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Modeling and Stress Analysis of Crankshaft Using FEM

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Abstract— **Crankshaft is large volume production component with a complex geometry in the Internal Combustion (I.C) Engine. This converts the reciprocating displacement of the piston in to a rotary motion of the crank..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 will be laborious 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. In this project, an attempt has been made to analyze the crankshaft of two different materials by using Finite element software ANSYS. The static analysis is conducted on the crankshaft with two different materials and results are validated by comparing various outcomes such as total deformation, equivalent stress and strain of these materials from which better material can be found.**

Index Terms*— *Crankshaft, Pro-E, ANSYS Workbench, FEM, Forged steel,Ti-6Al-4V +12%TiC

I. INTRODUCTION

The crankshaft plays a vital role in all Internal Combustion Engines. It is a large component, which converts the reciprocating displacement of the piston in to rotary motion with a four link mechanism. It has complex shape of geometry. The crankshaft experiences a cyclic load, due to the cyclic load fatigue failure occur over a period. The fatigue analysis has to be considered in the design stage itself. The design and development of crankshaft is always been an important task for the production industry, in order to reduce the manufacturing cost of the product, minimum weight possible and proper fatigue strength and other functional requirements. These improvements result in lighter and smaller engines with better fuel efficiency and higher power output. This study was conducted on a four cylinder four stroke cycle engine. Three different crankshafts from similar engines were studied in this research. The finite element analysis was performed or each crankshaft. Crankshaft must be strong enough to take the downward force of the power stroke without excessive bending so the reliability and life of the internal combustion engine depend on the strength of the crankshaft largely. The crank pin is like a built in beam with a distributed load along its length that varies with crank positions. Each web is like a cantilever beam subjected to bending and twisting.

1. Bending moment which causes tensile and compressive stresses.
2. Twisting moment causes shear stress.

There are many sources of failure in the engine one of the most common crankshaft failure is fatigue at thefilletareasduetothebendingloadcausesbythecombustion.At themomentofcombustiontheloadfromthepistonistransmitted to the crankpin, causing a large bending moment on the entire geometry of the crankshaft. At the root of the fillet areas stress concentrations exist and these high stress range locations are the points where cyclic loads could cause fatigue crank initiation leading to fracture.

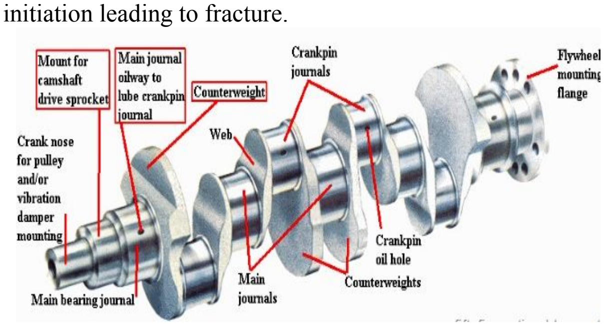

Figure 1.1: Multi cylinder crankshaft

Rinkle Garg and Sunil Baghl [1] have been analyzed crankshaft model and crank throw were created by Pro-E Software and then imported to ANSYS software. The result shows that the improvement in the strength of the crankshaft as the maximum limits of stress, total deformation, and the strain is reduced. The weight of the crankshaft is reduced .There by, reduces the inertia force. As the weight of the crankshaft is decreased this will decrease the cost of the crankshaft and increase the I.C engine performance. C.M. Balamurugan et al [2] has been 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 ductile cast iron. The Three dimensional model of crankshaft were created by solid edge software and then imported to ANSYS software. The optimization process included geometry changes compatible with the current engine, fillet rolling and results in increased fatigue strength and reduced cost of the crankshaft, without changing connecting rod and engine block.

Gu Yingkui, Zhou Zhibo. [3] have been discussed a three-Dimensional model of a diesel engine crankshaft created by using PRO/E software and analytical ANSYS Software tool, it shows that the high stress region mainly concentrates in the knuckles of the crank arm & the main

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journal and the crank arm & connecting rod journal, which is the area most easily broken. Abhishekchoubey, and Jamin Brahmbhatt.[4] have been analyzed crankshaft model and 3-dimentional model of the crankshaft were created by SOLID WORKS Software and imported to ANSYS software. The crankshaft maximum deformation appears at the centre of crankpin neck surface. The maximum stress appears at the fillets between the crankshaft journals and crank cheeks and near the central point journal. The edge of main journal is high stress area. R. J. Deshbhratar, and Y.R Suple.[5] have been analyzed4-cylinder crankshaft and model of the crankshaft were created by Pro/E Software and then imported to ANSYS software The maximum deformation appears at the centre of crankshaft surface. The maximum stress appears at the fillets between the crankshaft journal and crank cheeks, and near the central point. The edge of main journal is high stress area. The crankshaft deformation was mainly bending deformation under the lower frequency. And the maximum deformation was located at the link between main bearing journal and crankpin and crank cheeks.

