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DYNAMIC STRUCTURAL ANALYSIS OF ENGINE CRANKSHAFT AT DIFFERENT ANGLE OF CRANK TURNS FOR THREE DIFFERENT MATERIALS

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Abstract

For many years, engines have been one of the main power machinery for different kinds of applications, and the main part of power machinery is a crankshaft that converts the piston's reciprocating displacement with four-link mechanisms into rotary motion. . The major limitation of the engine crankshaft is fatigue failure due to repeated load caused by bending and torsional load. In this paper, the comparative dynamics structural analysis was carried out for three different materials such as forged steel, cast iron and chromium-molybdenum steel with different angles of turns of cranks from 0° to 720° and to predict the stresses, deformation and fatigue life of crankshaft without compromising its weight, strength and reliability. The 3D CAD model was simulated with FEA software. The simulated results show that by applying bending load and torsional load for three materials, the maximum stresses were produced in the fillet area of the main bearing journal and in the fillet area of the crankpin journal at a crank angle of 360° respectively. The deformation results revealed that maximum deformation occurs at the mid-surface of the crankpin. From fatigue life prediction it was observed that forged steel and chromium-molybdenum steel shows better fatigue life as compared to cast iron. Moreover, in the comparative study, it was concluded that chromium-molybdenum steel shows fewer stresses and better fatigue life. Therefore it is suggested that chromium-molybdenum steel would be the better option for manufacturing crankshaft.

Keywords: Dynamics Analysis, Engine Crankshaft, Finite Element Analysis, Fatigue Life, Stress Distribution, Deformation Distribution

I. Introduction

Modern Power Machinery is currently facing several challenges in terms of pollution, fuel consumption, noise and vibration levels. This has forced approaches to ensure significant fuel economy, reduced exhaust emissions and high specific power to boost the engine's mechanical efficiency by designing lightweight engine components [XII]. The crankshaft is a critical component of an internal combustion engine. Crankshaft failure makes an engine unworkable and results in expensive repairing. It is complex in geometry therefore while during operation its possesses complex loading patterns. The transient load of cylinder gas pressure is transferred to the crankshaft in internal combustion engines by connecting rods [VI].

Force is applied on the crankshaft due to the combustion of gas pressure in a cylinder. This force then results in bending and torsional load during the working of the engine [VIII]. The crankshaft should be powerful enough to take down the force of the power stroke without excessive bending, ensuring that the engine's reliability and life are not compromised [II].

When the engine piston is at the top dead center position, the crankshaft must oppose the bending stresses induced by connecting rod thrust. The crankpin is then directly influenced by the maximum gas pressure, which tends to bend the shaft and its bearings. The crankshaft should sustain bending and torsional load which is produced by the change of speed concerning time [IX]. The main component of an IC engine that must withstand the cyclic loads generated during combustion is the crankshaft. To improve the engine's efficiency, the crankshaft's weight should be as light as possible. It is important to choose the right material for every component to minimize its weight. To meet these requirements, an analysis of these components is required [XI].

There is competition, due to cost, efficiency, and weight, between materials and production processes. This is a direct result of industry demand for smaller, more efficient and cheaper manufacturing parts while retaining fatigue strength and other functional requirements at the same time [XIV]. During the operation, significant numbers of cycles were experienced by the crankshaft. Failures may be caused by several factors, including sudden overloads, insufficient engine operation and maintenance, or fatigue, which is caused by cyclic loads that are less than yield or ultimate material strength. [III].

Sandya et al [X] have attempted the use of FEA software i.e. ANSYS to analyze the crankshaft in different positions of the crank. They conducted a static analysis of three different materials in different orientations on the crankshaft. The results obtained from FEA analysis are validated with those theoretically calculated for different materials. Horváth and Égert [V] research are dealt with reducing the weight of single-cylinder engine crankshafts and accomplishment a more accurate distribution of stresses on crankshafts. On the crankshaft number of static FEA analyses have been carried out with different methods. The calculated results were then validated by CAD software i.e. CREO. Witek et al [XIII] In their research the diesel engine crankshafts failure study was carried out. The hardness test of the broken crankpin showed that high HRC values were only found in the central part of the pin. The FE approach was used to explain why the crankshaft was damaged prematurely. It was concluded after performed different investigations that the main cause of the early failure by fatigue in the outer zone of the cranks pin. Gopal et al [IV] in this research, studied crankshaft, piston and connecting rod assembly of gasoline engines. They considered a component of the assembly as a rigid body and they must run as a mechanism. In their research assembly was created by using CAD software according to the given dimensions of the design. And FEA analysis was done by using ANSYS software.

