculation for EN9Material

For the design calculation of connecting rod using EN9 a cross section of connecting rod is consider that standard cross section is I section as shown in fig.2.

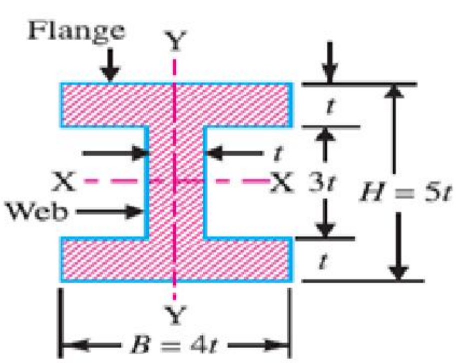

Figure 2: Standard cross section of connecting rod

Thickness of flange & web of the section = t

Width of section B= 4t

Height of section H=5t

Area of section A = (2(4t×t)) +3t×t

$A=11t^2$

Moment of Inertia of section about x axis:

$Ixx=1/12\ [(4t\times (5t)^3)-(3t\times (3t)^3)]$

$= 419/12t^4$

$= 34.91\ t^4$

Moment of Inertia of section about y axis:

$I_{YY} = [(((2\times t)/12)(4t)^3) + ((1/12)(3t)t^3)]$

$= 131/12\ t^4$

$= 10.91\ t^4$

Ixx/Iyy= 3.2

So Section is satisfactory.

Now for dimension of I- section. The connecting rod is designed by taking the force on the connecting rod (Fp) equal to the maximum force on the Piston (F_L) due to gas pressure, so

$Fp = F_L = (\pi D^2/4) \times P_{max}$

$= (3.14\times 20^2/4) \times 41.5$

$= 13037.60$ N

As connecting rod is designed for buckling about X – axis in plane of motion of connecting rod assume that both ends are hinged. So buckling load,

Buckling load W_B = Fp × F.O.S = 13037.60×3

= 39112.8285 N

σ_c = compressive yield stress for EN9

= 98.1 N/mm^2 = 981 MPa

a = constant = 1/7500

$A = 11t^2$

$K_{xx} = (I_{XX}/A)^{0.5}$

$= [(34.91\times t^4)/ (11\times t^2)]^{0.5}$

$K_{xx} = 1.78t$

a = 0.0002

By substituting σc, A, a, L, K_{xx} on W_b then

$W_b = (\sigma_c\times A)/(1+ a\times (L/K_{xx})^2)$

$39112.8285 = (98.1\times 11t^2)/ (1+ 0.000133\times (225/1.78t)^2)$

t = 6.08498 mm

So dimension of I section of Connecting rod:

For t = 14 mm

Width of section B = 4t =56 mm

Height of section H = 5t= 70 mm

Area A = $11t^2$ = 2156 mm^2

Height at the big end H_2 = 1.1H to 1.25H

H_2 = 87.5 mm

Height at the small end H_1 = 0.75H to 0.9H
H_1 = 63 mm

Dimension of the Big end bearing & Small end bearing:

Let d_c = diameter of big end bearing
l_c = length of big end bearing
Value of bearing pressure may be taken as 7N/mm^2 to 12.5 N/mm^2 depending on material and method of selection.
P_{bc} = Bearing Pressure = 10N/mm^2 for steel
Let d_c = Diameter of the crank pin in mm,
l_c = Length of the crank pin in mm,
P_{bc} = Allowable bearing pressure in N/mm^2, and
d_p, l_p and P_{bp} = Corresponding values for the piston pin,
Load on the crank pin = Projected area × Bearing pressure
$= d_c \times l_c \times P_{bc}$
Generally,$l_c = 1.25\ d_c$ to $1.5\ d_c$
$13037.63 = d_c \times (1.5d_c) \times 10$ ……For steel P_{bc} = 10 N/mm^2
d_c = 29.5 mm and l_c = 44.25 mm
Similarly,
Load on the gudgeon pin = $d_p \times l_p \times P_{bp}$
$13037.63 = dp \times (2d_p) \times 15$ Generally [$l_p = 1.5\ d_p$ to $2\ d_p$]
For steel P_{bp} = 15 N/mm^2
d_p = 20.84 mm and l_p = 41.68 mm

Maximum Tensile Force:

Mass of the connecting rod, m = volume× length × density
= 3.7837 kg
Max. Bending moment = $m \times \omega^2 \times r \times (l/9\sqrt{3})$
= 92832.74 Nmm
Section modulus = $I_{xx}/(5t/2) = (419 \times 14^4 \times 2)/(12 \times 14 \times 5)$
= 38324.53 mm^3
Maximum bending stress due to inertia bending forces = M_{max}/Z_{xx}= 2.4222 N/mm^2

Maximum tensile force = $m_r \times \omega^2 \times r \times (1+r/l)$
= 22.8329 N

IV. MODELING AND STATIC STRUCTURAL ANALYSIS OF CONNECTING ROD

In static structural analysis of plunger pump connecting rod, modelling of connecting rod is carried out using the modelling software Solid Edge ST6 and then it is imported to the analysis software Ansys 14.5 and then static structural analysis is carried out on the connecting rod in both compressive and tensile loading conditions. Connecting rod for material modelled by taking the designed parameter and then by using the Solid Edge ST6 software solid modelling is done which is shown in Fig. (3) And saved within this program in *.IGES format. The model is imported in Ansys and then the mechanical characteristics of the connecting rod are applied as shown below.

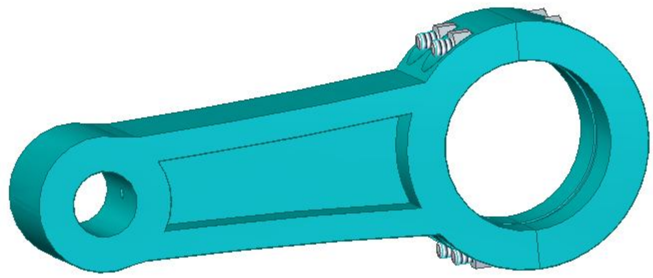

Figure 3: 3D View of connecting rod

Position	Parameters	EN9
Piston end	Inner diameter	34 mm
	Outer diameter	70 mm
	Height (H_1)	63 mm
Crank end	Inner diameter	88 mm
	Outer diameter	128 mm
	Height (H_2)	87.5 mm
	Total length	225 mm

Table 3: Dimensions of connecting rod

As shown in the figure 3 the connecting rod is modelled using Solid Edge ST6 Software with the dimensions shown in table 3 for Steel EN9.

4.1 Finite Element Analysis

The basis of FEA relies on the decomposition of the domain into a finite number of sub-domains (elements) for which the systematic approximate solution is constructed by applying the variation or weighted residual methods. In effect, FEA reduces problem to that of a finite number of unknowns by dividing the domain into elements and by expressing the unknown field variable in terms of the assumed approximating functions within each element. These functions (also called interpolation functions) are defined in terms of the values of the field variables at specific points, referred to as nodes. The finite element method is a numerical procedure that can be used to obtain solutions to a large class of engineering problems involving stress analysis, heat transfer, electro-magnetism, and fluid flow.

4.2 Meshing of Connecting Rod

Significant factor that will affect the possibilities to obtain acceptable results from the analysis is how the mesh is defined. A finer mesh will generate more accurate results, at the price of longer calculation time. Hexagonal meshing is done. The numbers of elements is 57070 and the numbers of nodes is 210797. It is necessary to mesh manually in subsequent simulations where the model is more detailed and the geometry is more complex. For this first analysis, element size is found out to be 3 mm for working in convergence zone. Figure 4 shown below is meshed model of connecting rod.

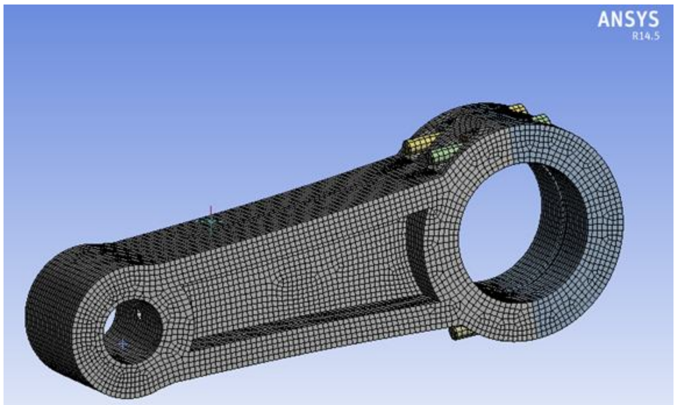

Figure 4: Meshed model of connecting rod.

