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Design and FEA Analysis of Connecting Rod of Marine Engine using Titanium Alloy (Grade 5)

Jay Kumar Gupta[1], Shubham Shah Kamlesh[2*], Ruby Mishra[3] and Nidhi Kumari[4]**

[1,2,3]KIIT University, Bhubaneswar
[3]SME, KIIT University Bhubaneswar
E-mail: [1]jay.gupta6588@gmail.com, [2]shubham.prasad1@gmail.com, [3]rbm_mis@rediff.com, [4]nsinha165@gmail.com

Abstract—*The connecting rod is the intermediary member between the piston and the crankshaft. Its prime purpose is to transmit the reciprocating motion from the piston pin into rotary motion of the crankshaft. This paper exemplifies designing and Analysis of connecting rod of a marine engine using titanium alloy (grade 5). Presently existing connecting rod is manufactured by using Cast iron. Finite element analysis of connecting rod is done by considering the same material. The finest blend of analytical parameters like Stress and strain in each direction, Deformation and Factor of safety for marine diesel engine are done in ANSYS software. Also inertial forces at various angles and time are analyzed using the same software. Titanium alloy (grade 5) has more hardness and tensile strength. Due to low density it is lighter than cast iron. Because of less thermal conductivity it is less harmful to the crankshaft. Titanium alloy is corrosion resistant and it is better for marine use. A parametric model of connecting rod is modelled using CATIA V5 R21 software and to that model, analysis is carried out by using ANSYS 14.0 Software.*

Keywords*: marine engine, 4-stroke engine connecting rod, Titanium alloy (grade 5), corrosion resistant, FEA, CATIA V5 R21, ANSYS 14.0*

1. INTRODUCTION

The connecting rod is the connection between the piston and the crankshaft. It joins the piston pin with the crankpin; small end of the connecting rod is connected to the piston and big end to the crank pin. The function of the connecting rod is to convert linear motion of the piston into rotary motion of the crankshaft. The lighter connecting rod and the piston greater than resulting power and less the vibration because of the reciprocating weight is less. The connecting rod carries the power thrust from piston to the crank pin and hence it must be very strong, rigid and also as light as possible.

Connecting rods are subjected to fatigue due to alternating loads. To sustain such high fatigue, fatigue strength of the material should be very high specially for large engines such as Diesel Marine Engines. High pressure is produced in diesel engines which is transferred to the connecting rod via piston pin inducing connecting rod to high loads.

Presently used materials for marine engine connecting rod are Cast Iron & Drop Forged Steel. These materials are less costly but they are very heavy in weight. These materials corrode faster in marine conditions due to constant contact with water that helps in oxidization process.

2. LITRATURE SURVEY

The connecting rod is subjected to a complex state of loading. It undergoes high cyclic loads, which range from high compressive loads due to combustion, to high tensile loads due to inertia. Therefore, durability of this component is of critical importance. Due to these factors, the connecting rod has been the topic of research on various aspects such as production technology, materials, performance simulation, fatigue, etc. This brief literature survey reviews some of these aspects.

For analysis of connecting rod using different material viz. forged steel by [1] Leela Krishna Vegi et al designed and analyzed a connecting rod of a 150cc Suzuki engine.

The paper successfully showed the stresses induced in various parts of connecting rod which included Von mises stress, normal and shear stresses and directional and total deformation. [2] Christy et al in their research in 2013 "Stress Analysis of Connecting Rod for Weight Reduction-A Review" showed the importance of weight reduction through Finite Element Method Analysis. In this paper optimization was done on the connecting rod for weight reduction using FEA. [3] Marthanapalli HariPriya et al in their research "Materialized Optimization of Connecting Rod for Four Stroke Single Cylinder Engine" Analyzed the design of connecting rod by changing it from I section to H section and also the material was changed from Carbon steel to Aluminum alloy A360. The weight of the connecting rod was reduced 4 times by using Aluminum alloy. [4] Mr. J.D.Ramani et al in his research "FE-Analysis of Connecting Rod of I.C.Engine by Using Ansys for Material Optimization" showed the production of stress during compressive and tensile loading of connecting rod leading to the possibility of weight reduction of steel connecting rods. this paper showed that weight reduction of steel connecting rods is possible by 15% while using steel through optimization. [5] Prof. Vivek C. Pathade et al in their research "Stress Analysis of I.C.Engine Connecting Rod by FEM and Photo elasticity" showed the possible failures in a connecting rod which can occur. this paper showed that failure can occur in the fillet section of both end by ANSYS Software which was verified experimentally by Photo elastic method.