This study aims to design a crankshaft with sufficient strength, rigidity and lightweight and consistent durability. In the present study, the FE analysis of single-cylinder engine crankshaft was investigated. The 3D model of the crankshaft was simulated by using ANSYS workbench. To analysis, the effect of bending and torsional load on crankshaft the three different materials such forged steel, cast iron and chromium-molybdenum steel were chosen under different loading conditions with different angle of cranks turns from 0° to 720° and to predict the von misses stress, deformation and fatigue life of three materials without compromising its strength and fatigue life.

II. Modeling of the Crankshaft

The crankshaft design parameters were taken from the literature to achieve this study's objectives. The crankshaft was designed by using engine specifications as shown in Table 1 by using 3D CAD modeling software CREO parametric 7.0 as shown in Fig 1. The CAD model of the crankshaft was then imported to ANSYS workbench for simulation.

Table 1. Parameters of the selected engine [VII]

Parameters	Values
Crankshaft radius	37mm
Piston diameter	89mm
Connecting rod Mass	0.283 kg
Piston assembly Mass	0.417 kg
Connecting rod Length	120.78 mm
Gas pressure (Maximum)	35 Bar

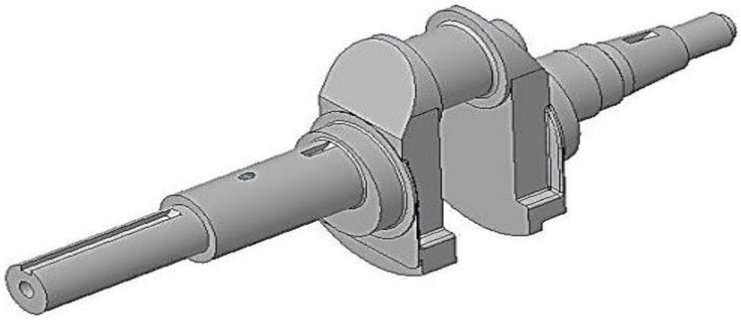


Fig. 1: Three Dimensional view of crankshaft model

III. Materials for crankshaft

The selection of different crankshaft materials plays an important role in this study. The availability and suitability of the material and, most significantly, the cost of the material are the factors that should be considered when choosing the material.

For proper operation, the crankshaft should be designed to withstand the forces it is subjected to, such as bending and torsional loads, as well as the minimum weight. To achieve the objectives of this study, three different materials for crankshaft were selected such as; forged steel, cast iron and chromium-molybdenum steel. The properties of selected materials are illustrated in Table 2.

Table 2: Properties of selected materials

Materials Properties	Materials			Units
	Forged steel	Cast iron	Chromium-molybdenum steel	
Density	7833	7197	7850	Kg/m3
Young's modulus	221000	178000	210000	Mpa
Poisson's ratio	0.30	0.30	0.30	-------

IV. Meshing of the crankshaft

In this section, the Discretization of the model was presented. Tetrahedral elements are used to mesh the geometry of the crankshaft as shown in Fig 2. In this analysis, tetrahedron mesh was chosen because the stiffness of the element is more comparable to other types of meshing. The refinement of mesh has been done on the crankpin fillet and journal fillet areas, which are usually crucial areas on the crankshaft. The 3D CAD model was subdivided into nodes and elements. To get more accurate results the finest mesh was considered. The element size in critical fillet area is 0.762 mm while, in the general element is size is 2.5 mm applied. The details of mesh applied to the crankshaft are given in Table 3**.**

Table 3: crankshaft discretization details

Element type	Elements	Nodes	Average Orthogonal quality
Tetrahedral	136262	215798	0.803

Govering equations

The method of transient structural analysis (also known as dynamic analysis) is used to determine a structure's dynamic response over time. To get time-dependent results like displacement, strain, stress, and reaction force of the structure transient analysis is used under any combination of steady-state, transient, and harmonic loads.

