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Design and Comparative Analysis of Connecting Rod Using Composite Materials

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ABSTRACT

The connecting rod is the intermediate member between the piston and the Crankshaft. It's primary function is to transmit the push and pull from the piston pin to the crank pin, thus converting the reciprocating motion of the piston into rotary motion of the crank. This thesis describes designing and Analysis of connecting rod using composite materials. In this, drawing is drafted from the calculations. A parametric model of Connecting rod is modeled using CATIA V5 R21 software. Analysis is carried out by using ANSYS Workbench 14.5 Software. Finite element analysis of connecting rod is done by considering the materials i.e, Titanium Ti-6Al-4V, Aluminum reinforced with Carbon nano tubes Al-MWCNT, E Glass Epoxy, Carbon steel. Analysis is carried out for the two different loading conditions i.e. first load is applied to big end(crank end) and in for second load is applied to small end(piston end) while the respective ends are held fixed. The best combination of parameters like Stress, deformation, weight reduction for Suzuki 150 cc of two wheeler were done using Static and dynamic analysis (Modal, Harmonic Response, Random Vibration, Response Spectrum Transient Structural,) Linear Buckling Analysis in ANSYS software. Compared to Ti-6Al-4v, E Glass and Carbon steel Al-MWCNT has more factor of safety, reduced weight, reduction in stress, and its cost also lesser in comparison.

Key Words : Crankshaft, Workbench, E Glass Epoxy, E Glass, Al-MWCNT, Linear Buckling Analysis, Carbon Steel

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I. INTRODUCTION

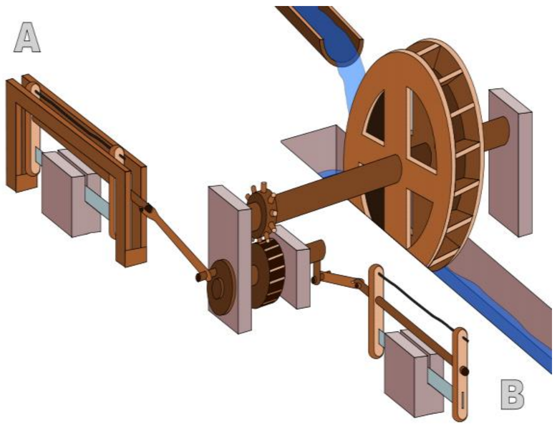
Connecting rods are widely used in variety of car engines. The function of connecting rod is transmit the thrust of the piston to the crankshaft, and as the result the reciprocating motion of the piston is translated into rotational motion of the crankshaft. It consists of a pin-end, a shank section and a crank end. Pin-end and crank-end pin holes are machined to permit accurate fitting of bearings. Ones end of the connecting rod is connected to the piston by the piston pin. The other end revolves with the crankshaft and is split to permit it to be clamped around the crankshaft. The two parts are then attached by two bolts. Connecting rods are subjected to forces generated by mass and fuel combustion.

These two forces results in axial and bending stresses. Bending stresses appear due to eccentricities, crankshaft, case wall deformation, and rotational mass force. Therefore, a connecting rod must be capable of transmitting axial tension, axial compression, and bending stresses caused by the thrust and pull on the piston and by centrifugal force. The connecting rod of the tractors is mostly made of cast iron through the forging or powder metallurgy. The main reason for applying these methods is to produce the components integrally and to reach high productivity with the lowest cost. Nevertheless, connecting rod design is complicated because the engine is to work in variably complicated conditions and the load on the rod mechanism is produced not only by pressure but also inertia.

When the repetitive stresses occur in connecting rod it leads to fatigue phenomenon which can cause so dangerous ruptures and damages. An example of the fatigue analysis and design was presented in 2003 by some researchers. A rupture due to the fatigue and the method of correcting the connecting rod design was also reported presented a strengthening method for the connecting rod design. Finite element (FEM) method is a modern way for fatigue analysis and estimation of the component longevity which has the following advantages compared to the other methods. Through this method, we can access the stress/strain distribution throughout the whole component which enables us to find the critical points authentically. This achievement seems so useful particularly when the component doesn't have a geometrical shape or the loading conditions are sophisticated. The Component optimization against the fatigue is performed easily and quickly.