3. OBJECTIVE

The main objective of this paper is to give an alternative material for connecting rod with more life cycles, which will be much lighter in weight, which will not corrode easily and last longer even when in contact with marine water.

Thus Titanium alloy (Grade 5) was selected. This material is rigid, has better fatigue strength, less density, better corrosion resistance than other materials.

Hence, connecting rod is designed and Analyzed using CATIA V5 R21 software and ANSYS V14 software respectively to find the stresses, strain and deformation occurring in the connecting rod.

1) Engine Specifications

Yanmar type 8SY-STP

Configuration : 4-stroke, vertical, water cooled diesel engine

Maximum output at crankshaft: 662 kW (900 hp) / 2300 rpm

Continuous rating output at crankshaft: 503 kW (655 hp) / 2100 rpm

Displacement: 15.6 L (952 cu in)

Bore x stroke: 127 mm x 154 mm (5.0 in x 6.1 in)

Cylinders: V8-type 90°

Combustion system: Direct injection

2) CALCULATION

Table 1: Nomenclature & Data used

Parameters	Symbol	Value
Bore	D	127 mm
Length of stroke	L	154 mm
Gas pressure	P	12.3 MPa
Max Power	P_b	662 Kw
Bearing pressure at small end	P_{b1}	12.5~15.4 MPa
Bearing Pressure at big end	P_{b2}	10.8~12.6 MPa
Marginal Thickness	T_m	5~15 mm
Bush Thickness	T_b	2~5 mm
Compressive Stress	σ_c	161.67 MPa
Factor of Safety	f_s	6

1. Formulas used

i) Pressure Calculation for 15.6 lit V8-type marine Engine

Density of diesel fuel = 860 kg/m^3

= 860× 10^{-9} kg/mm^3

Temperature = 15 °C

Mass = Density × Volume

From Gas Equation,

PV = Mtr R

= Rx/Mw

P = 12.3 MPa

ii) Design and Load calculation of Connecting rod

Force due to gas pressure (F_g)= $\frac{\pi}{4}D^2P$

Design Load = $F_g \times f_s$

Rankine's Formula =>

$$Fd = \frac{\sigma_c \times 11t^2}{1 + a[\frac{l}{k}]^2}$$

Inner diameter of the small end =>

$D_{is} = F_g/(P_{b1} \times L_1)$

Outer diameter of the small end =>

$D_{os} = D_{is} + (2\times T_b) + (2\times T_m)$

Inner diameter of the big end =>

$D_{ib} = F_g/(P_{b2} \times L_2)$

Outer diameter of the big end =>

$D_{ob} = D_{ib} + (2\times T_b) + (2\times T_m)$

Table 2: Specifications of Connecting Rod

Sr. No.	Parameters	Value
1	Thickness of the connecting rod (t)	23 mm
2	Width of the section (B = 4t)	92 mm
3	Height of the section(H = 5t)	115 mm
4	Height at the big end L_2 = (1.1 to 1.125)H	126.5 mm
5	Height at the small end L_1 = 0.9H to 0.75H	92 mm
6	Inner diameter of the small end (D_{is})	91.16 mm
7	Outer diameter of the small end (D_{os})	130 mm
8	Inner diameter of the big end (D_{ib})	108.65 mm
9	Outer diameter of the big end (D_{ob})	145 mm

