International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume – 02, Issue – 07, July – 2017, PP – 28-40

Structural and Dynamic Analysis of Six Cylinder Four Stroke Diesel Engine Crank Shaft Subjected to Various Loading Conditions

K.Dilip kumar [1], P.N.S.Srinivas [2], Dr P.Ravindra Babu [3]

[1]*M.Tech Student (Machine Design), Department of Mechanical Engineering, Gudlavalleru Engineering college, Krishna district, Andhra Pradesh*

[2] *Assistant Professor, Department of Mechanical Engineering, Gudlavalleru Engineering College, Krishna district, Andhra Pradesh*

[3] *Professor, Department of Mechanical Engineering, Gudlavalleru Engineering College, Krishna district, Andhra Pradesh*

Abstract: Crankshaft is one of the critical components for the effective and precise working of the internal combustion engine. It has a complex shape of geometry. In an arbitrary position of the crank due to tangential force, the crank arm will be subjected to transverse shear bending and twisting, while due to radial component it is subjected to direct stress and bending. It is complicated to consider all these straining actions in several positions of the crank. Generally, the crank is designed for two positions; those are maximum twisting moment and maximum bending moment. This work is about evaluating and comparing the static structural analysis and modal analysis of crankshafts manufactured by three different materials viz. Structural Steel, Al 6063+5% Sic+5%Al2o3+5%Graphite (Particle Reinforced Metal Matrix Composite) and High Strength Carbon Fiber. Three dimensional model of crankshaft is created using CREO 3.0. Static simulation has to be conducted on three different crankshafts from similar six cylinder four stroke engine. Finite Element Analysis (FEA) is to be performed to obtain the variation of stress magnitude at critical locations. The static analysis is done and is verified by simulations in finite element analysis software ANSYS. Comparisons for the properties such as equivalent stress and total deformation of crankshafts made up of structural steel , Al 6063+5% sic+5%Al2o3+5%graphite , and high strength carbon fiber were determined and the results were compared. Model theoretical calculations are performed for clear analysis. The output of result would provide a possible recommendation for the development of engine design.

Key words: crankshaft, bending, structural analysis, CREO 3.0, ANSYS

1. Introduction

Crank shaft is a large component with a complex geometry in the engine, which converts the reciprocating displacement of a piston to a rotary motion with a four link mechanism. A crankshaft related to crank is a mechanical part able to perform a conversion between reciprocating motion and rotational motion. In a reciprocating engine, it translates reciprocating motion of the piston into rotational motion; whereas in a reciprocating compressor, it converts the rotational motion into reciprocating motion. In order to do the conversion between two motions, the crankshaft has "crank throws" or "crankpins", additional bearing surfaces whose axis is offset from that of the crank, to which the "big ends" of the connecting rods from each cylinder are being attached. It is typically connected to a flywheel to reduce the pulsation characteristic of the four-stroke cycle, and sometimes a torsional or vibrational damper[1] at the opposite end, to reduce the torsional vibrations often caused along the length of the crankshaft by the cylinders farthest from the output end acting on the torsional elasticity of the metal This study was conducted on six cylinder engine of truck.

Crankshaft experiences large forces from gas combustion. This force is applied to the top of the piston and since the connecting rod connects the piston to the crankshaft, the force will be transmitted to the crankshaft. The magnitude of the force depends on many factors which consist of crank radius, connecting rod dimensions, weight of the connecting rod, piston, piston rings, and pin. Combustion and inertia forces acting on the crankshaft cause two types of loading on the crankshaft structure; tensional load and bending load. There are many sources of failure in the engine. They could be categorized as operating sources, mechanical sources, and repairing sources.

One of the most common crankshaft failures is fatigue at the fillet areas due to bending load caused by the combustion. Even with a soft case as journal bearing contact surface, in a crank shaft free of internal flaws[2] one would still expect a bending or tensional fatigue crack to initiate at the pin surface, radius, or at the surface of an oil hole. Due to the crankshaft geometry and engine mechanism, the crankshaft fillet experiences a large stress range during its service life. Based on the stress imposed on the component during the operation, operating temperatures and intended operation, the material to be selected for this component should posses following characteristics. The materials are categorized into Aluminium, copper and steel. Machining is yet another process which can be used to manufacture crankshafts. Crankshafts can be machined out of a billet, often using a bar of high quality vacuum re-melted steel. Machining process has following advantages Higher quality of steels, which cannot be forged can be used through machining process. No expensive tooling is required for machining process. Extremely high quality crankshafts can be manufactured. However, machining process also has following disadvantages. It is a highly expensive process because; it generally uses high quality material. Moreover, a significant quantity of material is also wasted during machining process. Additional heat treatments are required to get required material properties.

2. Literature Review

Ravi Kumar Goell et al [3](2014) in his research paper titled "Stress Analysis and Optimization of Crankshaft Using CAE Tools" has suggested optimum design parameters of the existing crankshaft by changing the design variables like journal diameter, crank pin diameter, filters and counterweights. Model of four cylinder diesel engine crankshaft was designed in the ANSYS Workbench and Finite Element Analysis was carried out under the same loading conditions. The maximum von-mises stress is 166.93MPa and the directional deformation is 0.211mm

Amit Solanki et al[4](2014) in his research entitled "Design and Stress Analysis of Crankshaft for Single cylinder 4-Stroke Diesel Engine has modeled crankshaft by using Pro-E software and conducted structural analysis by using ANSYS workbench. He has obtained von-mises stress and shear stress to be 119.88 MPa, 41.35 MPa which is nearer to theoretical 121.15 MPa and 57 MPa. He also suggested such useful resources for optimization of the crankshaft.

C.M.Balamurugan et al [5](2011) in his research entitled "Computer Aided Modeling and Optimization of Crankshaft has mainly studied the Computer aided Modeling and Optimization of crankshaft and compare the fatigue performance of two competing manufacturing technologies for automotive crankshafts, namely forged steel and Grey cast iron. The three dimensional model of crankshaft were created by solid edge software and then imported to ANSYS software. After a series of analysis he concluded that the forged iron crankshaft is able withstand the static load, it is concluded that there is no objection from strength point of view also, in the process of replacing the cast iron crankshaft by forged crankshaft. We also reduce forged crankshaft cost by producing the crankshaft in large quantity.

Farzin H. Montazersadgh et al[6](2007) in his research entitled "Optimization of a forged Steel Crankshaft Subject to Dynamic Loading has conducted dynamic simulations on a forged steel crankshaft from a single cylinder four stroke engine. Finite element analysis was performed to obtain the variation of the stress magnitude at the critical locations. The dynamic analysis resulted in the development of the load spectrum applied to the crank pin bearing.

