Finite Element Based Dynamic and Fatigue Analysis of a Single-Cylinder Engine Crankshaft with Geometric Optimization

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Abstract - *The crankshaft is a critical component of an internal combustion engine that converts the reciprocating motion of the piston into rotational motion. During operation, it experiences cyclic bending and torsional loads, making it susceptible to fatigue failure, particularly at regions of stress concentration. This study investigates the structural and fatigue performance of a single-cylinder engine crankshaft using Finite Element Analysis (FEA) and examines the influence of geometric optimization on its durability. A three-dimensional crankshaft model was developed in SOLIDWORKS and analyzed in ANSYS under appropriate loading and boundary conditions. The analysis focused on evaluating von Mises stress, shear stress, and fatigue life, with special attention given to the crankpin fillet region, a common site for crack initiation. To enhance performance, the crankpin fillet radius and crankpin diameter were modified, and their effects on stress distribution and fatigue behavior were assessed. The results indicate that increasing both parameters significantly reduces stress concentration and improves fatigue life. The optimized design achieved a maximum stress reduction of 25.88% and an increase in fatigue life of approximately 62.55% compared to the original configuration. The highest stress levels were observed at the fillet region between the crank web and journal, confirming it as the most critical failure location. Additionally, the numerical findings showed good agreement with theoretical calculations. The study demonstrates that geometric optimization is an effective method for enhancing crankshaft durability, minimizing fatigue-related failures, and improving the overall reliability and service life of engine components.*

Key Words: Crankshaft Optimization, Finite Element Analysis, Fatigue Life Assessment, Stress Concentration, Crankpin Fillet Radius.

1. INTRODUCTION

The crankshaft is one of the most critical rotating components in an internal combustion (IC) engine, characterized by its complex geometry and significant structural role. Its primary function is to convert the reciprocating motion of the piston into rotational motion, enabling the transmission of power to the drivetrain. Crankshafts are widely used in automotive engines and are also found in a broad range of applications, from small single-cylinder lawnmower engines to large marine propulsion systems. During engine operation, combustion gases generate high-pressure forces on the piston crown. These forces are transmitted through the connecting rod to the crankshaft, subjecting it to substantial bending and torsional loads. Consequently, the durability, reliability, and performance of an engine largely depend on the strength and fatigue resistance of the crankshaft, which must withstand repeated loading cycles without excessive deformation or failure [1,2].

For structural assessment, crankshafts are generally analyzed under maximum bending and torsional loading conditions. The highest bending stresses usually occur near the crankpin or main journal fillets, where combustion forces transmitted through the piston and connecting rod generate significant bending moments. Simultaneously, torsional loading can induce high shear stresses, making these locations particularly susceptible to fatigue crack formation. Repeated cyclic loading at these critical regions may eventually result in crack growth and final fracture of the crankshaft [14,15].

2. METHODOLOGY

Forged steel, forged iron and aluminum are the primary crankshaft material rivals now used in industry. The automobile industry is quite interested in comparing the performance of such materials with impact loads, static, and relevant cyclic. The performed a thorough evaluation of crankshaft production techniques in terms of design, completed cost, manufacturing features, and mechanical qualities. Because casting and forging are competing manufacturing techniques in the crankshaft production business, this section focuses on them 78. The factors that influence both processes are described in depth. Finally, the fabric qualities and production techniques of forged iron and solid steel items are compared. The crankshaft must meet the following characteristics in order to work properly 9:

- Adequate strength to withstand the forces applied to it, such as bending and twisting moments.
- Stiffness to reduce and strength to withstand stresses caused by torsional vibrations of the minimum weight, particularly in aviation engines.
- Adequate stiffness to reduce deformation to a bare minimum.

Table 1. Engine crankshaft material properties.

Material Type	Forged steel	Unit
Poisson‟s ratio	0.30	-
Density	7833	kg/m^3
Young‟s modulus	221	GPa
Ultimate tensile strength	827	MPa
Yield stress	625	MPa

3. RESULTS AND DISCUSSIONS

Solid work software was used to produce the single cylinder engine crankshaft model in this work. The solid work model was then loaded into ANSYS software for examination.