4. MODELING AND ANALYSIS

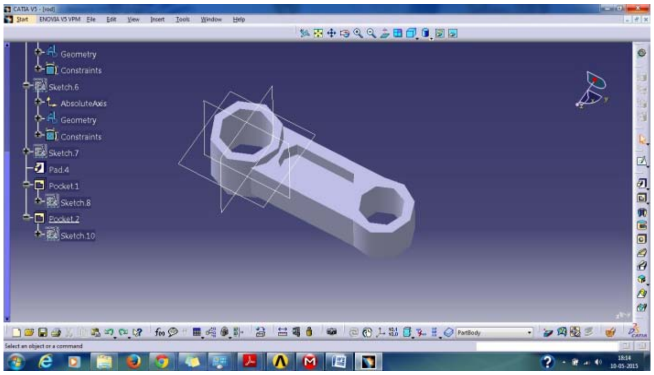

Fig. 1: Design of connecting rod

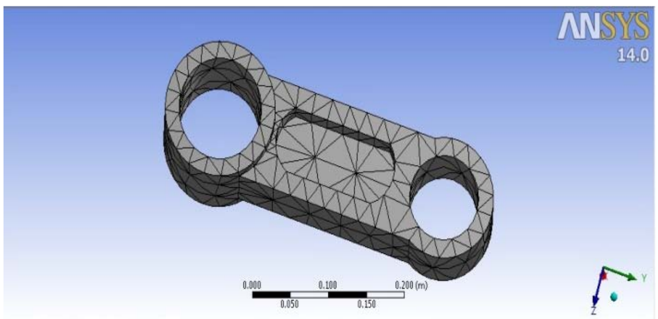

Fig. 2: Mesh model

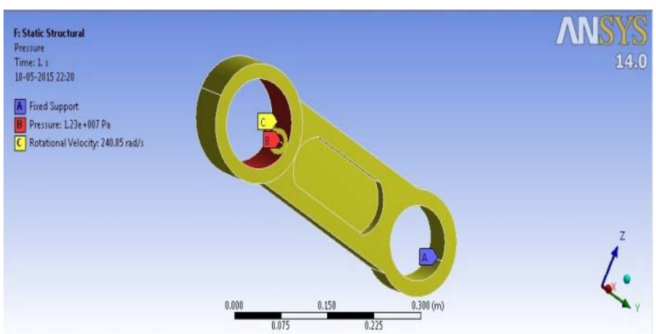

Fig. 3: Applied Pressure & Loads

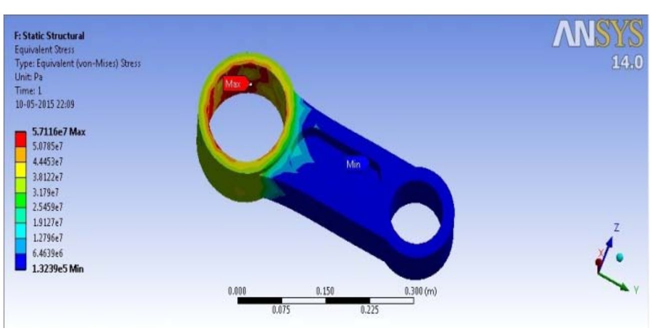

Fig. 4: Equivalent Stress (Von Mises)

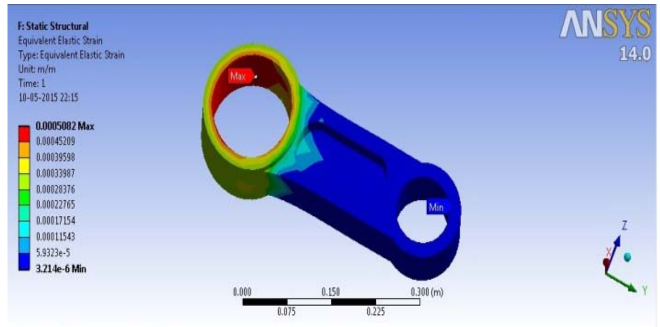

Fig. 5: Equivalent Elastic Strain (Von Mises)

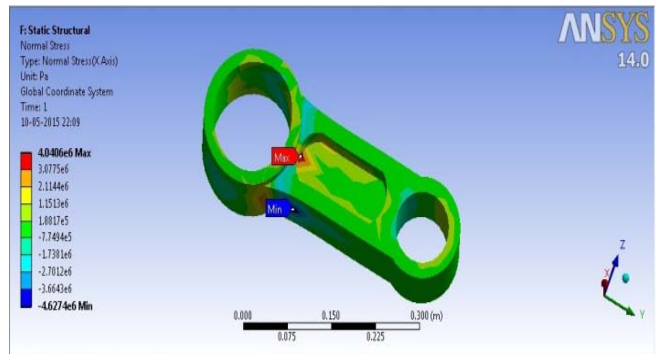

Fig. 6: Normal Stress (X axis)