$$[M]\ddot{a} + [D]\dot{a} + [C]\,a = F(t) \tag{1}$$

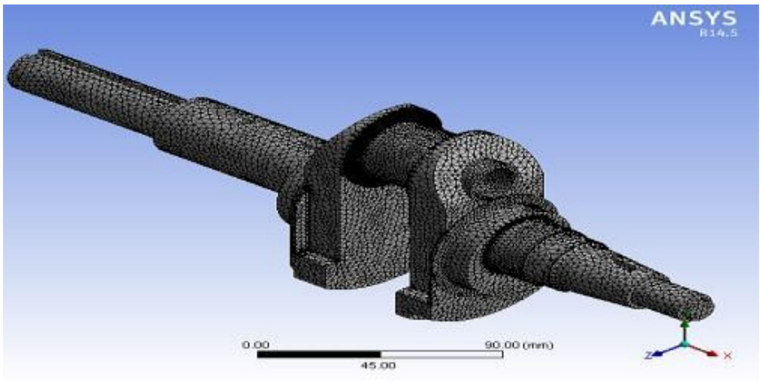


Fig. 2 : Discretization model of crankshaft

V. Applied Load and Boundary Conditions

In the finite element analysis process, the boundary condition of the model plays a vital role. Two types of loads were experienced by crankshafts such as bending and torsional load due to the combustion of gas. Since this research was focused on dynamics structural analysis, therefore at different angles of crank turns, only two main load conditions were applied to the surface of the crankshaft crankpin surface. At the top of the crankpin surface, the bending load is applied radially over120°, while the torsional load is applied tangentially.

Fixed surface constrained is applied over 180° to the ball bearing and fixed edge constrained is applied over 180° to the journal bearing. The maximum combustion pressure is applied to the crankpin surface and different loading conditions were applied at different angles of turns. In this research, the simulation of the crankshaft was done for 0.9 sec of the time interval and the cyclic load was applied at nine sub-steps at a different angle of crank turns from 0° to 720°. The setup of boundary conditions is shown in Fig 3.

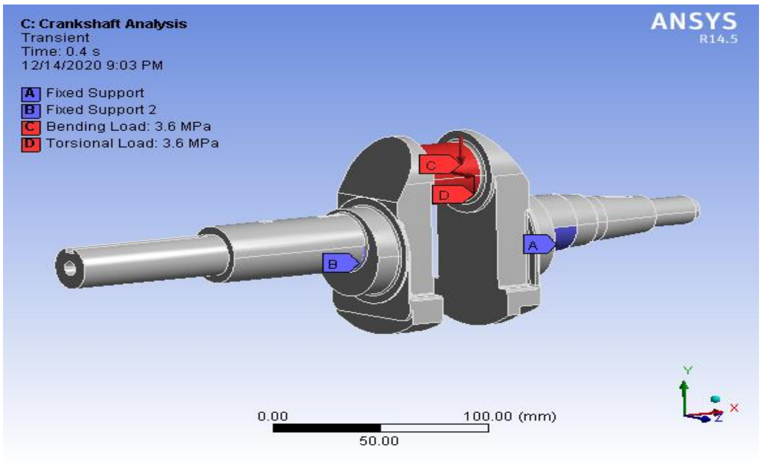


Fig. 3 : Applied loads and boundary constrained

VI. Load Analysis of the crankshaft

To predict the dynamic structural behavior of crankshaft throughout the complete cycle. The pressure vs crank angle diagram was used to apply load on the crankshaft. Since crankshaft experience, two types of loading results from gas pressure due to combustion inside the piston cylinder is transfer through connecting rod to crankpin causing bending and torsional loads. To get the bending effects, the radial load is applied at the top of the crankshaft crankpin whereas, for the torsional effects, the tangential load is applied at the surface of the crankshaft crankpin. These two loads are acting perpendicular to each other**.**