History of Connecting Rod

The earliest evidence for a connecting rod appears in the late 3rd century AD Roman Hierapolis sawmill. It also appears in two 6th century Eastern Roman saw mills excavated at Ephesus respectively Gerasa. The crank and connecting rod mechanism of these Roman watermills converted the rotary motion of the waterwheel into the linear movement of the saw blades. Sometime between 1174 and1206, the Arab inventor and engineer Al-Jazari described a machine which incorporated the connecting rod with a crankshaft to pump water as part of a water-raising machine, but the device was unnecessarily complex indicating that he still did not fully understand the concept of power conversion. In Renaissance Italy, the earliest evidence of a − albeit mechanically misunderstood –compound crank and connecting-rod is found in the sketch books of Taccola. A sound understanding of the motion involved displays the painter Pisanello (1455) who showed a piston-pump driven by a water-wheel and operated by two simple cranks and two connecting-rods.



1.1 Fig Scheme Of The Roman Hierapoils Sawmill, The Earliest Known Machine To Combine A Connecting Rod With A Crank

Mechanical properties of carbon steel, Titanium Ti-6Al-4V, E Glass Epoxy and Al-MWCNT

S. No	Mechanical Properties	Carbon steel	Ti-6Al-4V	E glass	Al-MWCNT

1	Density (g/cc)	7.87	4.43	2.6	2.35
2	Modulus of elasticity(G pa)	200	113.8	34	89
3	Compressive Strength ultimate(M pa)	415	970	450	435
4	Tensile Strength ultimate(M pa)	540	950	540	228
5	Poison ratio	0.29	0.0342	0.217	0.33

Table1: Mechanical properties of carbon steel, Titanium Ti-6Al-4V, E Glass Epoxy and Al-MWCNT

Pressure Calculation for 150cc Suzuki Engine

Engine type air cooled 4-stroke

Bore x Stroke (mm) = 57×58.6

Displacement = 149.5CC

Maximum Power = 13.8bhp@8500rpm

Maximum Torque = 13.4Nm@6000rpm

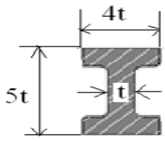
Compression Ratio = 9.35/1

Design Calculations for Ti-6Al-4V Connecting Rod

Thickness of flange & web of the section = t

Width of section B = **4t**

The standard dimension of I SECTION.



Standard Dimension of I – Section

Height of section H= **5t**

Area of section A= 2(4t×t) + 3t×t= **11t²**

MI of section about x axis:

$$Ixx = \frac{1}{12}[4t\,\{5t\}^3 - 3t\,\{3t\}^3] = \frac{419}{12}[t^4]$$

MI of section about y axis:

$$Iyy = \frac{2\times1}{12}\times t\times\{4t\}^3 + \frac{1}{12}\{3t\}t^3 = \frac{131}{12}[t^4]$$

$$\frac{Ixx}{Iyy} = \mathbf{3.2}$$

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

L **= 117.2 mm**

Buckling load W_B = maximum gas force × F.O.S

$$W_B = \frac{(\sigma_c \times A)}{(1+a\,(L/Kxx)2}\ = \mathbf{37663N}$$

σ_c= compressive yield stress = **970MPa**

$Kxx = \frac{Ixx}{A}$ = 1.78t

$a = \frac{\sigma_c}{\pi^2 E}$= **8.636x10^-4**

By substitutingσ_c, A, a, L, Kxx on WB then

$10670t^4-37663t^2-140934.946=0$

$t^2 = 5.8$

t = 2.4mm **= 2.4mm**

Width of section B = 4t = 4×2.4 = **9.6mm**

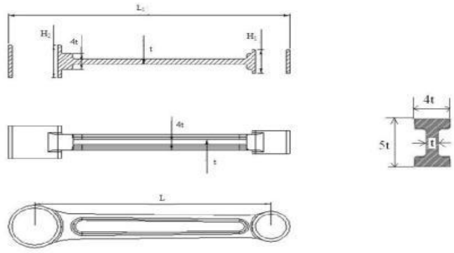
Height of section H = 5t = 5x2.4 = **12mm**

Area A = $11t^2$ = 11×2.4×2.4 = **63.36mm²**

Height at the big end (crank end) = H_2

= 1.1H to 1.25H= 1.2×12 **= 14.4mm**

Height at the small end (piston end) = 0.9H to 0.75H= 0.9×12 **= 10.8mm**



D Drawing for Connecting Rod

Stroke length (l) = **117.2mm**

Diameter of piston (D) = **57mm**

Radius of crank(r) =stroke length/2

= **58.6/2 = 29.3**

Maximum force on the piston due to pressure

$F_1 = \frac{\pi}{4xD^2xp}$ = π/4x(57)^2 x 2.45 = **6379.4N**

Maximum angular speed Wmax = $\frac{[2\pi Nmax]}{60}$ = $\frac{[2\pi\times 8500]}{60}$ = **768 rad/sec**