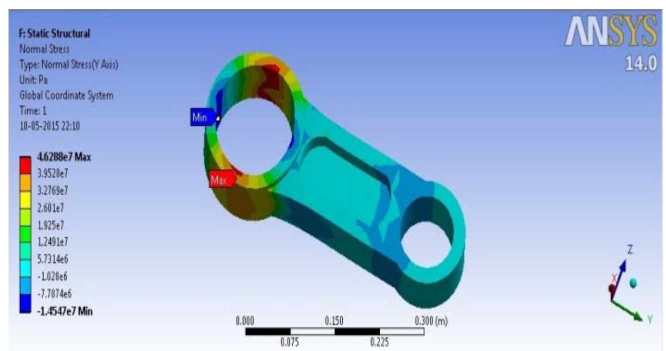

Fig. 7: Normal Stress (Y axis)

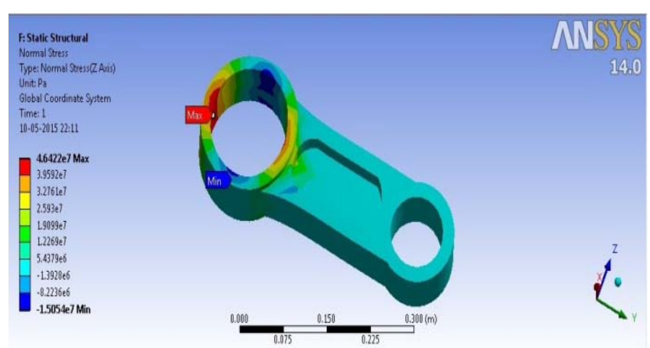

Fig. 8: Normal Stress (Z axis)

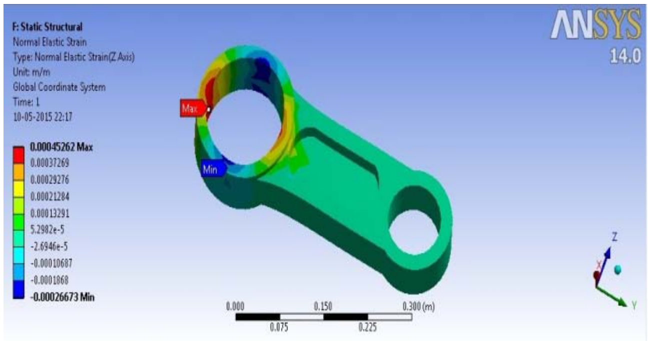

Fig. 9: Normal Elastic Strain

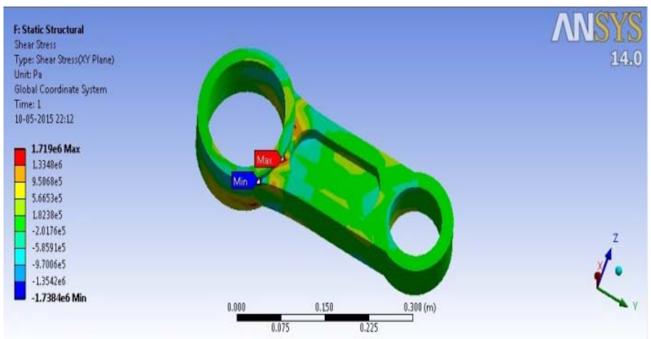

Fig. 10: Shear Stress (XY Plane)

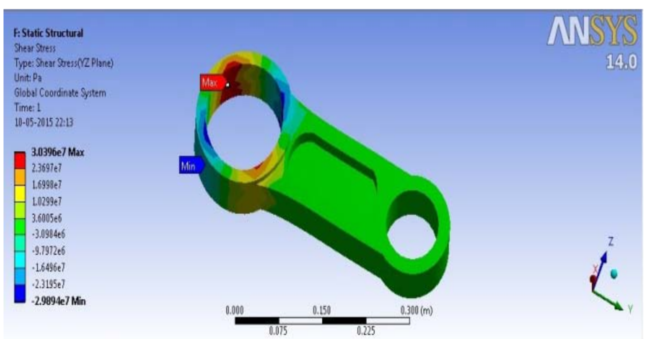

Fig. 11: Shear Stress (YZ Plane)