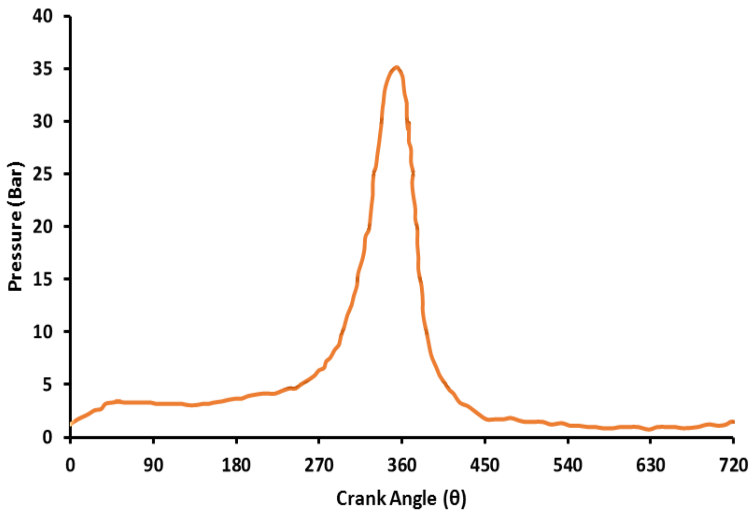


Fig. 4 : Pressure vs Crank angle diagram

VII. Results and Discussions

In this section, comparative dynamics structural analysis of single cylinder engine crankshaft was carried out, mainly concern with the stresses, deformation and fatigue life of crankshaft by applying bending and torsional loads. For comparative analysis three different materials were chosen such as forged steel, cast iron and chromium-molybdenum steel.

Von misses stress analysis due to bending load for three different materials

The results of von misses stress analysis are present for three different materials under bending load. Since the study was based on dynamics structural analysis, therefore results are obtained with different angles of turns of cranks from 0° to 720°. The maximum von misses stress for all selected materials was obtained by applying maximum bending load at the top of the crankpin surface as 78.14 Mpa, 80.30 Mpa and 76.62 Mpa at 360° of crank angle respectively as shown in Fig. 5(a), 5(b) and 5(c).

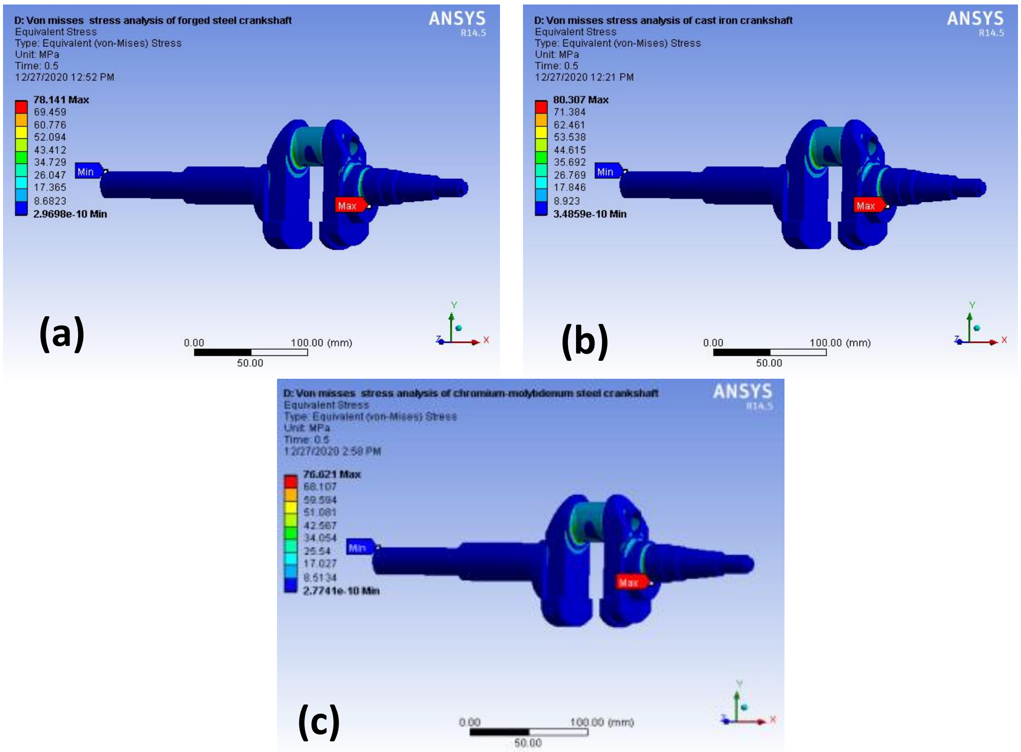


Fig. 5: Maximum von misses stresses due to bending loading (a) forged steel (b) cast iron (c) chromium-molybdenum steel

In Fig.6, the comparative analysis of von misses stress for three different materials with different angles of crank turns was presented. It was observed from Fig.6 that maximum von misses stresses for three different materials are produced at 360° of cranks angle at which combustion takes place.

