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Optimization of car crankshaft strength with ductile iron material through Solidworks simulation

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Abtract: This study aims to provide crucial insights into the performance of crankshaft designs under various loads and operational conditions. The method employed in this research is finite element analysis, facilitated by SolidWorks software, utilizing Ductile Iron material. Crankshafts crafted from ductile Iron are typically employed in vehicle engines due to their commendable mechanical properties and cost efficiency. The force exerted by the piston on the crankshaft generally ranges from 4500 N to 7500 N. The Factor of Safety within the crankshaft denotes the ratio between its material strength and the maximum stress it experiences during operation. The findings of this research indicate that the highest recorded maximum von Mises stress utilizing ductile iron material is 4.658 MPa, with a corresponding Factor of Safety in the crankshaft of 118.4. Consequently, the resilience of ductile iron crankshafts under varying loads and operational conditions can be ensured through meticulous analysis of crankshaft geometry.

Keywords : Finite Element Analysis; Crankshaft; Ductile Iron, Simulation

1. Introduction

The crankshaft is a pivotal component of the intricate geometry of internal combustion engines, converting the reciprocating motion of pistons into rotational motion [1], [2]. It consists of a rotating shaft on main bearings and crankpins, where the large end of the connecting rod attaches, connecting the crank arm to the belt that links the crankshaft to the shaft section. The crankshaft is a vital component in automobiles, transferring the reciprocating motion of pistons into rotational motion [3]. The strength and durability of the crankshaft are crucial for enhancing the efficiency and reliability of the engine. Research by Z. Wang et al. [4] highlights the crucial role of crankshaft strength in improving fuel efficiency and engine performance.

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The crankshaft rotates within a set of supporting bearings (main bearings), causing the output to rotate in a circle around the main pin center [5]. The crankshaft's intricate geometry and the cylinders' complex torque make its analysis challenging [6]. Given that the crankshaft undergoes lengthy and repetitive cycles during its lifespan, this part's fatigue strength and durability are considered in the planning process [7]. Design improvements are necessary for the creative industry of crankshaft manufacturing to produce more cost-effective components with conceivable base weights and adequate fatigue strength, among other useful conditions [8], [9].

Ductile Iron has become an increasingly popular material in manufacturing automotive components, including crankshafts, due to its combination of strength, durability, and competitive cost. For instance, research by G. Artola et al. [10] indicates that Ductile Iron can offer significant advantages in terms of performance and reliability for automotive engine components. It is highlighted that Ductile Iron exhibits sufficiently high strength to withstand operational loads of engines while maintaining resistance to fatigue and stress [11]. This renders it an appealing choice for automotive manufacturers prioritizing a blend of strength, durability, and cost competitiveness.

The utilization of simulation technology, such as SolidWorks, has become a common approach in optimizing the design of automotive components. Research by G. J. Rose et al. [12] demonstrates that SolidWorks simulation effectively estimates the behavior and performance of engine components, such as crankshafts, enabling the development of more substantial and efficient designs. Numerous studies have been conducted in the field of crankshaft shape analysis. In analyzing the 3D crankshaft model generated using SolidWorks software and imported into ANSYS software [13]. The crankshaft shape analysis aims to assess the structural integrity and performance of critical components in internal combustion engine crankshafts.

Furthermore, this study aims to assist engineers and designers in optimizing crankshaft designs and enhancing their performance, reliability, and service life [14], [15]. By creating detailed three-dimensional and crankshaft models, the research can comprehensively analyze the stresses and strains experienced by the components under various operating conditions. The methodology employed in this study is the Finite Element Method (FEM), which simulates the loads and forces acting on the crankshaft model [16].

Overall, this research provides crucial insights into the performance of crankshaft designs under various loads and operating conditions. By analyzing the crankshaft model, manufacturers can identify weaknesses in the model [17]. This information can be used to refine designs and enhance engine durability. Consequently, design optimization techniques can be applied to develop safer and more efficient vehicles. Utilizing Solidworks software enables in-depth analysis that can inform the design and fabrication of efficient internal combustion engines [18]. Such analysis provides valuable information to inform the design process and assist in optimizing the performance of crucial components like the crankshaft [19]. By properly analyzing the crankshaft, model makers can grasp the strengths and weaknesses of the model [20]. This can aid manufacturers in refining designs and enhancing the safety and security of the engine.

2. Methods

The methodology employed in this study utilizes finite element analysis [21]. A three-dimensional model of the crankshaft was created using SolidWorks software, with a relatively simplistic design and measurements in millimeters. Upon observing the crankshaft from a top view, the radii of the curved sides measure 180 mm, while the inner circle radius is 75 mm. The overall width of the crankshaft, as seen from the side, is 450 mm, with the connecting side to other motorcycle components having a diameter of 100 mm, the piston-supporting side measuring 100 mm, and the total length of the crankshaft being 1500 mm.