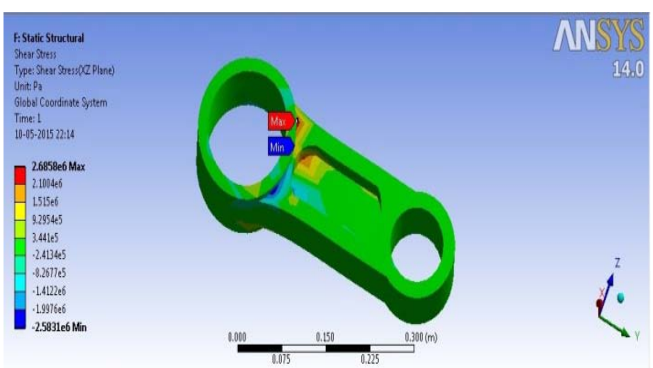

Fig. 12: Shear Stress (XZ Plane)

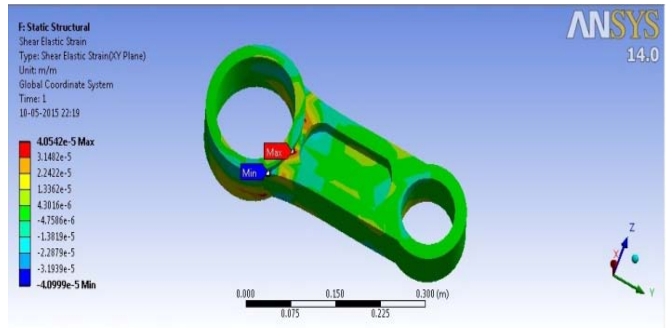

Fig. 13: Shear Elastic Strain

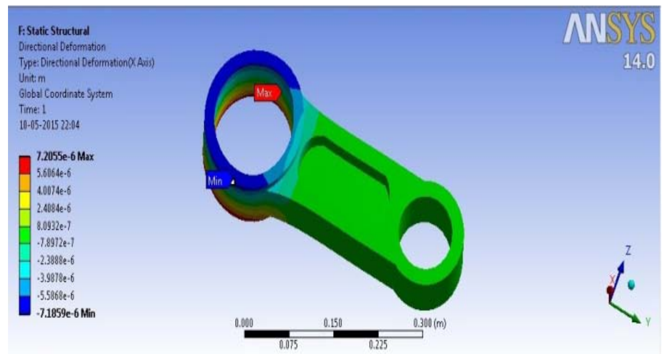

Fig. 14: Deformation (X axis)

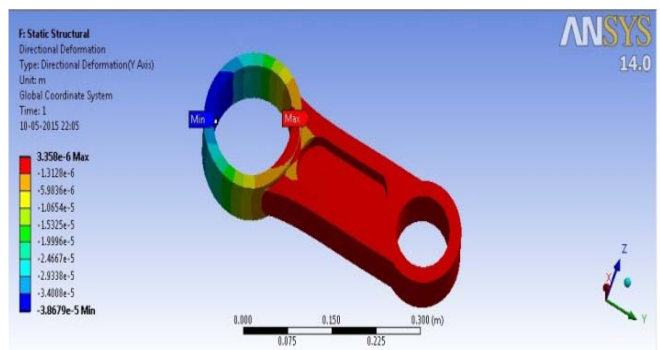

Fig. 15: Deformation (Y axis)

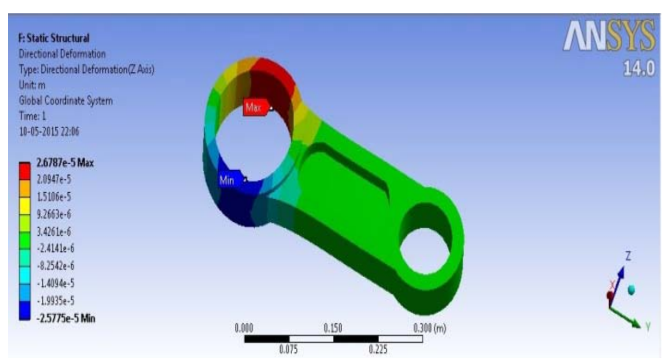

Fig. 16: Deformation (Z axis)