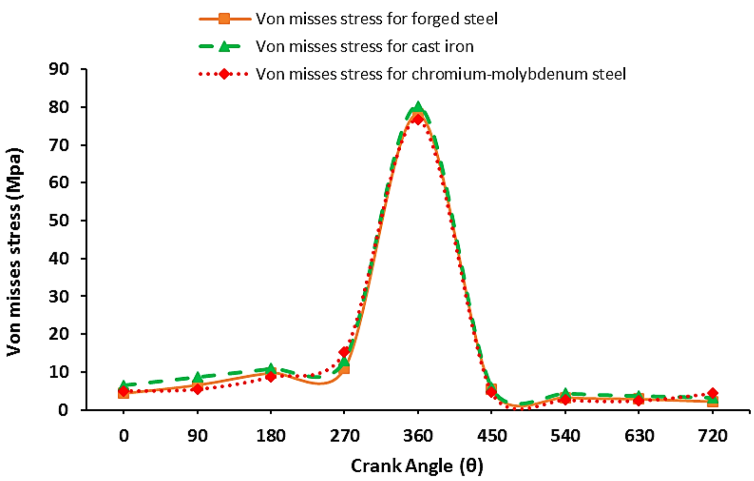
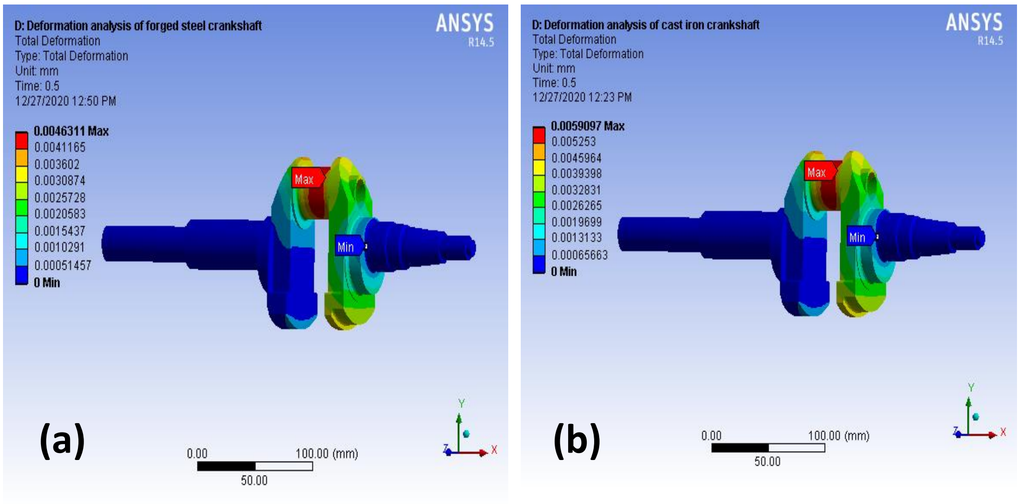


Fig. 6: Von misses stress results of three different materials with different angle of turn due to bending load

Deformation analysis due to bending load for three different materials

When the maximum pressure was applied at the top of the crankpin surface. The red colour portion indicates that the deformation in that region is maximum and the blue colour portion indicates that in that region the deformation is minimum. From Fig. 7(a), 7(b) and 7(c), it was observed that maximum deformation for all selected materials was 0.0046 mm, 0.0059 mm and 0.0048 mm at 360° of crank angle respectively. Furthermore, it was also noted that the large deformation is produced at the surface of the crankpin for all selected materials.