3. Analytical Procedure on Six Cylinder Four Stroke Diesel Engine Using Creo 3.0 & Ansys

The research was performed on six cylinder engine crank shaft of a heavy vehicle. At first theoretical results of a structural steel material is validated with simulation results. Secondly two materials were chosen for crank shaft one is Al6063 metal matrix composite. Al6063 matrix alloy consists of alumina silicon carbide and graphite. Another is high strength carbon fiber. Simulation results of both these materials are compared and best material is selected based upon the values of von-mises stress, shear stress and total deformation. A free vibration analysis is carried out on best material and a set of natural frequencies are obtained. So engine operating speed should not overlap with these natural frequencies.

3.1 Materials considered for research purpose

1. Structural steel

Steel exhibits desirable physical properties that make it one of the most versatile structural materials in use

Young's Modulus	2*10^5 MPa

Poisson ratio	0.3
Density	7850 kg/m^3
Shear Modulus	29.6 GPa
Tensile Strength	460 MPa
Shear Strength	250 MPa

Table 1 indicating properties of structural steel

2. Aluminium Metal Matrix composite:

In the present research work, Al 6063 is selected as the matrix alloy and the reinforcements are alumina Silicon Carbide and Graphite. Table illustrates the percentage compositions of the samples considered for the research work with varying weight fractions

Particulars	Weight fraction with reinforcements
Al 6063+5% Sic+5%Al2o3+5%Graphite	170 gm of Al, 5%(10 gm) of SiC, 5%(10g) of Al2o3 and 5%(10 gm) of Graphite
Young's modulus	74166 Mpa
Poisson ratio	0.33
Shear modulus	28089 Mpa
density	2.69 /cm

Table 2 indicating properties of Aluminium Metal Matrix composite

3. High Strength Carbon fiber.

Young's Modulus	100GPa
Poisson ratio	0.1
Density	1600 kg/m^3
Shear Modulus	0.6 Msi
Tensile Strength	75.85 N/mm^2
Shear Strength	600 MPa

Table 3 indicating properties of High strength carbon fiber

4. Methodology and Calculations

This module mainly focused on geometry generation used for finite element analysis and explains the simplifications that were made to obtain an efficient FE model. Mesh generation and its convergence are discussed. Using proper boundary conditions and type of loading are important since they strongly affect the results of the finite element analysis. Identifying appropriate boundary conditions and loading situation are also discussed. Finite element models of three components were analyzed; the AL6063, high strength carbon fiber crankshaft and structural steel crank shaft. Since these three crankshafts are from different engines, loading used are different for both. This facilitates proper comparison of the components made from three different manufacturing materials

4.1 Modeling of crankshaft using CREO
4.2 Meshing in HYPERMESH
4.3 Procedure for static Analysis by FEM
4.5 Applying Material Properties

4.5 Defining the boundary conditions and applying proper load type.
4.6 Result Analysis

5 Design calculations

Bore diameter	131mm
Force on the piston	141.38 KN
Length of the connecting rod	316mm
Crank radius	79 mm
Tangential force on the crank shaft	86.109 KN
Radial force on the crankshaft	113.52 KN
Bending moment at the center of crank shaft	7435.56 KN-mm
Twisting moment at the crank pin	3400.95 KN-mm

Table 4 indicating dimensional parameters of crank shaft

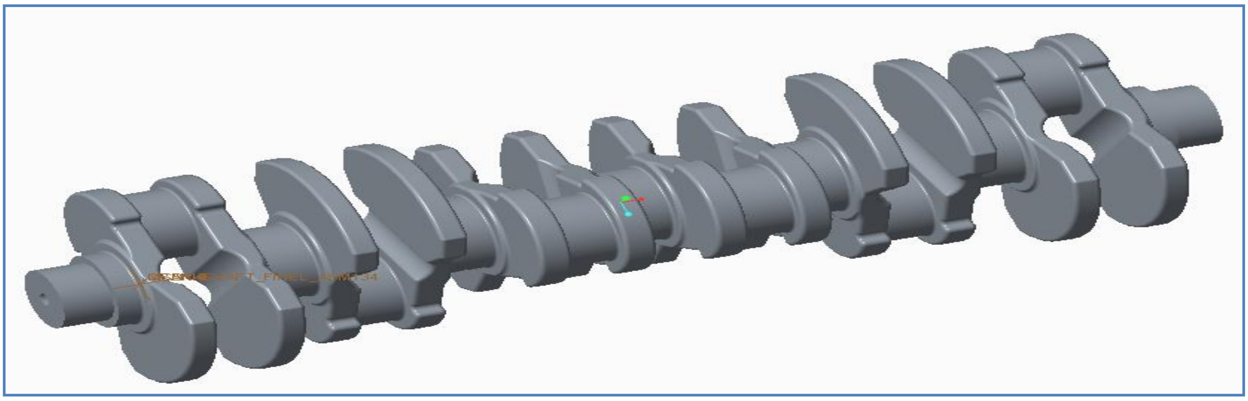

Fig 1 indicating CREO model of Crankshaft

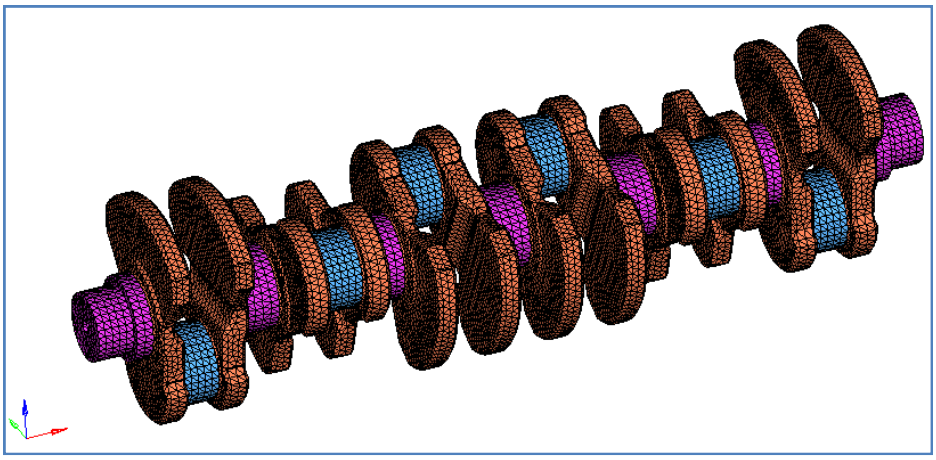

Figure 2 indicating Hypermesh model of crankshaft

Define boundary condition for analysis:

The crank-shaft is displacements for bearings position. The components of the connecting rod thrust force such as tangential and radial forces acting on each crank pin

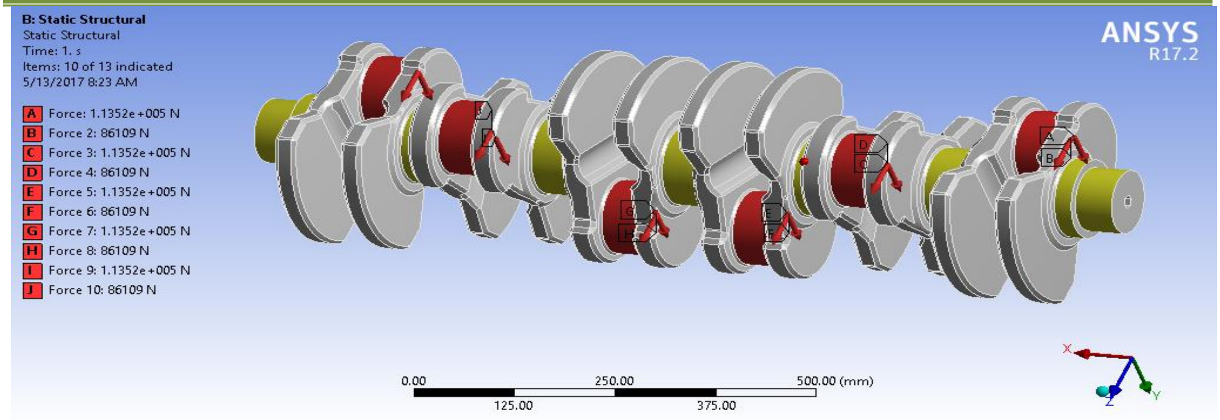

Figure 3 indicating application of load & displacement constraints

Results &discussion:

Material: Structural steel

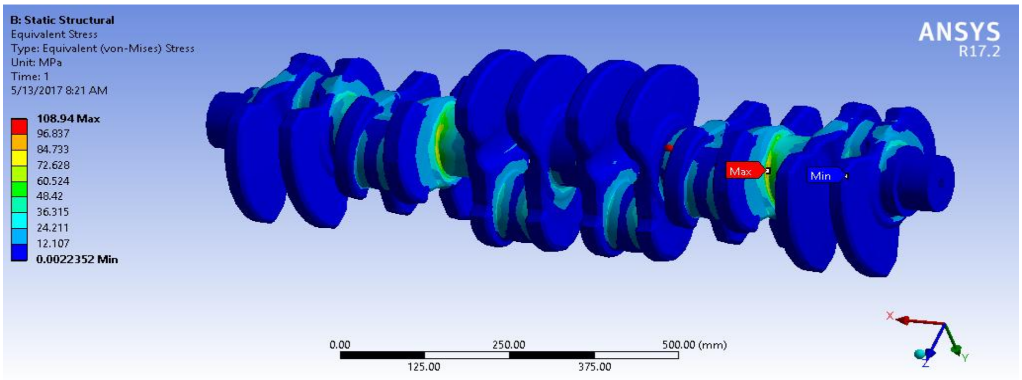

Figure 3 indicating Equivalent stress on structural steel crank-shaft

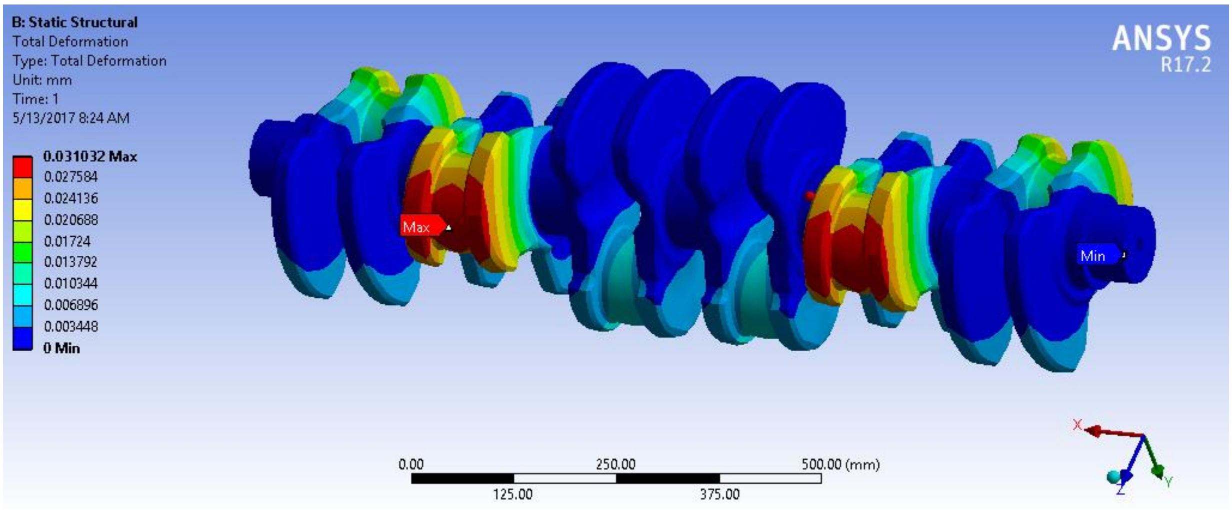

Figure 4: Total deformation on structural steel crank-shaft (mm)