Ratio of the length of connecting rod to the radius of crank

N = $\frac{l}{r}$ = 117.2/ (29.3) = **4**

Maximum Inertia force of reciprocating parts

F_{im} = Mr (Wmax)^2 r(cosθ + $\frac{COS\ 2\theta}{n}$)

(Or)

F_{im} = Mr (Wmax)^2 r(1+$\frac{1}{n}$)

= 0.11x($2\pi * 8500/60)^2$ x (0.0293) x (1+ (1/4)) = **3586N**

Inner diameter of the small end $d_1 = \frac{F_g}{Pb_1 \times l_1}$

= $\frac{6277.167}{14\times 1.8d_1}$ = **16mm**

Where,

Design bearing pressure for small end p_{b1} = 12.5 to 15.4N/mm^2

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

Outer diameter of the small end = $d_1+2t_b+2t_m$ = 16+2×3.5+2×10=30 mm

Where,

Thickness of the bush t_b = 2 to 5 mm

Marginal thickness t_m = 5 to 15 mm

Inner diameter of the big end $d_2 = \frac{F_g}{Pb_2 \times l_2}$

= $\frac{6277.167}{11\times 1.2d_1}$ = **22mm**

Where,

Design bearing pressure for big end p_{b2} = 10.8 to 12.6N/mm^2

Length of the crank pin l_2 = (1.0 to 1.25)d_2

Root diameter of the bolt = ($\frac{(2F_{im})}{(\pi x S t)})^{1/2}$

= $(\frac{2\times 3586}{\pi\times 56.667})^{1/2}$ = **6.3mm**

Outer diameter of the big end = $d_2 + 2t_b + 2d_b + 2t_m$ = 22+2×3.5+2×7.62+2×10= **52mm**

Where,

Thickness of the bush t_b = 2 to 5 mm

Marginal thickness t_m = 5 to 15 mm

Nominal diameter of bolt d_b= 1.2 x root diameter of the bolt

= 1.2 × 6.3 = **7.62mm**

II. DESIGNING OF CONNECTING ROD

Designing Procedure of Connecting Rod in CATIA-V5 : The modeling of the connecting rod is done using Catia V5 R21 software. Initially the inner and outer end i.e. piston end and the crank end diameter are drawn. Then the small end and the big end diameter circles are padded respectively. After completion of padding of both big and small the stem of the connecting rod is created. The constructed steam is padded. After finishing the padding of steam pocket is applied to one side of the steam, mirror extent pocket is given in order to pocket the other side of stem. Edge fillets are assigned at the desired locations. Thus the required connecting rod is modeled using catia software.

III. ANALYSIS OF CONNECTING ROD

Introduction of Finite Element Method

The basic idea in the Finite Element Method is to find the solution of complicated problems with relatively easy way. The Finite Element Method has been a powerful tool for the numerical solution of a wide range of engineering problems. Applications range from deformation and stress analysis of automotive, aircraft, building, defense, and missile and bridge structures to the field of analysis of dynamics, stability, fracture mechanics, heat flux, fluid flow, magnetic flux, seepage, and other flow problems. With the advances in computer technology and CAD systems, complex problems can be modelled with relative ease. Several alternate configurations can be tried out on a computer before the first prototype is built. The basics in engineering field are must to idealize the given structure for the required behaviour. In the Finite Element Method, the solution region is considered as many small, interconnected sub regions called Finite elements.

Most often it is not possible to ascertain the behavior of complex continuous systems without some form of approximations. For simple members like uniform beams, plates etc., classical solutions can be sought by forming differential and/or integral equations through structures like machine tool frames, pressure vessels, automobile bodies, ships, aircraft structures, domes etc. need some approximate treatment to arrive at their behavior,