4.3 Loading and Boundary Conditions

Static analysis is used to determine the displacement stresses, strains and forces in structures or components due to loads that do not include significance inertia and damping effects. Steady loading in response conditions are assumed. The kinds of loading that can be applied in a static analysis include externally applied forces and pressures, steady state inertial forces such as gravity or rational velocity imposed (nonzero) displacements. A static analysis can be linear or non-linear. In our present work, we consider linear static analysis. Analysis done with load applied at the piston end and restrained at the crank end or other load applied at the crank end and restrained at the piston end. Here the load applied at the piston end and cylindrical support was given at the crank end. The analysis carried out under axial load. Here the tensile or compressive load was equal to 13038N. Figure 5 shows loads applied to model of connecting rod.

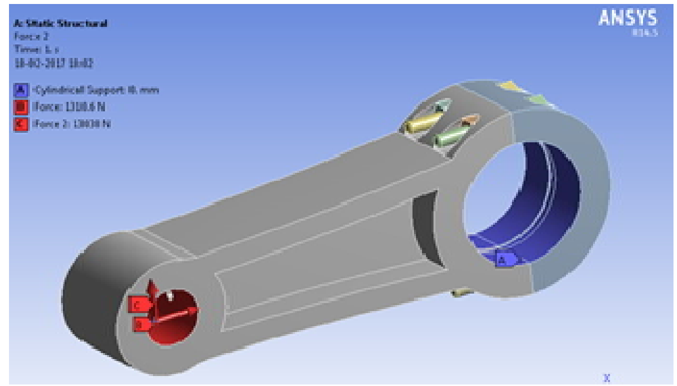

Figure 5: Loading conditions for connecting rod

4.4 Static Structural Analysis of Connecting Rod

When a compressive load is applied on big end for steel EN9 the equivalent von mises stress is

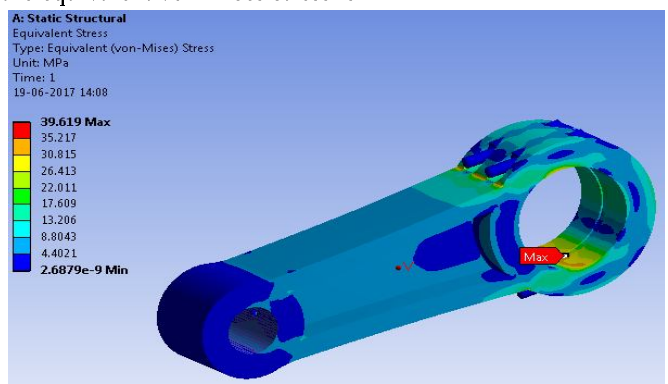

Figure 6: Equivalent von mises stress when compressive load at big end for steel EN9 is 39.619 MPa.

When a compressive load is applied on big end for steel EN9 the shear stress is

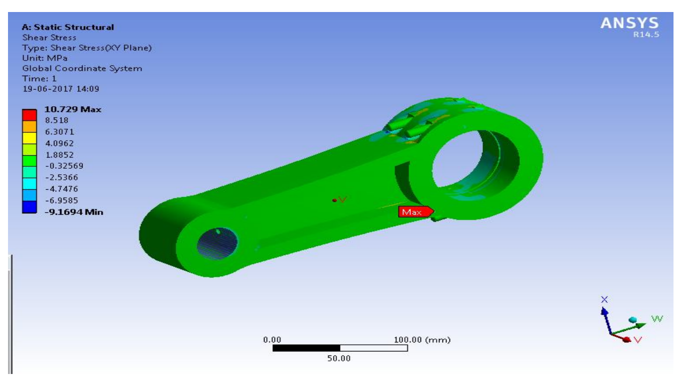

Figure 7: Shear stress when compressive load at big end for steel EN9 is 10.729 MPa.

When a compressive load is applied on big end for steel EN9 the total deformation is

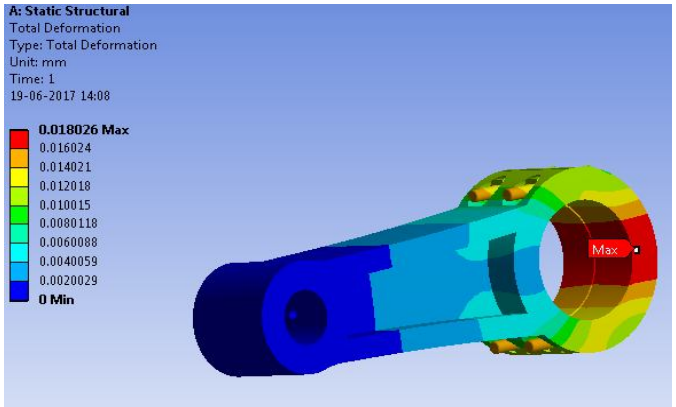

Figure 8: Total deformation when compressive load at big end for steel EN9 is 0.01802 mm.