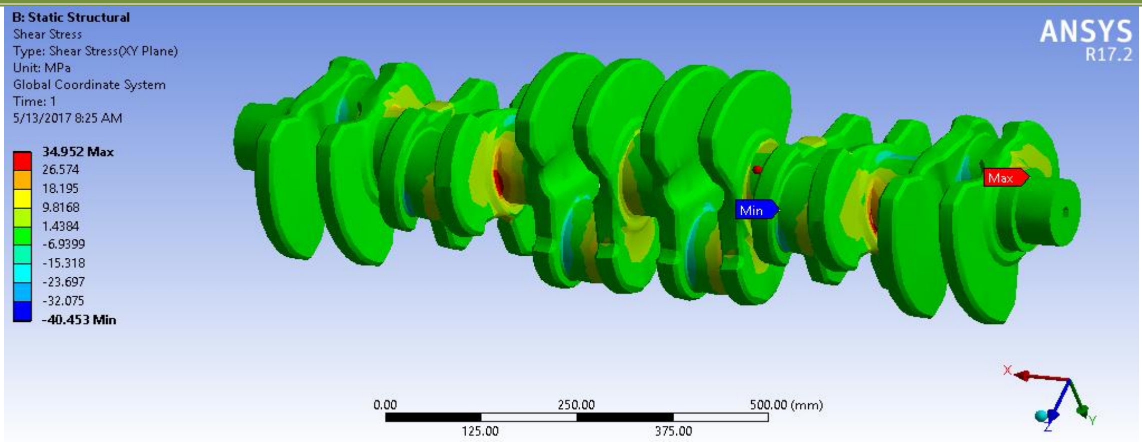

Figure 5: Shear stress distribution structural steel in the Crank-Shaft

Material type:- AL6063

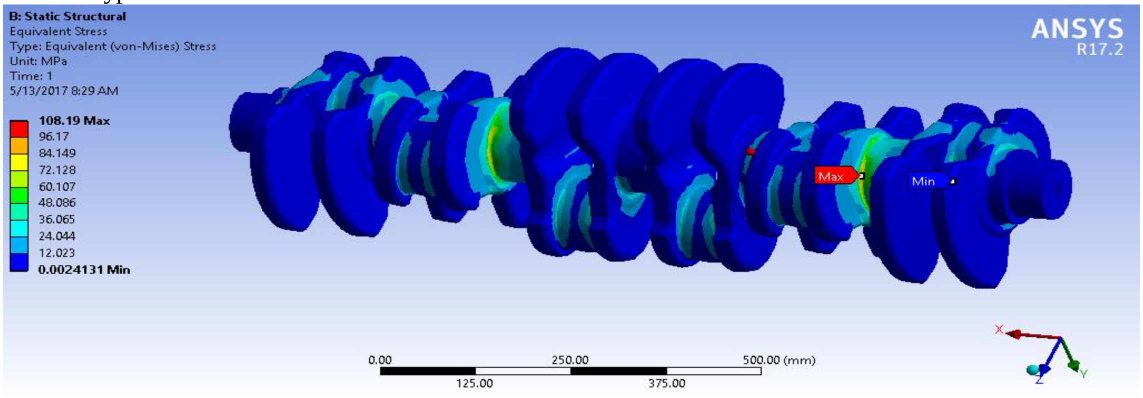

Figure 6: Equivalent stress on AL6063 crank-shaft

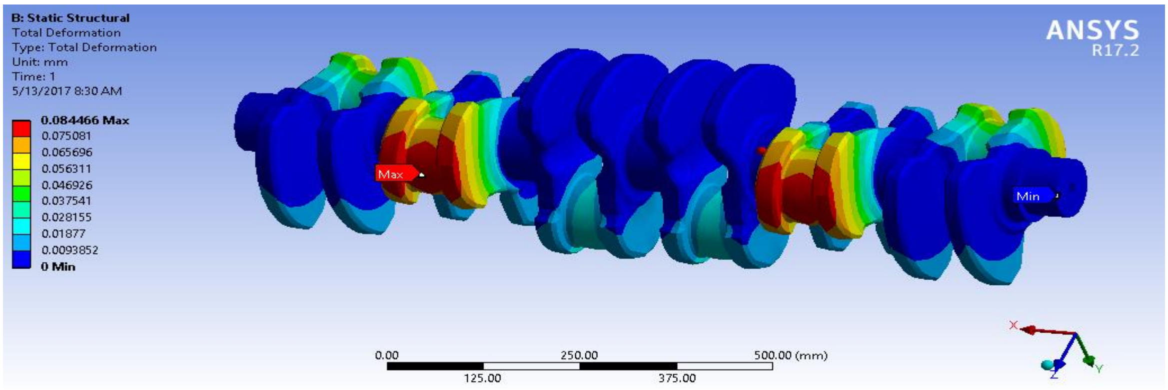

Figure 7: Total deformation on AL6063 crank-shaft (mm)