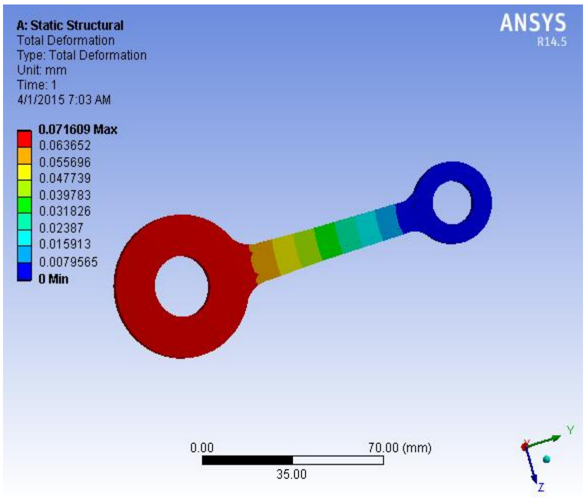


Fig: Total Deformation

Modal Analysis Of Ti-6Al-4V

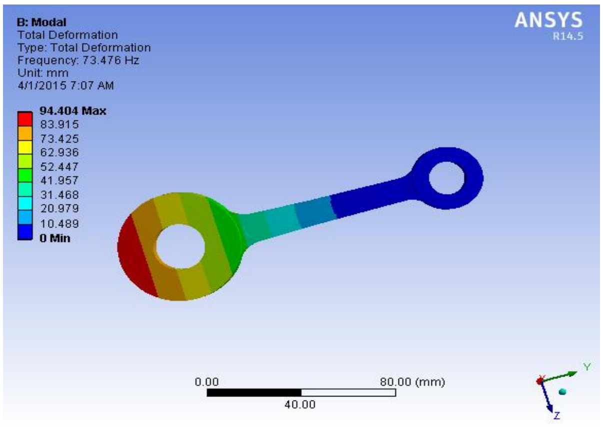


Fig: Mode shape1

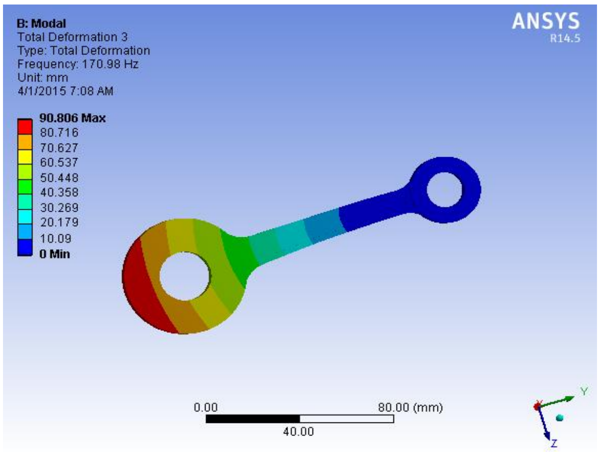


Fig: Mode shape2

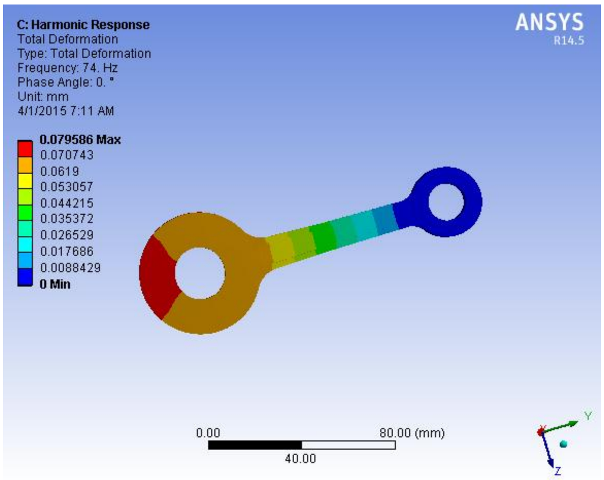


Fig : Total Deformation

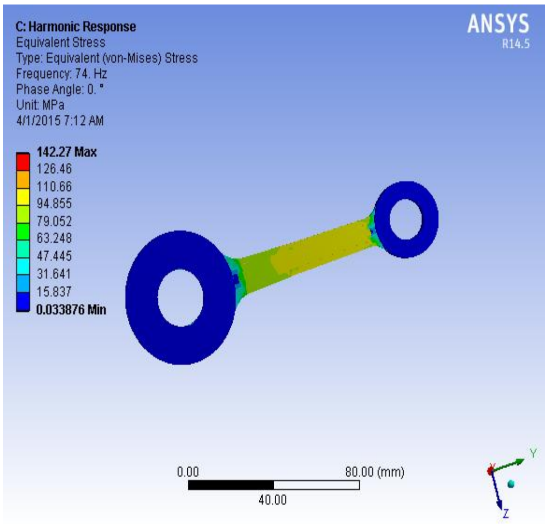


Fig: Equivalent Stress