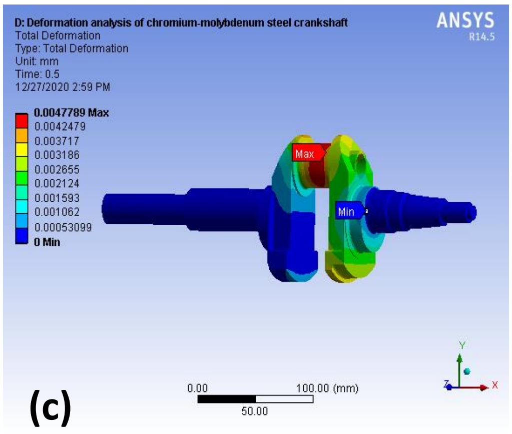


Fig. 7: Maximum deformation due to bending loading (a) forged steel (b) cast iron (c) chromium-molybdenum steel

In Fig. 8, the comparative results of total deformation for all three materials under bending loading conditions were presented. From Fig. 8 it is observed that chromium-molybdenum steel and forged steel materials show less deformation as compared to the cast iron materials.

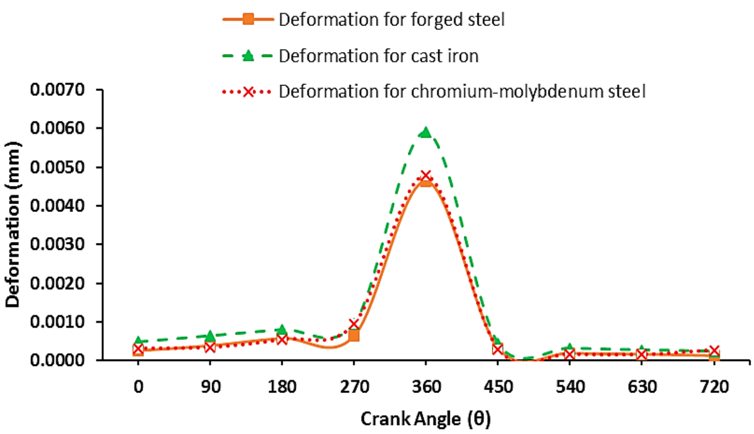


Fig. 8: Deformation results of three different materials with different angle of turn due to bending load

Von misses stress analysis due to torsional load for three different materials

The equivalent (von-misses) stresses developed in fillet area under the Torsional loads for three different materials are presented in Fig. 9(a), 9(b) and 9(c) respectively. The maximum stress observed at the fillet for three different materials was 44.75 Mpa, 45.13 Mpa and 43.01 Mpa at 360° of crank angle, which is below the yield stress of materials. The result indicates that maximum stress is produced at the critical locations of the crankshaft respectively.

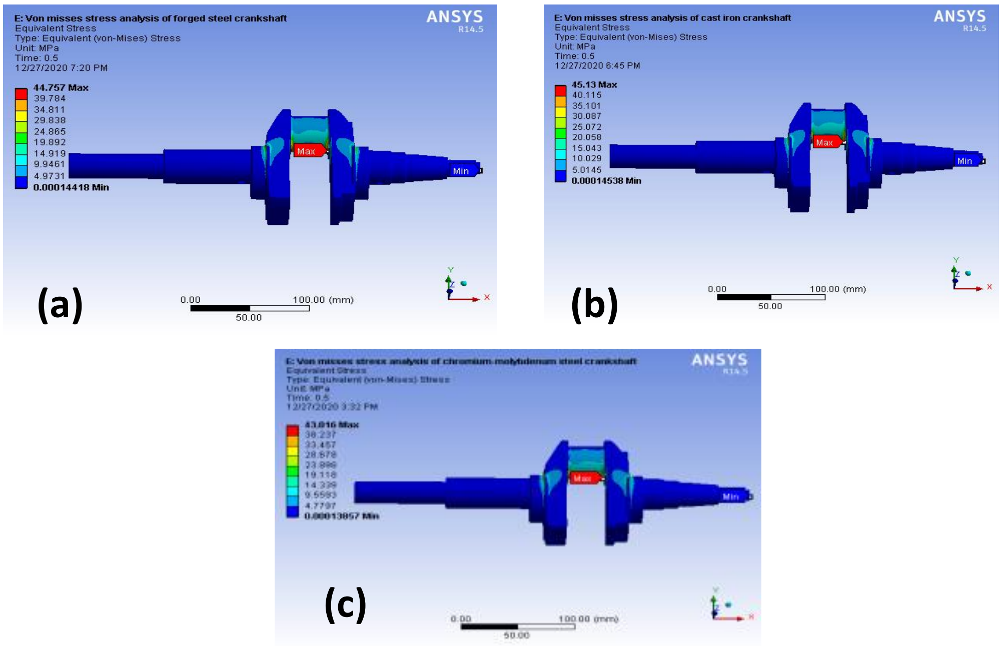


Fig. 9: Maximum von misses stresses due to torsional loading (a) forged steel (b) cast iron (c) chromium-molybdenum steel