An extensive literature review on crankshafts was performed by Zoroufi and Fatemi (2005) (6). Their study presents a literature survey focused on fatigue performance evaluation and comparisons of forged steel and ductile cast iron crankshafts. In their study, crankshaft specifications, operation conditions, and various failure sources are discussed. The common crankshaft material and manufacturing process technologies in use were compared with regards to their durability performance. In their literature review, geometry optimization of crankshafts, cost analysis and potential cost saving opportunities are also briefly discussed. Solanki et al. [7] presented literature review on crankshaft design and optimization. The materials, manufacturing process, failure analysis, design consideration etc. were reviewed. The design of the crankshaft considers the dynamic loading and the optimization can lead to a shaft diameter satisfying the requirements of the automobile specifications with cost and size effectiveness. They concluded that crack grows faster on the free surface while the central part of the crack front be comes straighter. Fatigue is the dominant mechanism of failure of the crankshaft.
Meng et al. [8] discussed the stress analysis andmodalanalysisofa4cylindercrankshaft.FEMsoftwareANSYSwas used to analyze the vibration modal and distortion and stress status of crank throw. The relationship between frequency and the vibration modal was explained by the modal analysis of crankshaft. This provides a valuable theoretical foundation for the optimization and improvement of engine design. Maximum deformation appears at the centre of the crankpin neck surface. The maximum stress appears at the fillet between the crankshaft journal and crank cheeks, and near the central point journal. The crankshaft deformation was mainly bending deformation was mainly bending deformation under the lower frequency. Maximum deformation was located at the link between main bearing journal and crankpin and crank cheeks. So, the area prone to appear the bending fatigue crack.

Montazersadgh and Fatemi [9] choose forged steel and a cast iron crankshaft of a single cylinder four stroke engine. Both crankshafts were digitized using a CMM machine. Load analysis was performed and verification of results by ADAMS modeling of the engine. At the next step, geometry and manufacturing cost optimization wasperformed. Considering torsional load in the overall dynamic loading conditions has no effect on von misses stress atthecritically stressed location. Experimental stress and FEA results showed close agreement, within 7%difference.Critical locations on the crankshaft are all located on the fillet areas because of high stress gradients in these locations. Geometry optimization results in 18%weightreduction of the forged steel. Fillet rolling induces compressive residual stress in the fillet areas, which results in 165% increase in fatigue strength of the crankshaft.

II. OBJECTIVES

1. To model the crankshaft using PRO-E software
2. Static analysis by using ANSYS WORKBENCH software

III. MODELING OFCRANKSHAFT

Configuration of the Engine to which the crankshaft belongs

Table 1: Dimensions for crankshaft

Length of crank pin	12.7
Diameter of crank pin	25.4
Shaft diameter	19.05
Bore diameter	68.3
Stroke length	51.8
Maximum pressure	3.15 N/mm2

Force on the piston:

Bore diameter (D) =68.30mm,

1)F_p= Area of the bore *Max. Combustion pressure

$$= \pi/4 * D^2 * P_{max}$$

F_p =11.53KN

2) Angle of inclination of the connecting rod with the line of stroke (i.e. angle Ø).

SinØ = sinθ/(l/r)

Take l/r=5,The maximum value of tangential force lies when the crank is at an angle of θ=35° (from 30^0 to 40^0 for diesel engines)

Ø=6.35°

3) Thrust Force in the connecting rod,

$F_Q = F_P/\cos Ø$

F_Q =11.60KN

4) Thrust on the crankshaft can be split into tangential component and radial component.

(i) Tangential force on the crankshaft,

$$F_T = F_Q \sin(\theta + Ø)$$
$$=7.66KN$$

(ii) Radial force on the crankshaft,

$$F_R = F_Q \cos(\theta + Ø)$$
$$=8.70KN$$

5) Reactions at bearings due to tangential force is given by

$$H_{T1}=H_{T2}= F_T/2$$
$$=3.83KN$$

6) Reactions at bearings due to radial force is given by

$H_{R1} = H_{R2}= F_R/2$

$$=4.35KN$$

7) Bending moment at the centre of the crankshaft
$M_C=H_{R1}*b_2$
Where $b_2 = 9.65$mm
=41.977KN-mm
8) Twisting moment on the crankpin
$T_C=H_{T1}*r$
(Where r is the radius of the crank pin,r=12.7mm)
T_C =48.641KN-mm

9) The von Misses stress induced in the crank-pin σ_v is,
$M_{ev} = \sqrt{(K_b*M_c)^2+0.75(K_t*T_c)^2}$
=105.1 KN-mm
Here, K_b = combined shock and fatigue factor for bending (Take K_b=2)
K_t = combined shock and fatigue factor for torsion (Take K_t =1.5)
$M_{ev} =\pi/32*d^3*\sigma_v$
σ_v= 131.20N/mm^2

First prepare Assembly in Pro-E 5.0 for crankshaft and Save as this part as .iges for Exporting into ANSYS 14.5. for meshing and static analysis.