3.1 Fillet radius

1) Stress at different fillet radius

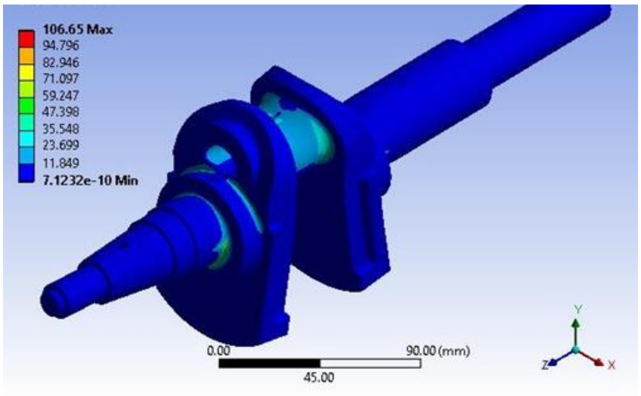

Fig. 1 Von Mises stress at a fillet radius of 3.0 mm

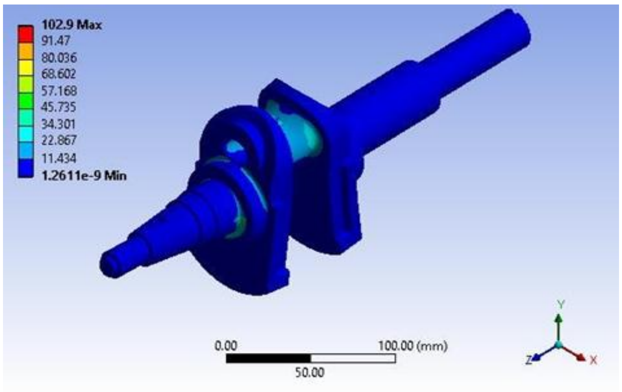

Fig. 2 Von Mises stress at a fillet radius of 3.50 mm

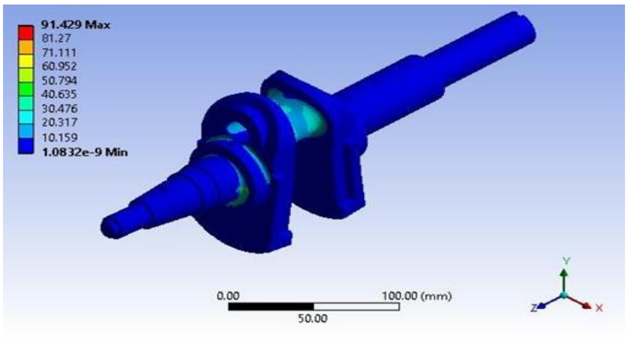

Fig. 3 Von Mises stress at a fillet radius of 4.0 mm

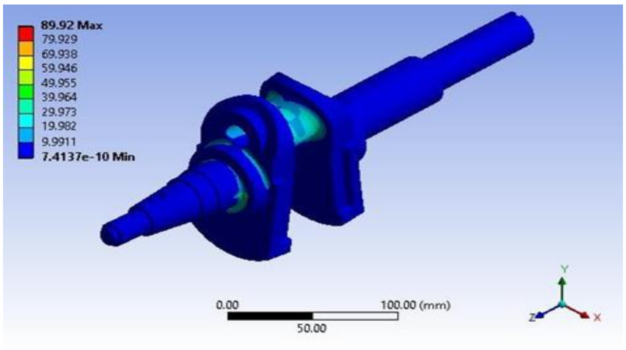

Fig. 4 Von Mises stress at a fillet radius of 4.50 mm

2) Shear stress at different fillet radius

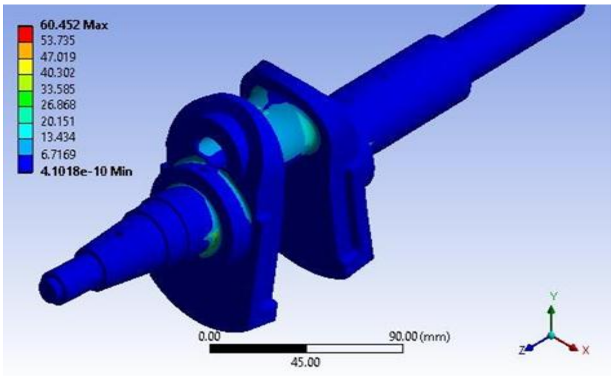

Fig. 5 Shear stress at a fillet radius of 3.0 mm

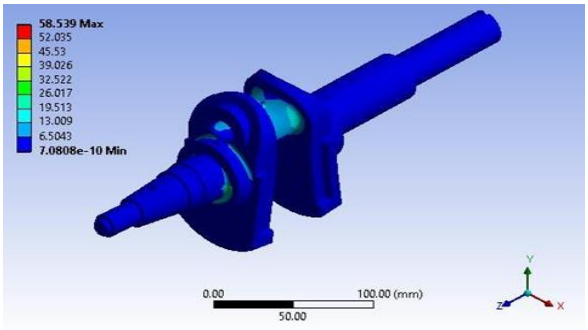

Fig. 6 Shear stress at a fillet radius of 3.50 mm