Comparative analysis of crankshaft made of three different materials under torsional load at a different angle of crank turns are shown in Fig.10. Chromium-molybdenum steel materials show fewer stresses as compared with the other two materials. It can be also noted that maximum stress is produced for all materials at 360° of crank angle in which combustion of gas takes place.

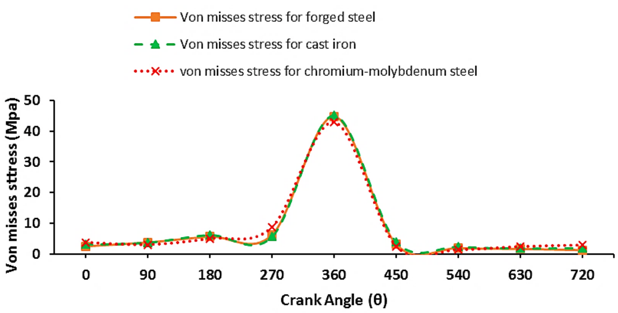


Fig. 10: Von misses stress results of three different materials with different angle of turn due to torsional load

Deformation analysis due to torsional load for three different materials

The deformation due to torsional load for three materials are presented in Fig.11(a), 11(b) and 11(c). By applying maximum gas pressure tangentially at the crankpin surface at a different angle of turns, the total deformation for forged steel, cast iron and chromium-molybdenum steel was observed as 0.0036 mm, 0.0045 mm and 0.0036 mm at 360° respectively.

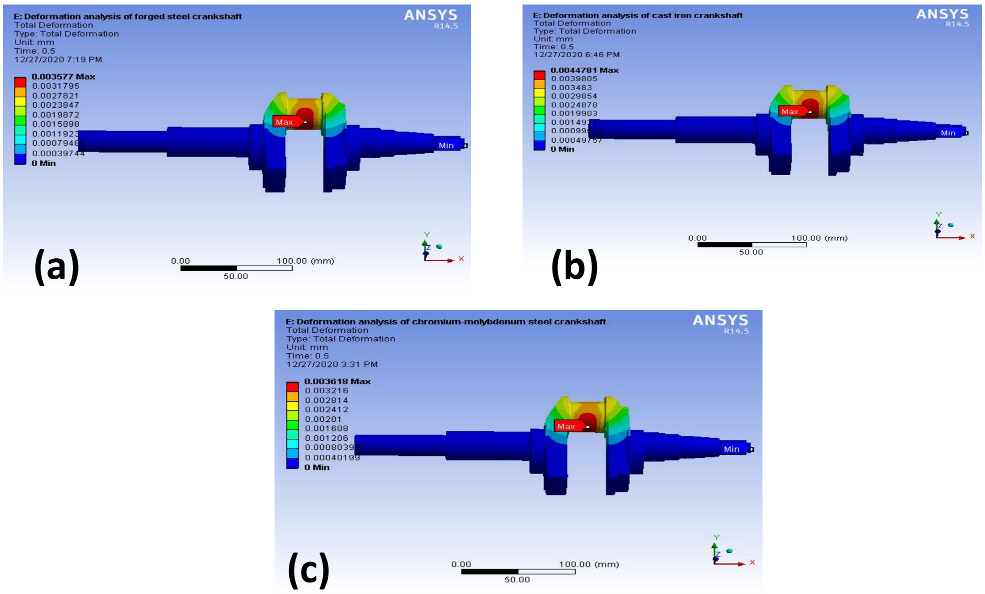


Fig. 11: Maximum deformation due to torsional loading (a) forged steel (b) cast iron (c) chromium-molybdenum steel