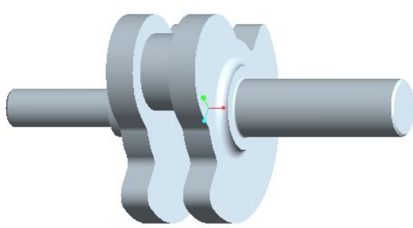

Figure :- 3.1. Model created in Pro-E

IV. MESHING OF CRANKSHAFT

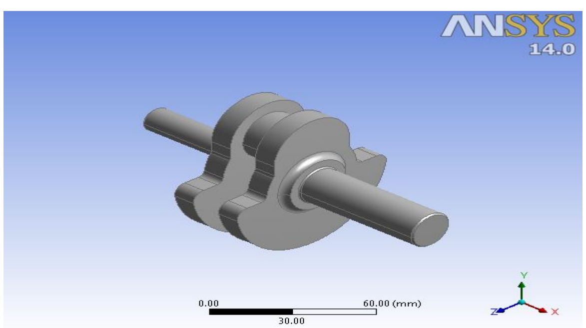

Figure:- 4.1. Model imported from Pro-E in ANSYS

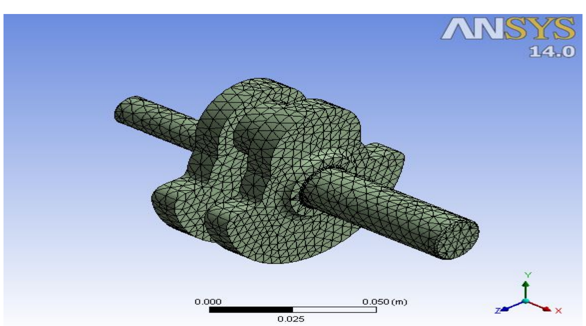

Figure:- 4.2. Meshed view of crankshaft

V. ANALYSIS

ANSYS is general-purpose Finite Element Analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user designed size) called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. The ANSYS Workbench environment is an intuitive up-front finite element analysis tool that is used in conjunction with CAD systems and/or Design Model. ANSYS Workbench is a software environment for performing structural, thermal, and electromagnetic analyses. The Workbench focuses on attaching existing geometry, setting up the finite element model, solving, and reviewing results

5.1 Static Structural Analysis

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed that is, the loads and the structure's response are assumed to vary slowly with respect to time. The types of loading that can be applied in a static analysis include externally applied forces and pressures, Steady-state inertial forces (such as gravity or rotational velocity), Imposed (nonzero) displacements, Temperatures (for thermal strain).

5.2 Materials used for Crankshaft

Forged steel,
Ti-6Al-4V +12%TiC

5.3 Applying Material Properties for analysis

1. Ti-6Al-4V+12%TiC

Young's modulus : 1.14E14 Pa
Density : 4430kg/m^3
Poisson's ratio : 0.342

2. Forged steel

Young's modulus : 2.21E11Pa
Density : 7833kg/m^3
Poisson's ratio : 0.3

5.4 Define boundary condition for analysis:

Boundary conditions play an important role in Finite Element Analysis.Here we have taken both remote displacements for bearing supports are fixed. Then apply force and moment on the crankpin
Inputs given for the analysis of crank shaft

Moment: 41.977 KN-mm
Force : 11.53 KN

VI. ANALYSIS RESULTS

(i) For Forged Steel

Various analysis results for forged steel are as follows:

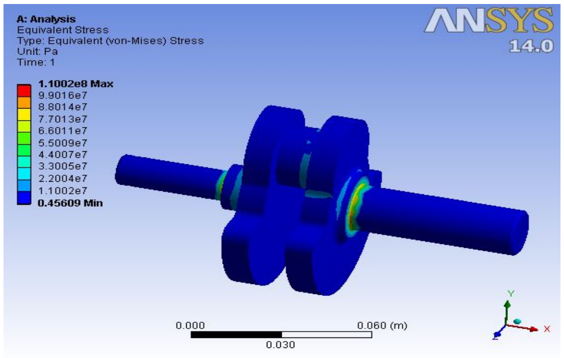

Figure:- 6.1Equivalent stress

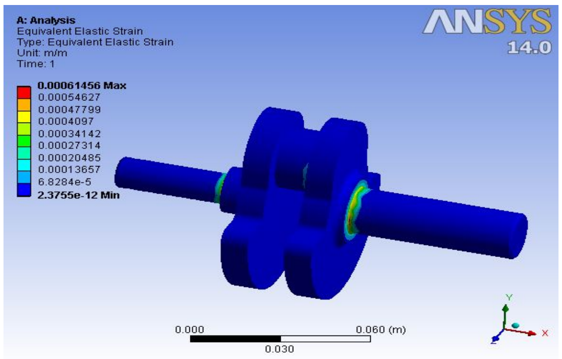

Figure:- 6.2 Equivalent strain

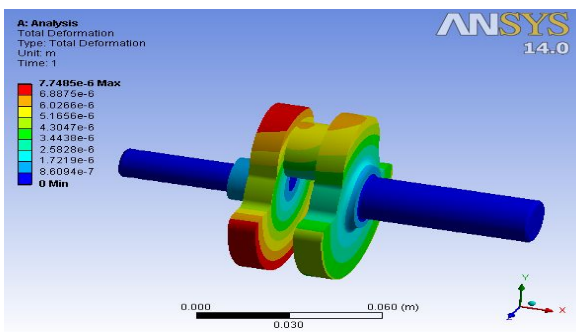

Figure:- 6.3Total deformation

(ii) Ti-6Al-4V+12%TiC

Various analysis results for forged steel are as follows:

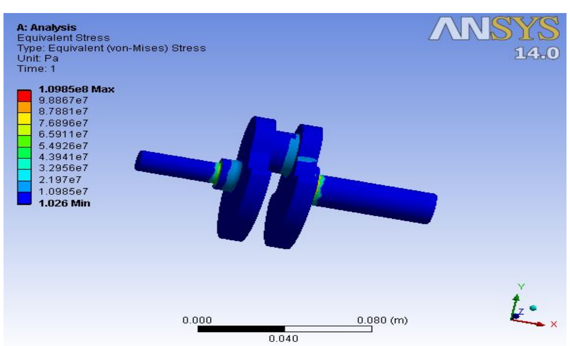

Figure: 6.4Equivalent stress

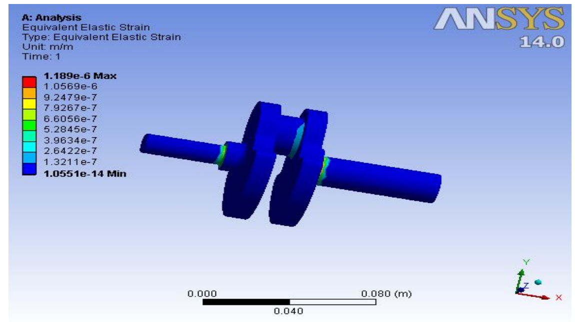

Figure: 6.5 Equivalent strain

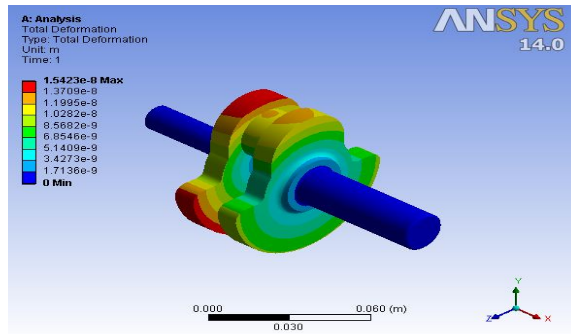

Figure: 6.6Total deformation

VII. VALIDATED RESULTS

Table 7.1 Comparison of results between Forged steel and Ti-6Al-4V+12% TIC

PARAMETERS	Forged steel		Ti-6Al-4V+12% TIC	
	MIN	MAX	MIN	MAX
Total deformation (m)	0	7.749E-6	0	1.54E-8
Equivalent Elastic Strain(m/m)	2.38E-12	0.0006146	1.05E-14	1.18E-6
Equivalent stress (Pa)	0.4561	1.1E8	1.02	1.09E8
Life(cycles)	394.74	1E6	364.82	1E6
Damage	1000	3.753E7	1000	3.68E7

CONCLUSION

The analysis of crank shaft we found that the Ti-6Al-4V+12% TiC is material have a good physical properties and it have a appreciable deformation under the moment when compared with forged material steel. The stress, strain of the Ti-6Al-4V+12% TiC is low compared when compared with forged steel. Hence, in this analysis Ti-6Al-4V+12% TiC is found to be better material for crankshaft than forged steel.

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