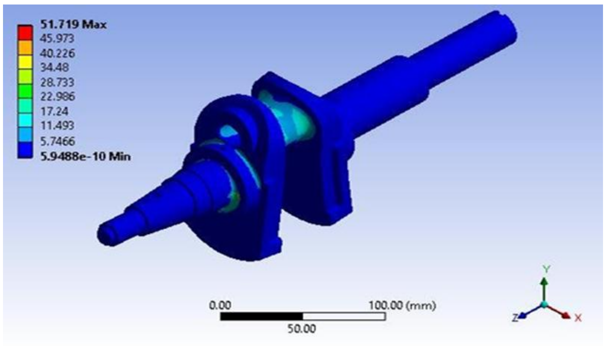

Fig. 7 Shear stress at a fillet radius of 4.0 mm

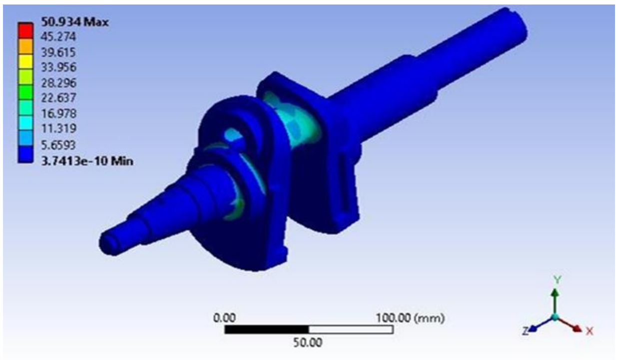

Fig. 8 Shear stress at a fillet radius of 4.50 mm

3) Life at different fillet radius

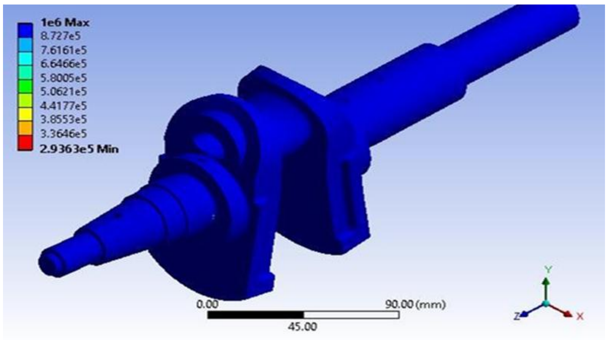

Fig. 9 Life at a fillet radius of 3.0 mm

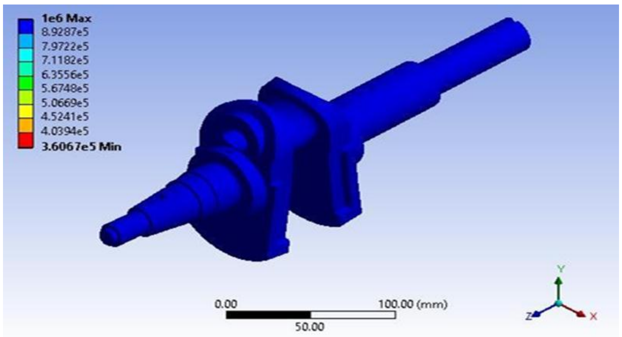

Fig. 10 Life at a fillet radius of 3.50 mm

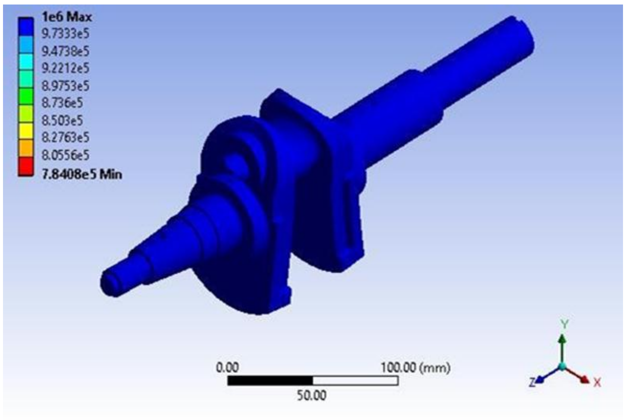

Fig. 11 Life at a fillet radius of 4.0 mm

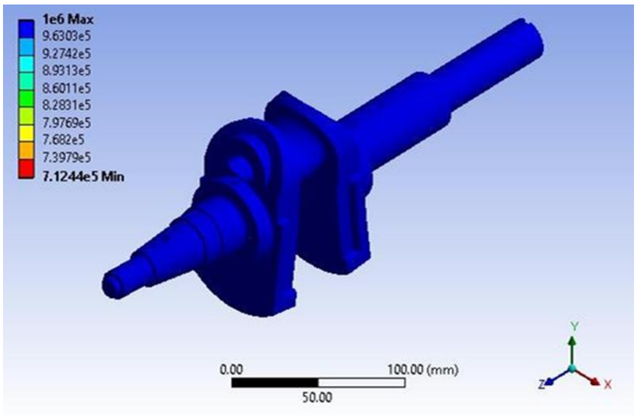

Fig. 12 Life at a fillet radius of 4.50 mm

4.50 mm is the optimised one since its stress is less and its life is longer than the others. As a result, it can be used to replace the original.