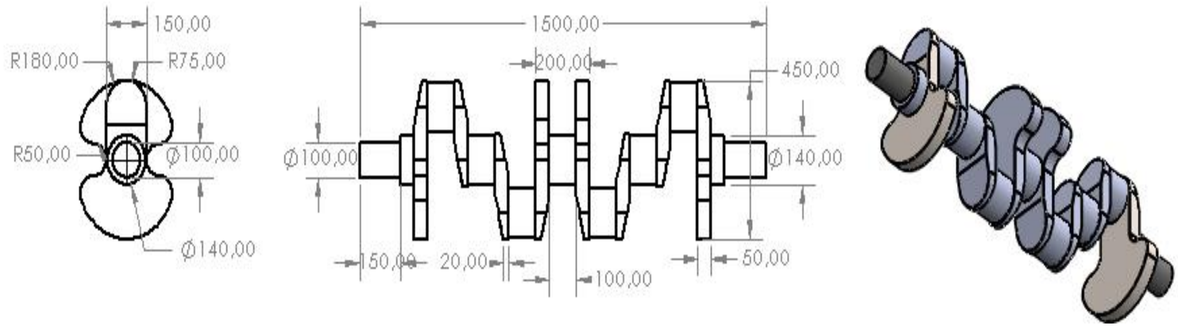

Figure 1: Design of Crankshaft

Material selection in engineering design involves systematically choosing the best-suited material for a specific application [22]. Furthermore, prioritizing the analysis of strength, durability, and safety factors remains essential during material selection. The material utilized in modeling the crankshaft is "Ductile Iron" [23], chosen for its excellent mechanical properties and cost-effectiveness. Its material properties are displayed in Table 1.

Table 1: Material Property

Property	Value	Units
Tensile Strength	861.695	N/mm^2
Yield Strength	551.485	N/mm^2
Mass Density	7100	Kg/m^3
Thermal Conductivity	75	W/(M.K)
Elastic Modulus	120000	N/M^2
Poisson's Ratio	0,31	N/A

2.1 Fixed geometry

The region indicated by the green color (Fixed Geometry) denotes immobile or constrained surfaces during the simulation process [24].

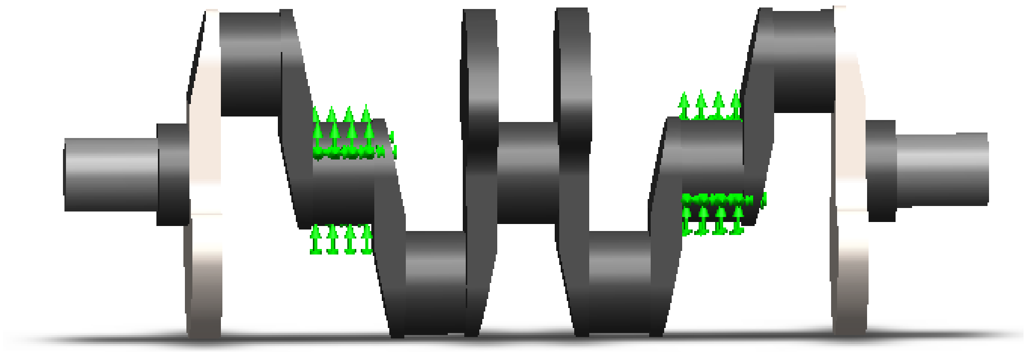

Figure 2: Fixed Geometry

2.2 Application of force

The part marked in purple (Force) is the surface on which the piston rests or the force exerted on the crankshaft. In general, there is pressure between 4500 N and 7500 N. After the simulation is carried out, it is obtained:

Force against the X-axis = 0,156 N
Force against the Y-axis = 6000,81 N
Force against the Z-axis = 0,660 N
Then, the resultant force is obtained:

$$R = \sqrt{F(X)^2 - F(Y)^2 + F(Z)^2} = 6001 \text{ N}$$

Hence, the resultant force value is 6001 N in the direction of the Y-axis or the Earth's gravitational force.