Response Spectrum of Ti-6Al-4V

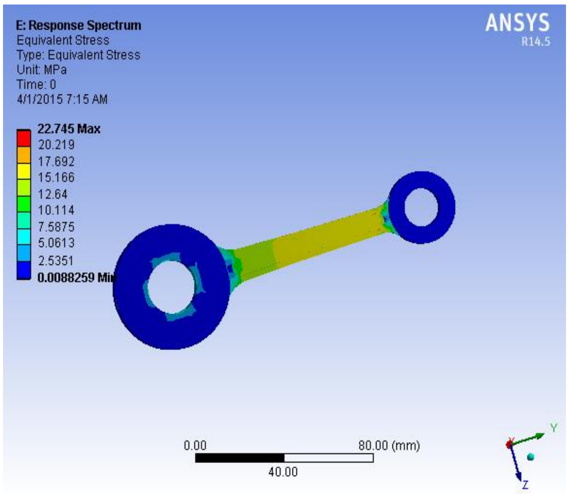


Fig : Equivalent Stress

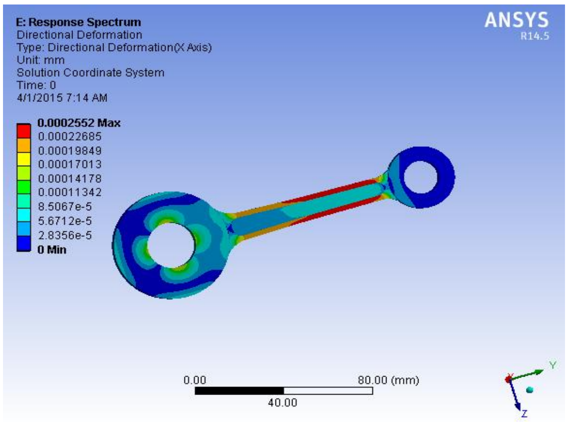


Fig : Directional Deformation (X Axis)

Random Vibration Of Ti-6Al-4V

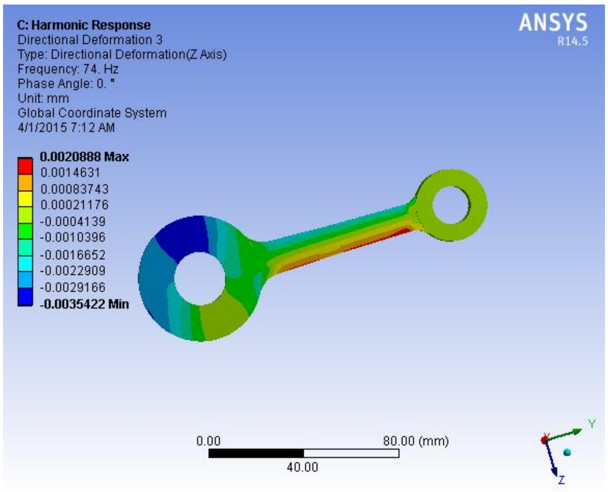


Fig: Directional Deformation (Z Axis)

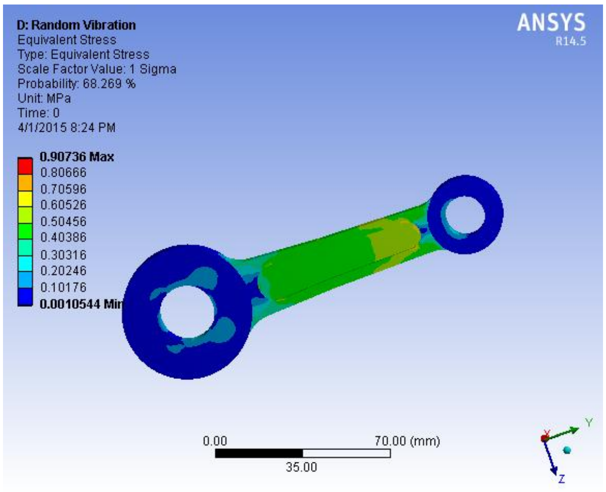


Fig: Equivalent Stress

3.