Crankpin diameter

4) Stress at different crankpin diameter

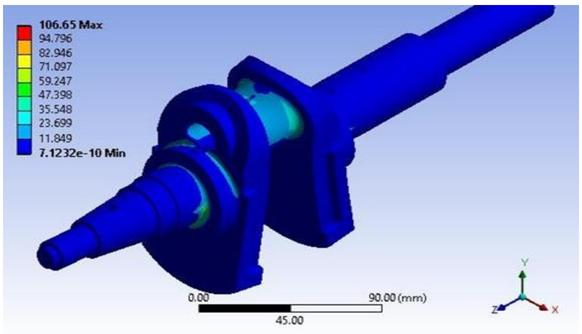

Fig. 13 Von mises stress at 37.0 mm crankpin diameter

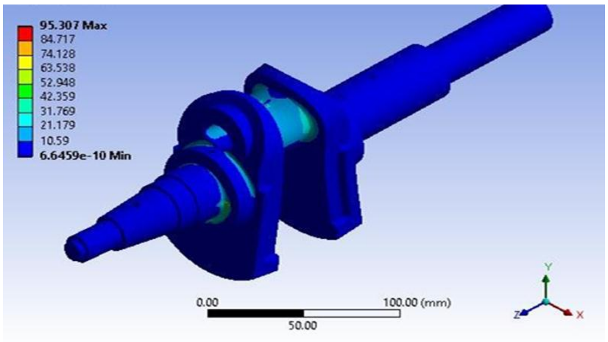

Fig. 14 Von mises stress at 38.0 mm crankpin diameter

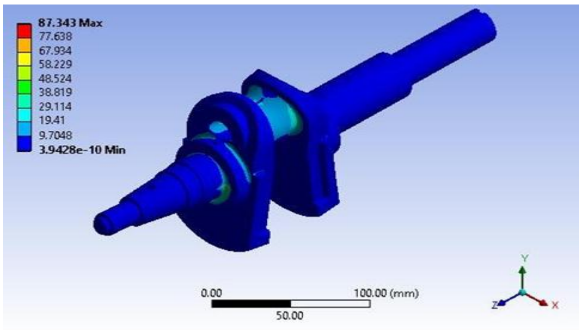

Fig. 15 Von mises stress at 39.0 mm crankpin diameter

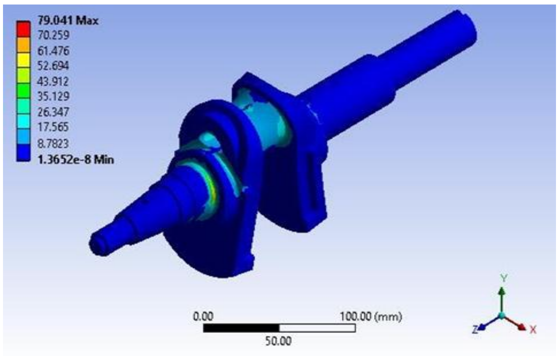

Fig. 16 Von mises stress at 40.0 mm crankpin diameter

5) Shear stress at different crankpin diameter

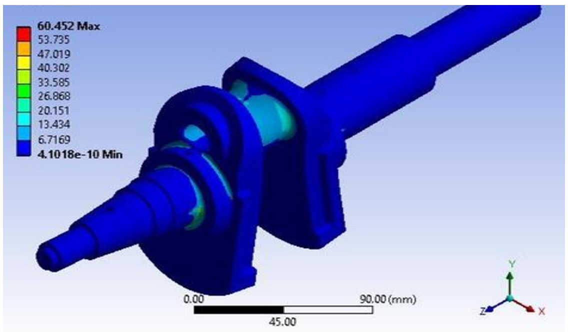

Fig. 17 Shear stress at 37.0 mm crankpin diameter

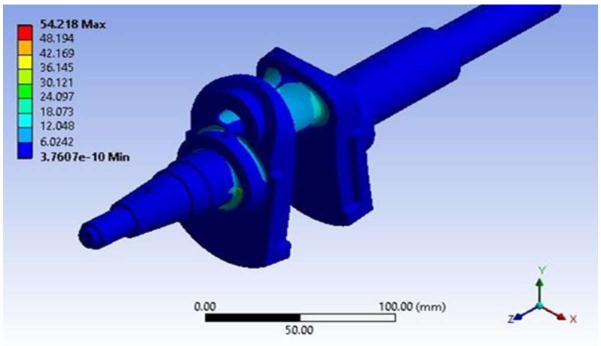

Fig. 18 Shear stress at 38.0 mm crankpin diameter

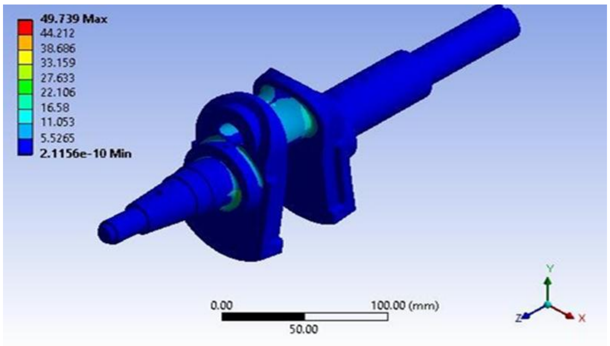

Fig. 19 Shear stress at 39.0 mm crankpin diameter

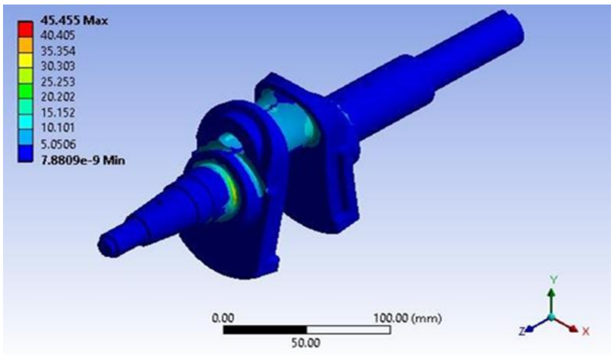

Fig. 20 Shear stress at 40.0 mm crankpin diameter

6) Life at different crankpin diameter

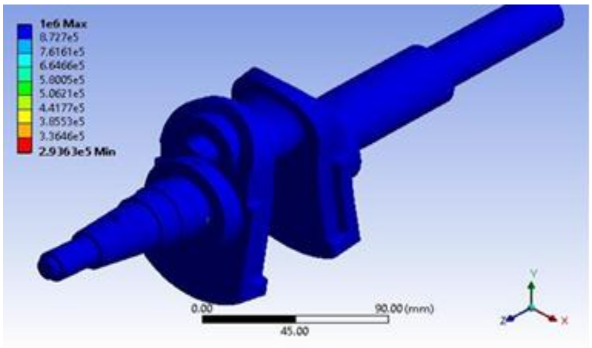

Fig. 21 Life at 37.0 mm crankpin diameter