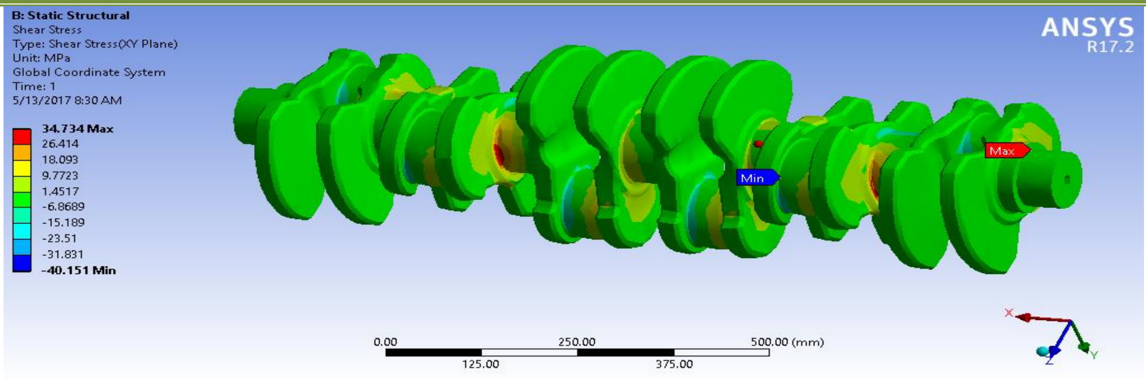

Figure 8: Shear stress distribution AL6063 in the Crank-Shaft

Material type:- High Strength Carbon Fiber

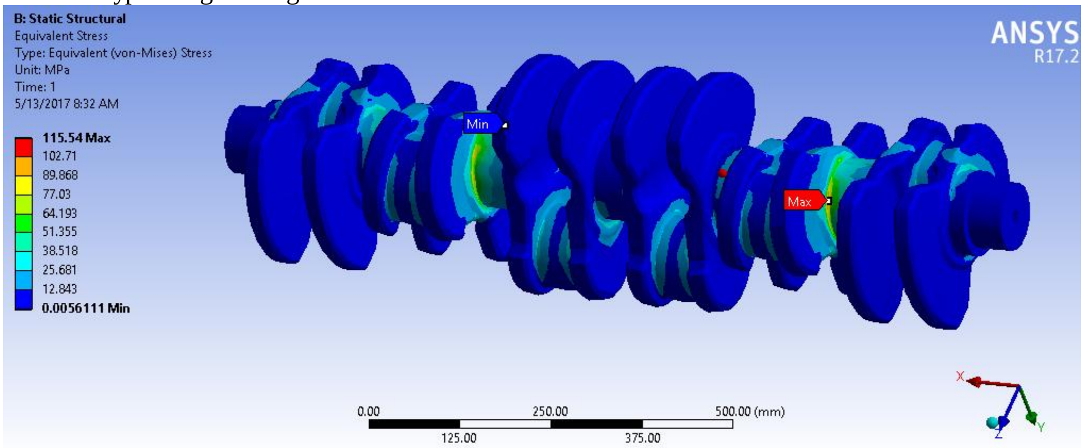

Figure 9: Equivalent stress on High Strength Carbon Fiber crank-shaft

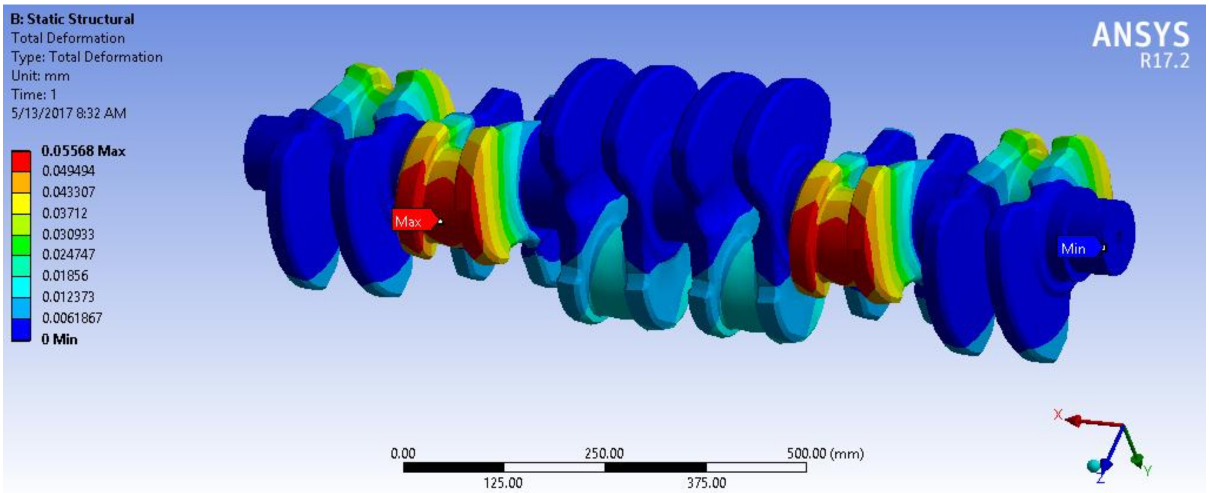

Fig 10: Total deformation on High Strength Carbon crank-shaft (mm)

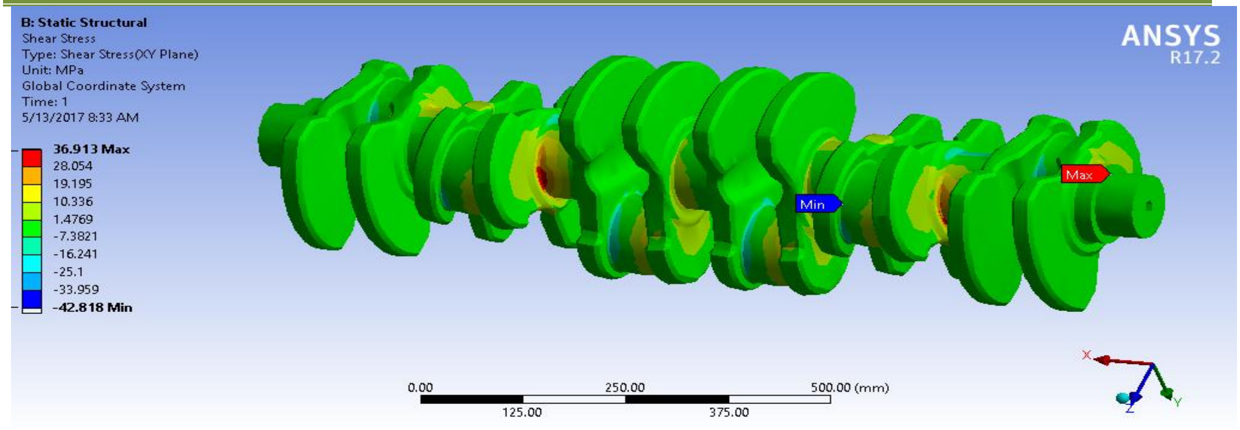

Figure 11: Shear stress distribution High Strength Carbon in the Crank-Shaft

MATERIAL	TOTAL DEFORMATION(mm)	EQUIVALENT STRESS(MPa)	SHEAR STESS(MPa)
Structural steel	0.031032	108.94	34.95
Aluminium Metal matrix composite	0.08446	108.19	34.73
High Strength Carbon Fiber	0.05568	115.54	36.91

Table 5 comparing different materials with the deformation, equivalent stress and shear stress

Dynamic analysis of six cylinder four stroke diesel engine:

- **Free vibration analysis**

Material I: Structural steel

Mode	Frequencies [Hz]	Type of mode
1	0	Rigid body displacement
2	0	Rigid body displacement
3	0	Rigid body displacement
4	0	Rigid body displacement
5	1.4831e-004	Rigid body displacement
6	2.4553e-004	Rigid body displacement
7	118.96	Bending
8	136.71	Bending
9	283.97	Bending + Torsion
10	320.67	Bending + Torsion

Table 6 indicating Natural frequencies and the corresponding Mode displacement

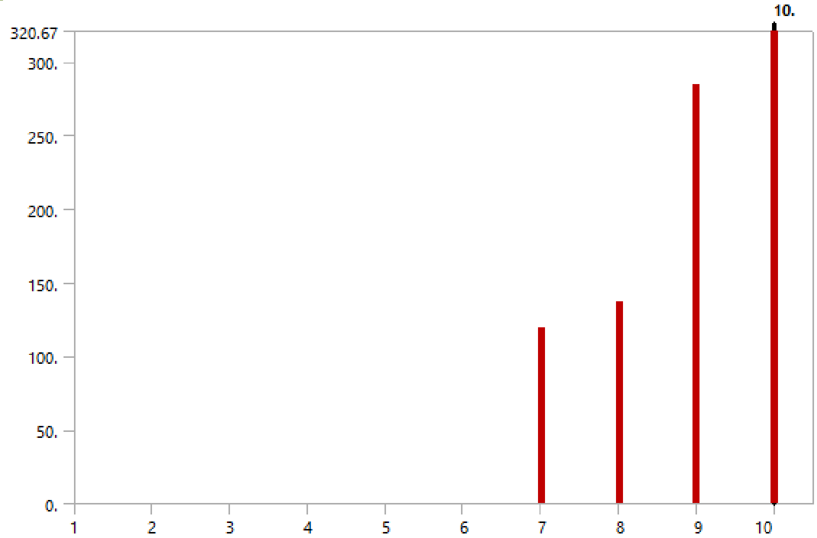

Figure 12: variation of number of modes vs frequency. X-axis contains number of modes and Y-axis contains frequencies

