

Fatigue Life Estimation of Forged Steel and Ductile Iron Crankshaft of Single Cylinder Engine Using Fatigue assessment Techniques

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Abstract:- Crankshaft is one of the critical components of an IC engine, failure of which may result in disaster and makes engine useless unless costly repair performed. It possesses intricate geometry and while operation experiences complex loading pattern. In IC engines, the transient load of cylinder gas pressure is transmitted to crankshaft through connecting rod, which is dynamic in nature with respect to magnitude and direction. However, the piston along with connecting rod and crankshaft illustrate respective reciprocating and rotating system of components. the dynamic load and rotating system exerts repeated bending and shear stress due to torsion, which are common stresses acting on crankshaft and mostly responsible for crankshaft fatigue failure. Hence, fatigue strength and life assessment plays an important role in crankshaft development considering its safety and reliable operation. The present paper is based on comparative studies of two crankshafts of fatigue life assessment of a single cylinder diesel engine crankshaft by using High cycle fatigue (HCF) technique

Keywords – Forged steel, crankshaft, FEA, High cycle fatigue

1. INTRODUCTION

1.1 Background: Crankshaft is a large component with a complex geometry in the engine, which converts the reciprocating displacement of the piston to a rotary motion with a four link mechanism. Since the crankshaft experiences a large number of load cycles during its service life, fatigue performance and durability of this component has to be considered in the design process. The most common application of a crankshaft is in an automobile engine. However, there are many other applications of a crankshaft which range from small one cylinder lawnmower engines to very large multi cylinder marine crankshafts and everything in between.

1.2 Crankshaft description

A crankshaft consists of main journals, webs, and connecting rod journals, commonly known as crank-pins. The main components of a crankshaft are shown in Figure 1.2. The crankshaft rotates on bearings inside the engine. The bearings supporting the crankshaft are the main bearings of an engine and the part of the crankshaft that rides on the bearings are called the main bearing journals. The number of main bearings and main journals in an engine depend on its size. Small one cylinder engines have only two main bearings, one at each end of the crankshaft. Larger multi-cylinder engines usually have more than two main bearings at the ends and include some in the center part of the crankshaft for more support. The piston connects to the crankshaft on a bearing journal, referred to as a crank-pin. The crank-pins are

offset from the central rotating axis of the crankshaft causing the pistons to move when the crankshaft rotates. The webs create the offset between the central axis and the crankpins. The number of crank-pins depends on the type of engine and number of cylinders.

A single –cylinder engine will have only one crank-pin and two webs. Multi- cylinder engines will have one crank-pin per piston if the engine is a straight engine, meaning that all cylinders are in a line. If the engine is a V-engine, one bank of cylinders on each side of the crankshaft, two pistons will attach to the same crank-pin. Commonly a crankshaft will be classified by the number of crank throws or simply throws, which simply refers to the combination of the two webs and crank-pin. Therefore, a straight four cylinder engine will have four crank-pins as will a V-8 engine and both will be classifieds four throw crankshafts.

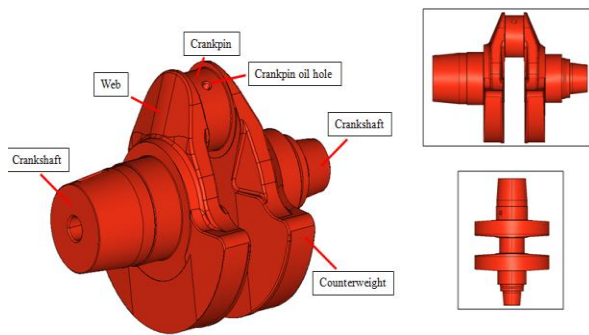


Fig.1.2- Geometry of crankshaft with different views

2. LITERATURE REVIEW

A literature survey was taken up to review research conducted on fatigue failures of crankshafts have been an important issues in the field of automotive industry. Since crankshaft experiences a large number of load cycles during its service life, its fatigue performance and durability has to be considered in this design process. Design development have always been an important issues in the crankshaft production industry, in order to manufacture a less expensive component with proper and higher fatigue strength satisfying the functional requirement. Hence fatigue analysis of crankshaft through different techniques like stress

life method and strain life method gives better insight of fatigue life of crank shaft. This led me to carry out this project.