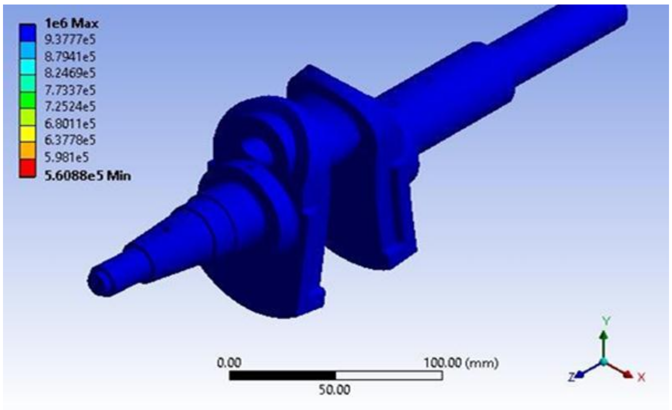

Fig. 22 Life at 38.0 mm crankpin diameter

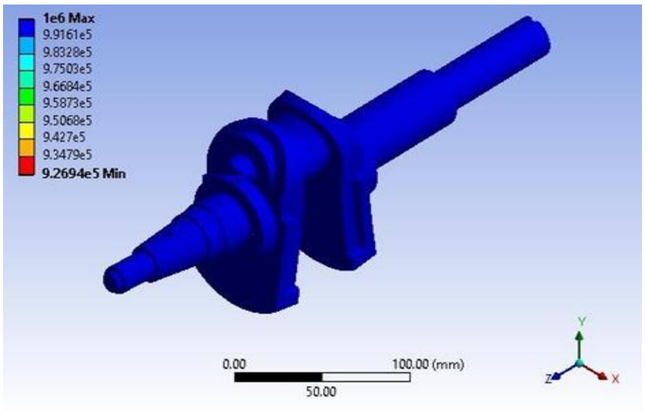

Fig. 23 Life at 39.0 mm crankpin diameter

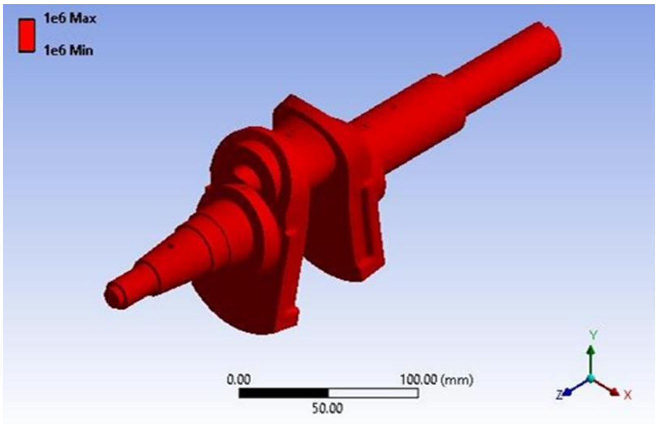

Fig. 24 Life at 40.0 mm crankpin diameter

According to the FE study presented in Fig. above, in both parameters, the red position has the most stress and the blue area has the lowest stress over service life and the opportunity for material removal and weight reduction.

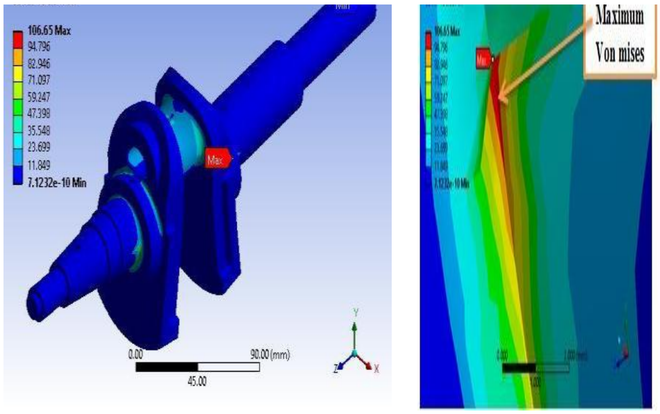

Fig. 25 Maximum von mises stress of original crankshaft

CONCLUSION

The crankshaft model was created in SOLIDWORKS and analyzed in ANSYS using Finite Element Analysis (FEA). Geometric optimization was carried out by varying the crankpin fillet radius and crankpin diameter to improve stress distribution and fatigue life. Tetrahedral elements were used for meshing, with finer meshes applied to the journal and crankpin fillet regions, where stress concentrations are most critical. The analysis revealed that the fillet region between the crank web and journal experiences the highest stress and is the primary location for fatigue crack initiation. Results showed that increasing the crankpin fillet radius and diameter significantly reduced stress levels and enhanced fatigue performance. The optimized design achieved a stress reduction of 25.88% and an improvement in fatigue life of 62.55% compared to the original crankshaft. Changes in crankpin diameter further increased fatigue life by up to 70.63%. Both von Mises and shear stresses decreased as the fillet radius and diameter increased, resulting in a higher number of cycles to failure. Analytical calculations showed good agreement with FEA results, validating the numerical model. Overall, the optimized crankshaft demonstrated superior durability, reliability, and service life, making it a practical alternative to the original design for engine applications.

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