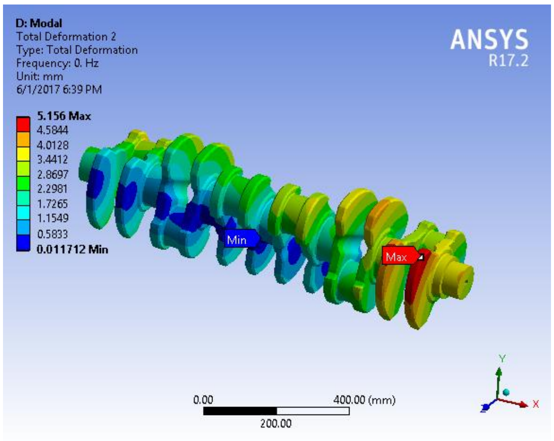

Fig. 13- Mode 1(rigid body displacement)

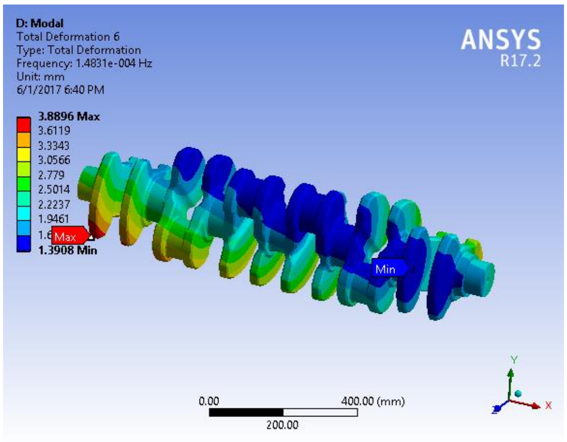

Fig.14 - Mode 5(rigid body displacement)

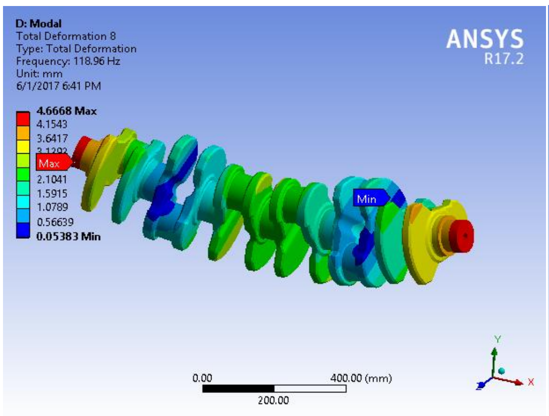

Fig15. -Mode 7(bending mode)

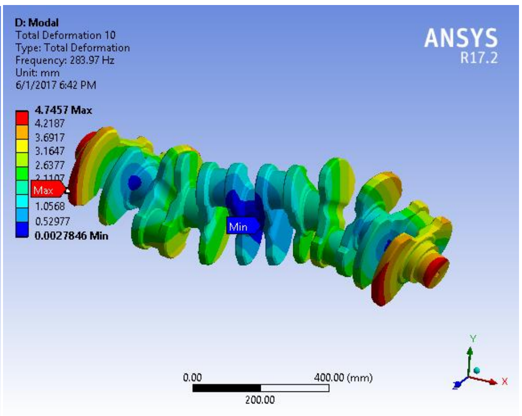

Fig.16 - Mode 9(combined bending and torsion)

Material II: **AL 6063+Sic+Graphite+Al_2o_3**

Mode	Frequencies [Hz]	Type of mode
1	0	Rigid body displacement
2	0	Rigid body displacement
3	1.486e-004	Rigid body displacement
4	2.427e-004	Rigid body displacement
5	3.3458e-004	Rigid body displacement
6	3.905e-004	Rigid body displacement
7	124.23	Bending
8	142.36	Bending
9	295.72	Bending + Torsion
10	333.5	Bending + Torsion

Table 7 indicating Natural frequencies and the corresponding Mode displacement

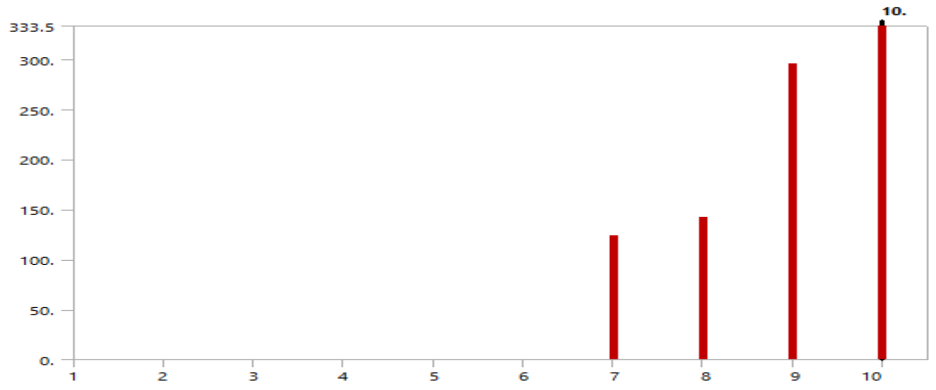

Fig 17- variation of number of modes vs frequency. X-axis contains number of modes and Y-axis contains frequencies

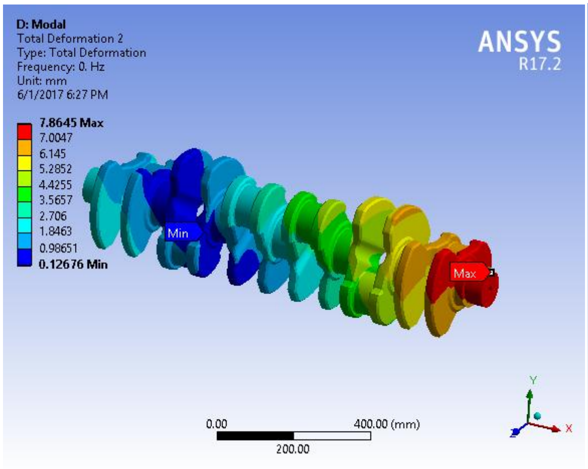

Fig 18- Mode 1(rigid body displacement)