When a compressive load is applied on small end for steel EN9 the equivalent von mises stress is

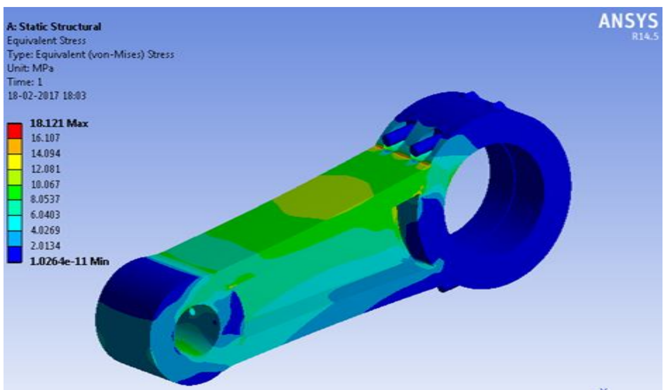

Figure 9: Equivalent von mises stress when compressive load at small end for steel EN9 is 18.121 MPa.

When a compressive load is applied on big end for steel EN9 the shear stress is

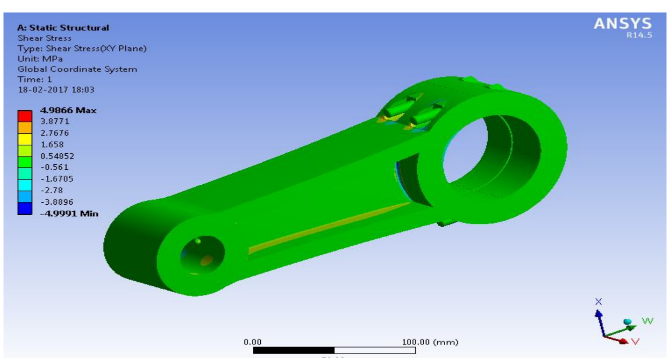

Figure 10: Shear stress when compressive load at small end for steel EN9 is 4.9866 MPa.

When a compressive load is applied on big end for steel EN9 the total deformation is

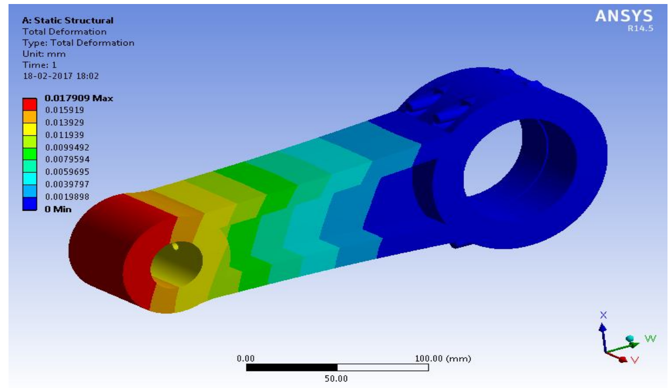

Figure 11: Total deformation when compressive load at small end for steel EN9 is 0.01790 mm.

4.5 Structural Analysis Results of Connecting Rod

The maximum and minimum values of the structural analysis results for the given loading conditions to the EN9 steel connecting rod are mentioned in the following table4.

Sr. No.	Parameter	Maximum Small end	Minimum Big end
1	Von mises stress (MPa)	18.121	39.619
2	Shear stress (MPa)	4.9866	10.729
3	Total deformation (mm)	0.017909	0.018026

Table 4: Structural analysis results for EN9 steel connecting rod

V. CONCLUSIONS

By checking and comparing the results of material in above tables and finalizing the results are shown in below.

1) Objective of the research is successfully achieved in this theoretical and static structural analysis of connecting rod.
2) By comparing the stresses on the connecting rod ends it can be concluded that more stresses occurs on the big end of the connecting rod as compared to the small end. The maximum von mises stress 39.619 MPa occurs at the big end of body. The maximum displacement is 0.018026 mm, belongs to the small deformation range. Results of the stress and displacement show that the connecting rod can work safely.
3) The peak stresses mostly occurred in the transition area between pin end, crank end and shank region in connecting rod. The value of stress at the middle of shank region is well below allowable limit.

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