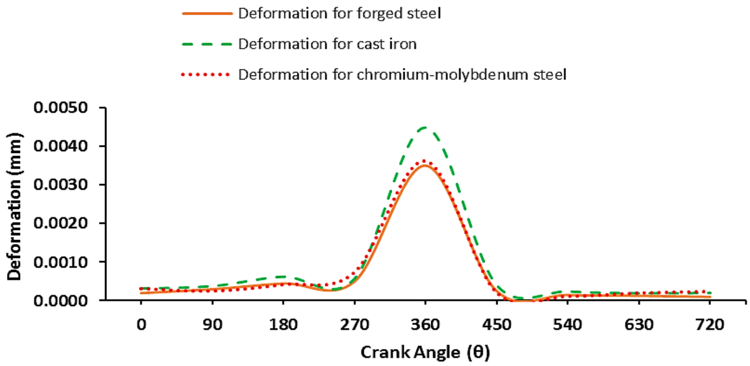


Fig. 12: Deformation results of three different materials with different angle of turn due to bending load

Fatigue life analysis of crankshaft for three materials under bending and torsional loads

In this section fatigue life analysis of three different materials under bending and torsional loading conditions by using goodman theory are presented. Maximum and minimum number of cycles that crankshaft can bear for three different materials under bending load conditions are observed as $1e^6$ cycles or an infinite number of cycles without failure and 14248, 13264 and 15321 cycles before failure respectively. For torsional load maximum and minimum numbers of cycles are observed as $1e^6$ cycles or an infinite number of cycles without failure and 2154, 1665 and 2607 cycles before failure respectively.From Fig. 13(a) and 13(b) it is concluded that chromium-molybdenum materials show better fatigue life as compared with the other two materials.

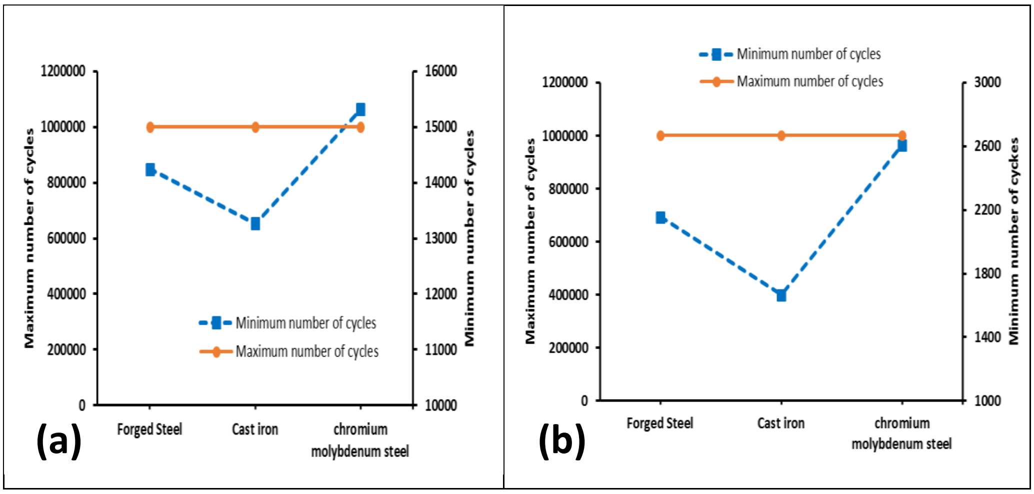


Fig. 13: Fatigue life prediction (a) bending load (b) torsional load

VIII. Conclusion

This resarch aimed to compare the dynamics structural analysis for three different materials under different loading conditions at a various angles of crank turns. The simulation has been carried out on ANSYS FEA software. In this study, three design materials were selected such as forged steel, cast iron and chromium-molybdenum steel. Results of stress distribution under bending load revealed that maximum stress for three materials produced in critical locations of main journal shaft at the 360 ° of crank angle and under torsional load maximum stress produced in fillet region of crankpin shaft at the 360 ° of crank angle. The deformation distribution under bending and torsional load revealed that large deformation occurs at the neck of the crankpin surface at the 360 ° of crank angle. Whereas, from fatigue life prediction it is observed that chromium-molybdenum steel shows better fatigue life as compared with the other two materials. It is concluded that chromium-molybdenum steel materials show satisfactory results when their strength, fatigue life and durability are evaluated based on comparative analysis between three materials.

Conflict of Interest:

No conflict of interest regarding this article

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