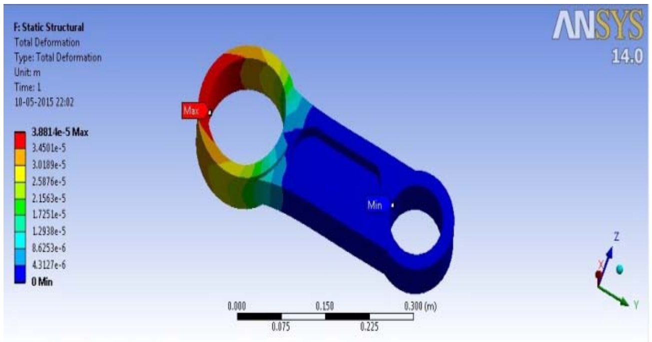

Fig. 17: Total Deformation

5. DISCUSSION

Fig. 1. Connecting rod was designed as per calculations in CATIA V5 R21 software.

Fig. 2. To do a finite element analysis Meshing of model of connecting rod was done in ANSYS V14.0 Software.

Fig. 3. Fixed support was selected. Pressure was applied on the big end side and inertial forces were applied as rotational velocity.

Fig. 4&5. Von- mises stress and strains were Analyzed taking in consideration the above pressures and loads.

Fig. 6, 7 & 8. Normal stress in different directions affecting the connecting rod were analyzed.

Fig. 10, 11 & 12. Shear stresses in different planes affecting the connecting rod were analyzed.

Fig. 14, 15 & 16. Deformation in each direction were analyzed.

Fig. 17 Total deformation caused by the loads and pressure were analyzed and max deformation was found using ANSYS V14.0 software.

6. RESULTS

Table 3: Stress, Strain & Deformations of Titanium alloy (Grade 5)

Sr. No.	Parameters	Min. Value	Max. Value
1	Equivalent stress (von-mises)	1.3239×e^5 Pa	5.7116× e^7 Pa
2	Equivalent elastic strain (von-mises)	3.214× e^-6	5.082× E^-4
3	Normal stress (X axis)	-4.6274× e^6 Pa	4.0406× e^6 Pa
4	Normal stress (Y axis)	-1.4547× e^7 Pa	4.6288× e^7 Pa
5	Normal stress (Z axis)	-1.5054× e^7 Pa	4.6422× e^7 Pa
6	Normal elastic strain	-2.6673× e^-4	4.5262× e^-4
7	Shear elastic strain	-4.0999× e^-5	4.0542× e^-5
8	Shear stress (XY plane)	-1.7384×e^6 Pa	1.719× e^6 Pa
9	Shear stress (YZ plane)	-2.9894×e^7 Pa	3.0396× e^7 Pa
10	Shear stress (XZ plane)	-2.5831×e^6 Pa	2.6858× e^6 Pa
11	Deformation (X axis)	-7.1859× e^-6 m	7.2055× e^-6 m
12	Deformation (Y axis)	-3.8679× e^-5 m	3.3580× e^-6 m
13	Deformation (Z axis)	-2.5775× e^-5 m	2.6787× e^-5 m
14	Total Deformation	0 m	3.8814× e^-5 m

Table 4: Mechanical &Thermal properties of Titanium Alloy (Grade 5)

Parameters	Value
Density	4430 kg m^-3
Young's Modulus	1.138e+011 Pa
Poisson's Ratio	0.342
Bulk Modulus	1.2004e+011 Pa
Shear Modulus	4.2399e+010 Pa
Compressive Yield strength	9.7e+008 Pa
Tensile Yield strength	8.8e+008 Pa

7. CONCLUSION

After studying and analyzing connecting rod using Titanium alloy (grade 5) following conclusions were drawn:

a) The connecting rod made of titanium alloy (grade 5) is lighter than the existing connecting rod.

b) No. of cycles for this material is around 10^7 while existing material has life cycle of 10^6.

c) Total deformation of titanium alloy is less than the current material used

d) Von mises stress induced in the connecting rod using titanium alloy is less than using cast iron.

e) According to study the corrosion resistant property of titanium alloy (grade 5) is much higher than cast iron.

Thus, although there are designing requirements to optimize and reduce vibration in connecting rod of a marine engine, Titanium alloy (grade 5) is safe to use as connecting rod and a much better option.

8. ACKNOWLEDGEMENTS

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