Their study presents a literature focused on fatigue performance evaluation and comparisons of forged steel and ductile cast iron crankshafts. In this project, material of crankshafts is discussed and a brief literature review related to this topic is presented. Since this study is mostly about fatigue life evaluation of forged and ductile cast iron subjected to bending loads from the cylinder to the crank pin. Finite element modeling, static and fatigue analysis has been carried out to evaluate the structural integrity and durability of the crankshaft concerning these issues are also summarized and discussed in this chapter.

3. MONOTONIC AND FATIGUE MATERIAL PROPERTIES

Monotonic Properties	Forged Steel	Cast iron
Average Hardness, HRC	23	18
Modulus of Elasticity, E , GPa	221	178
Yield Strength (0.2 % Offset), MPa	625	412
Ultimate Strength, S _u , MPa	827	658
Percent Elongation, % EL	54%	10%
Percent Reduction in area, %	58%	6%
Strength coefficient , K, MPa	1316	119
Strain hardening exponent, n	0.152	0.183
True fracture strength, σ _f , Pa	980	658
True fracture ductility, ε _f	87%	6%

Cyclic Properties	Forged Steel	Cast Iron
Fatigue strength coefficient, σ_f' , MPa	1124	927
Fatigue strength exponent, b	-0.079	-0.087
Fatigue ductility coefficient, ϵ_f'	0.671	0.202
Fatigue ductility exponent, c	-597	0.696
Cyclic yield strength, YS' , MPa	505	519
Cyclic strength coefficient, K' ,	1159	1061
Cyclic strain hardening exponent, n'	1.128	0.114
$S_f = \sigma_f' (2N)^b$ at $N_f = 10^6$, MPa	359	263
Average E' , MPa	204	174

considered to give an accurate and reasonable solution whenever laboratory testing is not available.

Finite element modeling was performed on the forged steel and the ductile cast iron crankshafts. A linear elastic analysis was used due to the high cycle fatigue situation which requires nominally elastic loading. The finite element analysis was used to determine the critical location of the crankshafts, determine the stress concentration factors for the critical fillet locations, and determine the nominal stress applied for the purpose of life prediction. Using the stress concentration factor approach rather than directly using the local stress and strain at the critical locations from finite element analysis eliminates the need for a separate analysis for each load level.

The finite element model of the crankshaft geometry is modeled with quadrilateral tetrahedral elements as the geometry is complex, with global element size of 5mm and local element size of 0.25 mm at the fillets where the stresses are higher due to stresses concentrations. As a crankshaft is designed for very long life, stresses must be in the linear elastic range of the material. Therefore, all carried analysis is based on the monotonic and cyclic material properties.