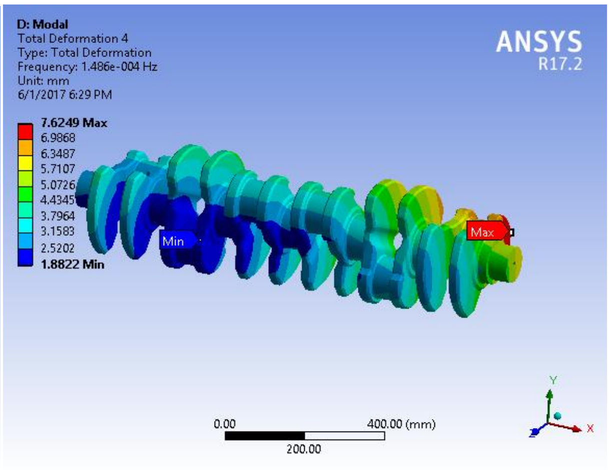

Fig 19- Mode 3(rigid body displacement)

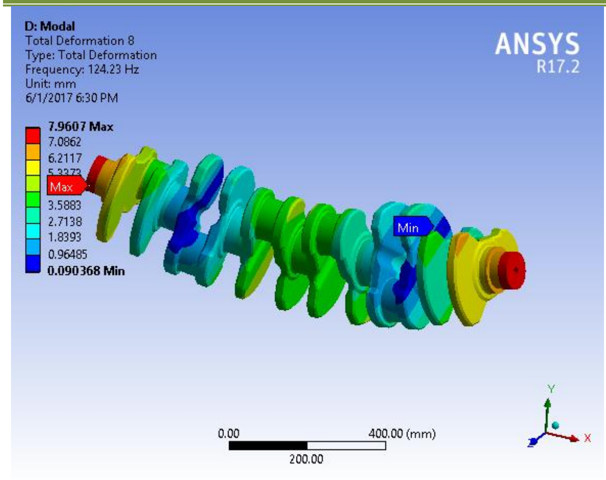

Fig 20. -Mode 7(bending mode)

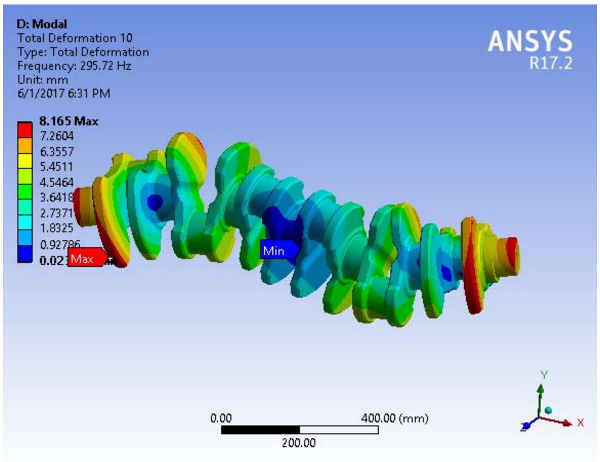

Fig 21. - Mode 9(combined bending and torsion)

Material III: High strength carbon fiber

Mode	Frequencies [Hz]	Type of mode
1	0	Rigid body displacement
2	0	Rigid body displacement
3	0	Rigid body displacement
4	3.0325e-004	Rigid body displacement
5	4.1804e-004	Rigid body displacement
6	4.356e-004	Rigid body displacement
7	180.72	Bending
8	212.71	Bending
9	438.76	Bending + Torsion
10	502.52	Bending + Torsion

Table 8 indicating Natural frequencies and corresponding mode positions

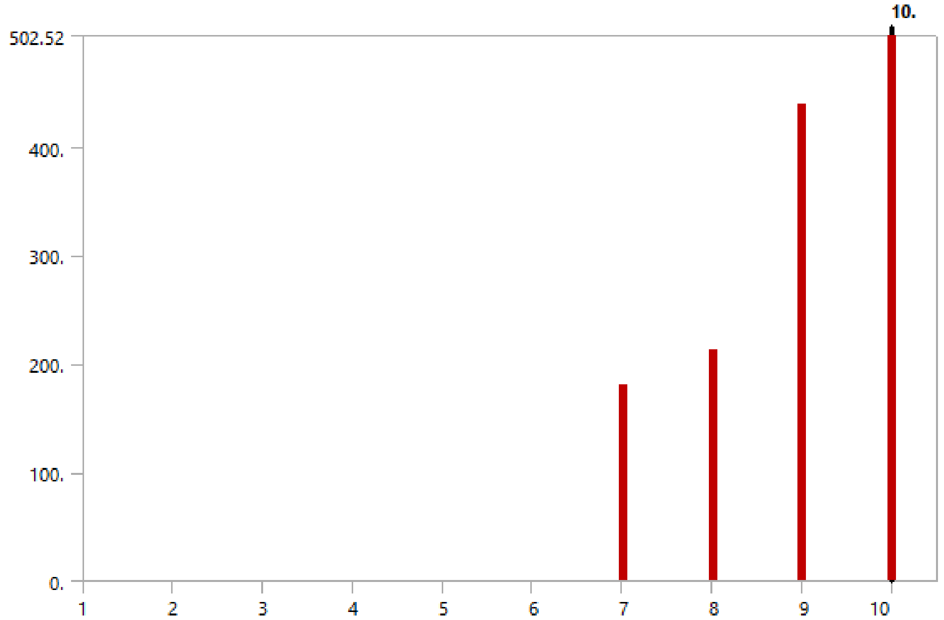

Fig 22.- variation of number of modes vs frequency.