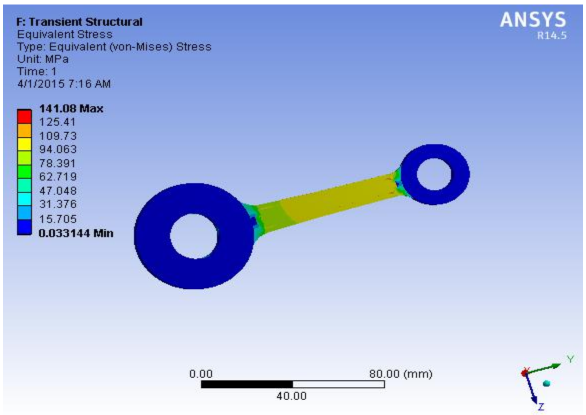


Fig: Equivalent Stress

Linear Buckling Of Ti-6Al-4V

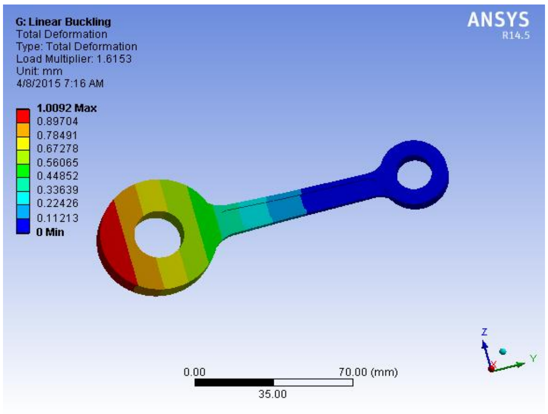


Fig: Total Deformation, Static Structural Of Al-MWCNT

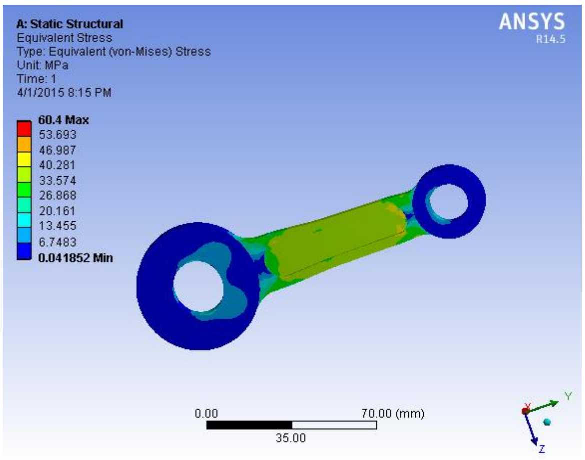


Fig: Equivalent Stress

IV. Results and Discussions

Tables

Material	Static stress(	Modal Frequency(H	Harmonic stress(M pa)	Transient stress(M pa)	Random Vibration	Response vibration	Buckling deformation(
Al-MWCNT	60.4	366.54	62.655	62.366	0.90736	0.66509	1.009
Ti-6Al-4V	139.16	73.476	142.27	141.08	19.716	22.745	1.0092
E Glass	96.315	85.779	95.52	98.418	18.054	41.073	1.0091
Carbon Steel	150.27	70.769	152.5	152.16	5.6927	1.4935	1.0092

V. CONCLUSION

The connecting rod model was created by using Catia software where the drawing is drafted from the calculations and saved in Stp format. Then, the model is imported to ANSYS WORKBENCH software. Two loading conditions are considered throughout the entire analysis process i.e. in all the analysis force is applied to both big and small end of the connecting rod while the respective ends are held to be fixed. By checking and comparing the results of all materials Al-MWCNT, Ti-6Al-4V, E glass, Carbon Steel in the above graphs for various analysis Static, Dynamic (Modal, Harmonic Response, Random Vibration, Response spectrum, Transient Structural) and Linear Buckling.

The Value of Von-Misses Stresses that comes out from the analysis of Al-MWCNT is far less than Ti-6Al-4V, E Glass and Carbon Steel material stress for both static and dynamic analysis.

The Al-MWCNT connecting rod has factor of safety approximately equal to the theoretical factor of safety (6), the weight of Al-MWCNT connecting is much lesser when compared to the other material connecting rods, also Al-MWCNT has reduction in stress in comparison to other materials, and its also lesser in cost . Al-MWCNT is more reliable in all aspects when compared to Ti-6Al-4V, E Glass and Carbon Steel. From all the analysis results we can conclude that our design is safe and we should go for optimization of material. Hence the Al-MWCNT composite material can be widely used for the manufacturing of connecting rod .Thus the entire designing and analysis process has proved to be an apt choice in the design of the connecting rod.

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