4. MESHING OF CRANKSHAFT

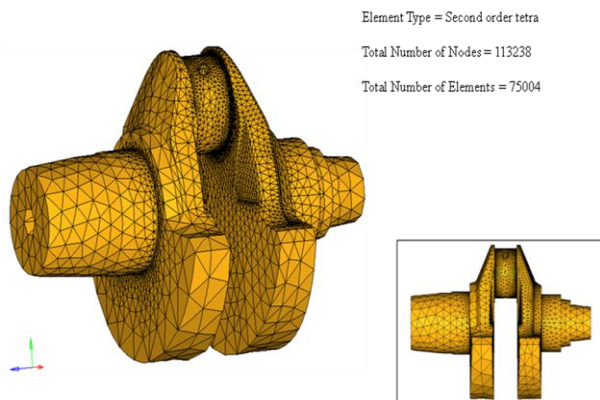


Fig4:finite element meshing of crankshaft

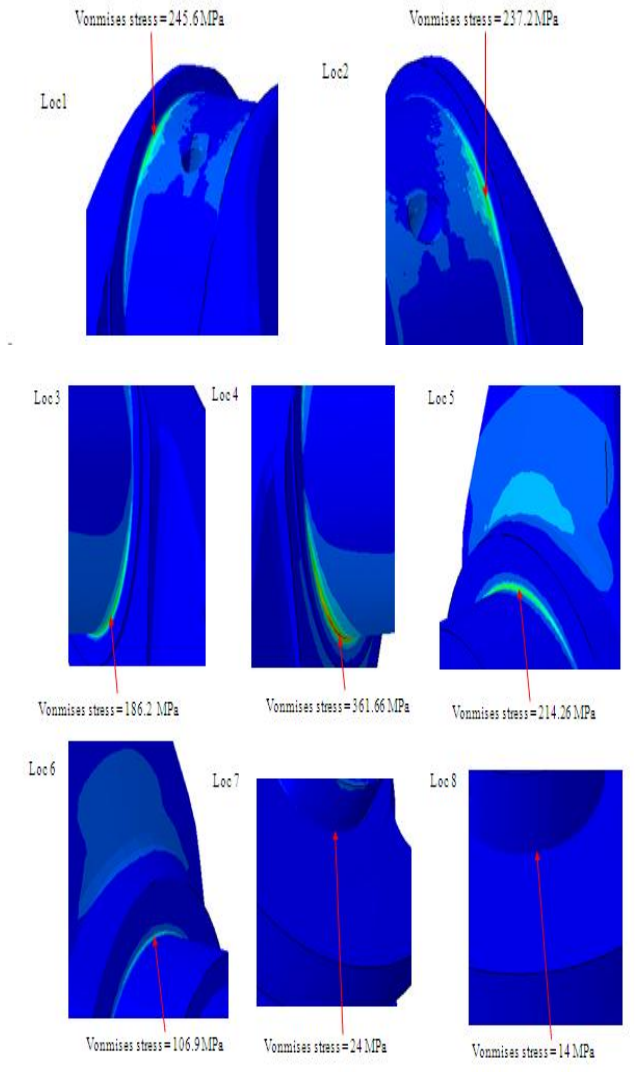
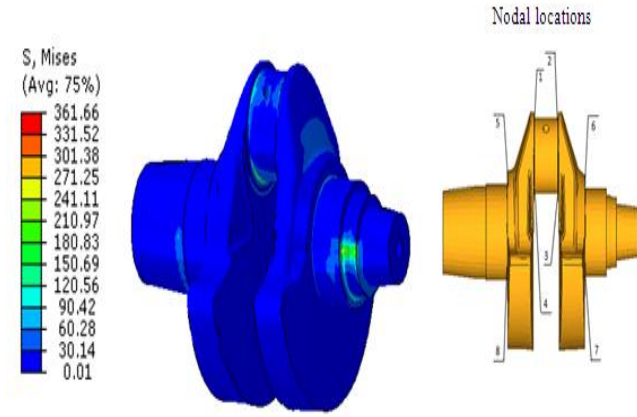
5. FINITE ELEMENT MODELLING AND ANALYSIS

Since the crankshaft has a complex geometry for analysis, finite element models have been