X-axis contains number of modes and Y-axis contains frequencies

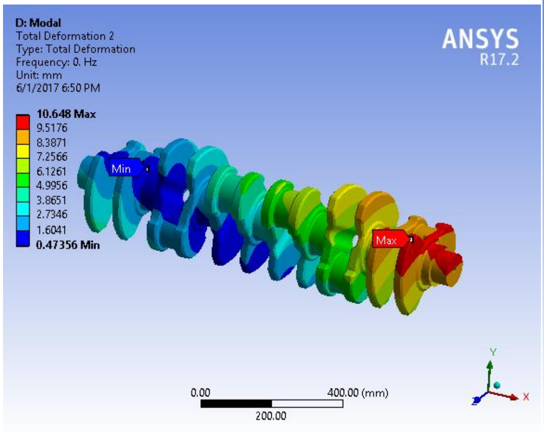

Fig 23- Mode 1(rigid body displacement)

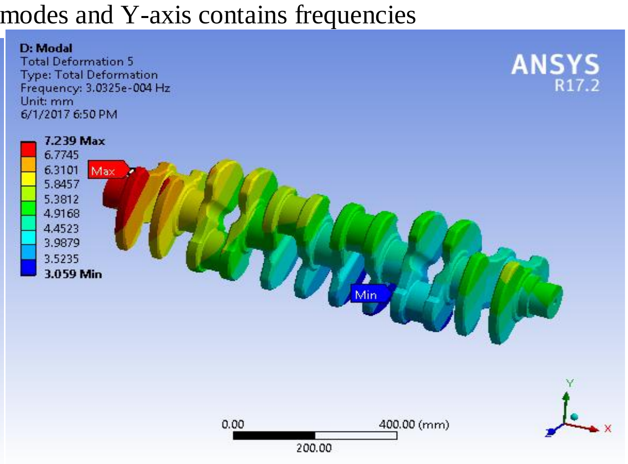

Fig 24. - Mode 4(rigid body displacement)

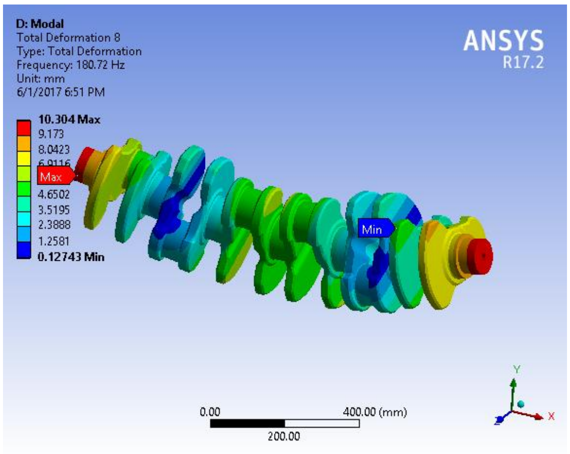

Fig 25 -Mode 7(bending mode)

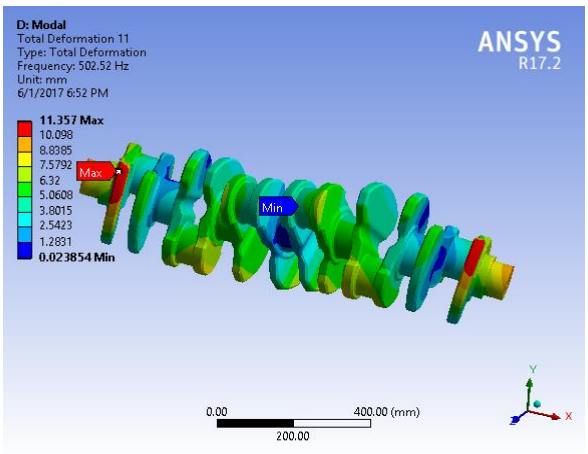

Fig 26 - Mode 10(combined bending and torsion)

5. Conclusions:

1. Design calculations of six cylinder four stroke diesel engine are calculated as per design standards of design of machine elements and CREO model of crank shaft is done and analysis using ANSYS WORKBENCH is carried successfully
2. The deformation obtained in structural steel is 0.031032 mm which is less when compared to Aluminum metal matrix composite and high strength carbon fiber which is having 0.08446 mm & 0.05568 mm respectively
3. Equivalent Von- mises stress is less for Aluminium metal matrix composite is less when compared to structural steel and high strength carbon fiber
4. Shear stress is less for Aluminium metal matrix composite is less when compared to structural steel and high strength carbon fiber
5. At 360^0 crank angle position the total deformation is 0.0331 mm ,max von-mises stress is 115.32 MPa and Max shear stress is 43.295 MPa is for structural steel
6. At 360^0 crank angle position the total deformation is 0.0902 mm ,max von-mises stress is 114.67 MPa and Max shear stress is 43.01 MPa is for Aluminium metal matrix composite
7. At 360^0 crank angle position the total deformation is 0.0593 mm ,max von-mises stress is 121.65 MPa and Max shear stress is 45.83 MPa is for high strength carbon fiber
8. At mode 10 of 320.67 Hz the mode of bending and torsion is obtained in structural steel.
9. At mode 10 of 333.5 Hz the mode of bending and torsion is obtained in Aluminium metal matrix composite
10. At mode 10 of 502.57 Hz the mode of bending and torsion is obtained in high strength carbon fiber

References

[1]. E.Brusa, C.Delprete, G.Genta (2007) “TORSIONAL VIBRATION OF CRANKSHAFTS: EFFECTS OF NON-CONSTANT MOMENTS OF INERTIA” in journal of sound and vibration of volume 205 Issue2.

[2]. Ravi Kumar Goel1, Harshwadhan Sharma and Annima Panwar(2014)” Stress Analysis and Optimization of Crankshaft Using CAE Tools” in International journal of Mechanical engineering and Robotics research ISSN 2278 – 0149 www.ijmerr.com Special Issue, Vol. 1, No. 1, January 2014.

[3]. Amit Solanki , Jaydeepsinh Dodiya (2014) “Design and Stress Analysis of Crankshaft for Single Cylinder 4-Stroke Diesel Engine” INTERNATIONAL JOURNAL FOR RES EARCH IN AP PL I ED SC I ENC E AND ENGINEERING TECHNOLOGY (IJRAS ET) Vol. 2 Issue V, May 2014 ISSN: 2321-9653.

[4]. Jaimin Brahmbhatt(2012) “Design And Analysis Of Crankshaft For Single Cylinder 4-Stroke Deisel Engine”, International Journal of Advanced Engineering Research and Studies- E-ISSN2249– 8974.

[5]. Yu Ding and Xiaobo Li.,2011, “ Crankshaft Strength Analysis of a Diesel Engine Using Finite Element Method,” Asia-Pacific Power and Energy Engineering Conference.

[6]. Jian Meng., Yongqi Liu., Ruixiang Liu.,2011,“Finite Element Analysis of 4- Cylinder Diesel Crankshaft, ” I.J. Image, Graphics and Signal Processing, 5, 22-29.

[7]. Nitin S Gokhale and Sanjay S Deshpande (2008),”Practical Finite Element Analysis”, Finite to Infinite, India.

[8]. Sun Lianke, Tang-Bin, XueDongxin, Song Xigeng (2007), “FEA Optimal Design of Diesel Engine Crankshaft”. Tractor_Farm Transporter, Vol. 34(3), pp. 54-55.