6. RESULTS

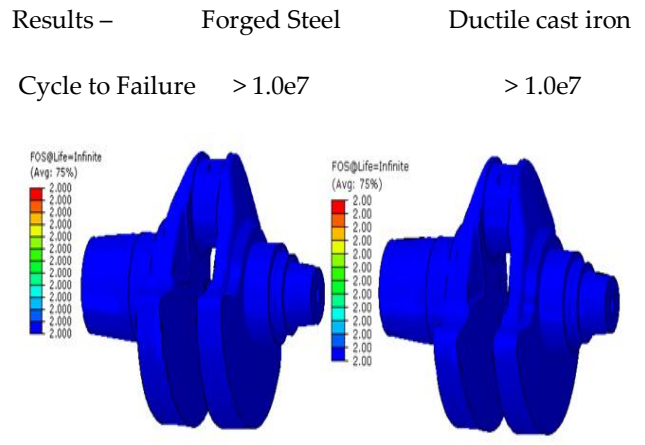
1.STATIC ANALYSIS RESULTS FOR 21 KN BENDING LOAD

Vonmises Stress Plot

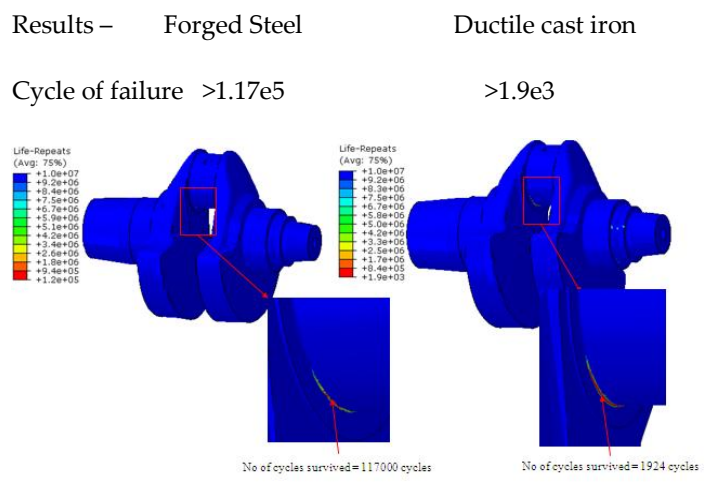


II. FATIGUE ANALYSIS OF 21 KN BENDING LOAD

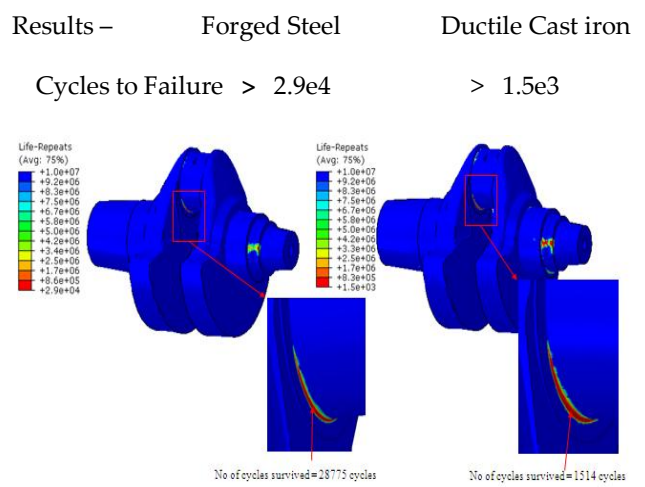
A. Fatigue life calculations without Mean stress correction, Nueber's rule and stress concentration factor



B. Fatigue life calculation with Mean stress correction, Neuber's rule and with out the stress concentration

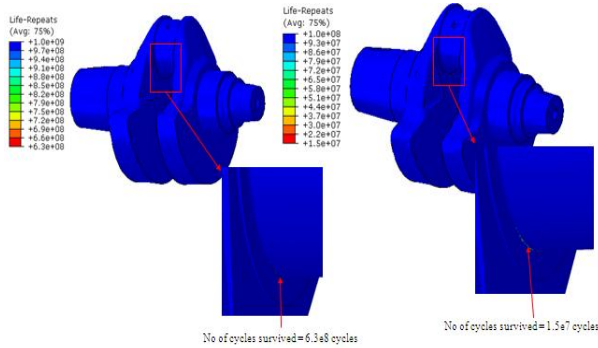


C. Fatigue life calculation with Mean stress correction, Neuber's rule and stress concentration



D.Fatigue life calculations with Mean stress correction, Neuber’s rule , stress concentration and Induction Hardening

Results – Forged Steel Ductile Cast iron
 Cycles to Failure > 6.3e8 > 1.5e7



SUMMARY OF RESULTS

1.The fatigue life of the crankshaft using the stress life approach is above 10e7 cycles in forged steel and ductile cast iron crankshaft without the considering the effect of the mean stress correction and fatigue notch factor

1. The fatigue life predictions using the Stress life approach is strongly influenced by an notch sensitivity of a material and mean stress correction factor
2. The fatigue life of the crankshaft accounting the Neuber’s rule is moderately influencing the fatigue life
3. The fatigue life of the crankshaft for forged steel crankshaft with induction hardening is having more life than ductile cast iron with induction hardening

The location 4 identified in static analysis results is in agreement with fatigue analysis results where least life has been predicated

5. CONCLUSION

The fatigue behaviors of forged steel and cast iron crankshafts from a single cylinder engine were obtained and compared with forged steel and ductile cast iron crankshaft. Results from finite element

analysis were used to obtain the stresses in the crankshafts. Fatigue life predictions using the S-N approach were then carried out using the stress results from static analysis. Based on the analyses performed the following conclusions were drawn:

1. These results indicate non-symmetric bending stresses on the crankpin bearing due to the lack of symmetry in a geometry indicating the need for FEA modeling due to the relatively complex geometry of the crankshaft.
2. There are two different load sources in an engine; inertia and combustion. These two load source cause both bending and torsional load on the crankshaft. The maximum load occurs at the crank angle of 355 degrees for this specific engine. At this angle only bending load is applied to the crankshaft.
3. The forged steel crankshaft has 97% more life than ductile cast iron considering mean stress correction, fatigue notch factor, Neuber’s rule and induction hardening.
4. Induction hardening induces the compressive stresses in the fillet areas which results in 100% increase in fatigue strength of the crankshaft and increases the life of the component significantly in forged steel and ductile cast iron crankshaft
5. Critical locations on the crankshaft geometry are all located on the fillet areas because of high stress gradients in these locations, which result in high stress concentration factors. This has been verified by static and fatigue analysis results.
6. The high cycle fatigue technique has been successful implemented in predicting the life of the forged steel and ductile iron crankshaft

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