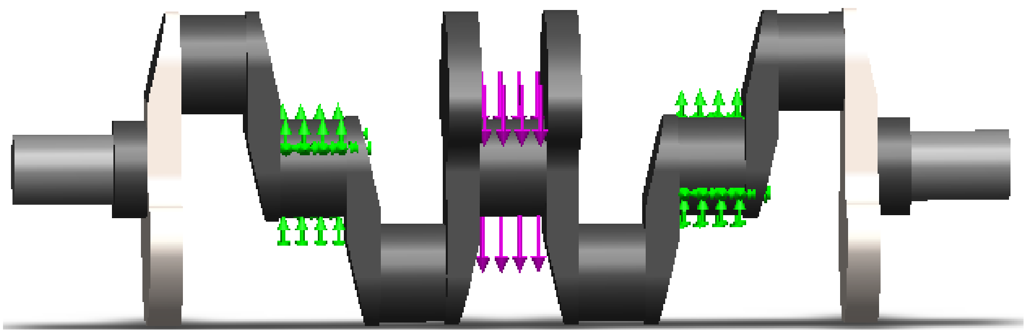

Figure 3: Application of power

2.3 Meshing

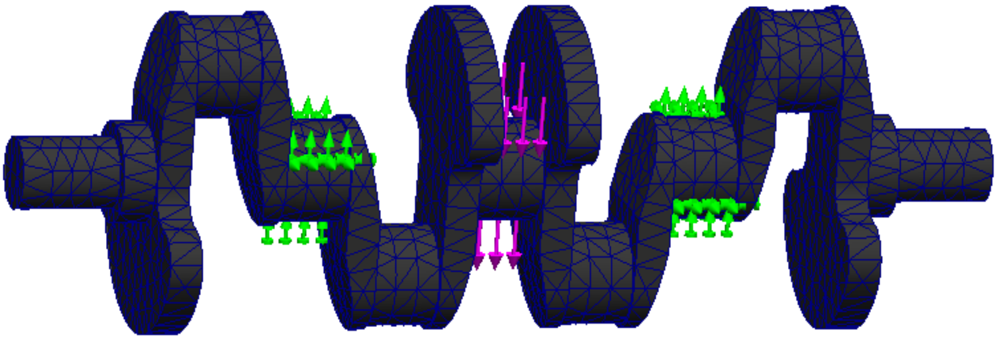

Figure 4: Meshing

From the mesh results in the initial design that we did, data was obtained using the solid mesh element type. The element size is 33.5278 mm, the number of nodes is 15881, and consists of 9196 elements. The mesh details are shown in Table 2.

Table 2: Meshing

Study name	Static 1 [-Default-]
Mesh type	Solid Mesh
Mesher Used	Standard mesh
Automatic Transition	Off
Include Mesh Auto Loops	Off
Jacobian points for High-quality mesh	16 points
Element size	33,5278 mm
Tolerance	1,67639 mm
Mesh quality	Hight
Total nodes	15881
Total elements	9196
Maximum Aspect Ratio	6,9137
Percentage of elements with Aspect Ratio < 3	94,3
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0
Number of distorted elements	0
Time to complete mesh(hh:mm:ss)	00:00:02

3. Results and discussion

After determining the methodology and materials, the crankshaft was analyzed using SolidWorks simulation. Below are the evaluation results of the crankshaft testing.

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3.1 Von-Misses stress crankshaft

The outcome of the Von-Misses stress analysis on the crankshaft utilizing Ductile Iron material revealed that the location of the maximum Von-Misses stress value amounted to 4,658 MPa.

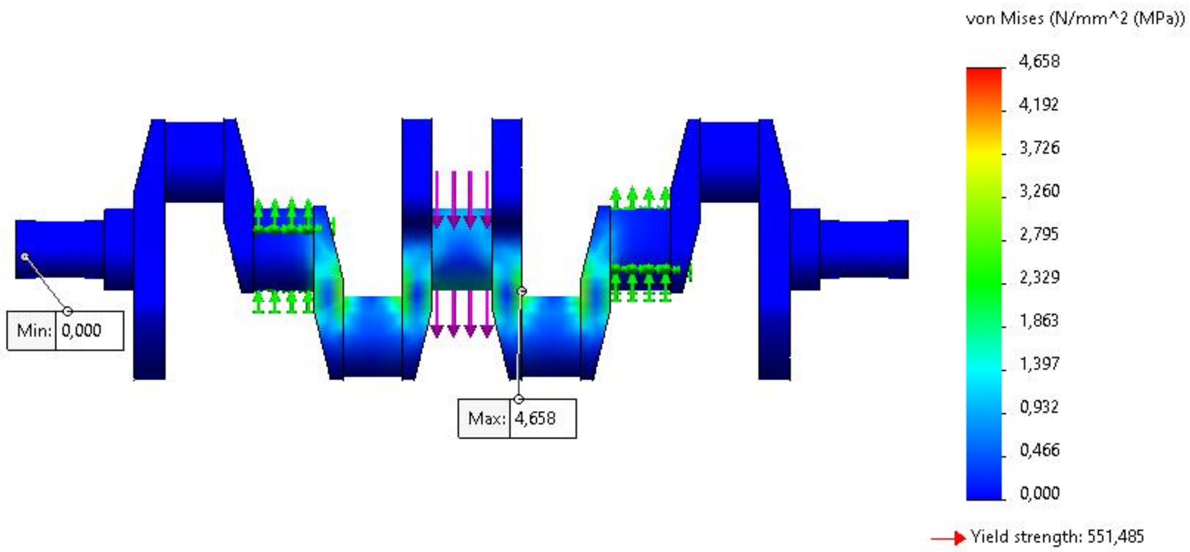

Figure 5: Von-Misses stress

3.2 Static strain

The results of the Static Strain Analysis on the crankshaft, which uses Ductile Iron material, are getting the maximum value of the static strain of ductile iron material, which is 0.00003 MPa.

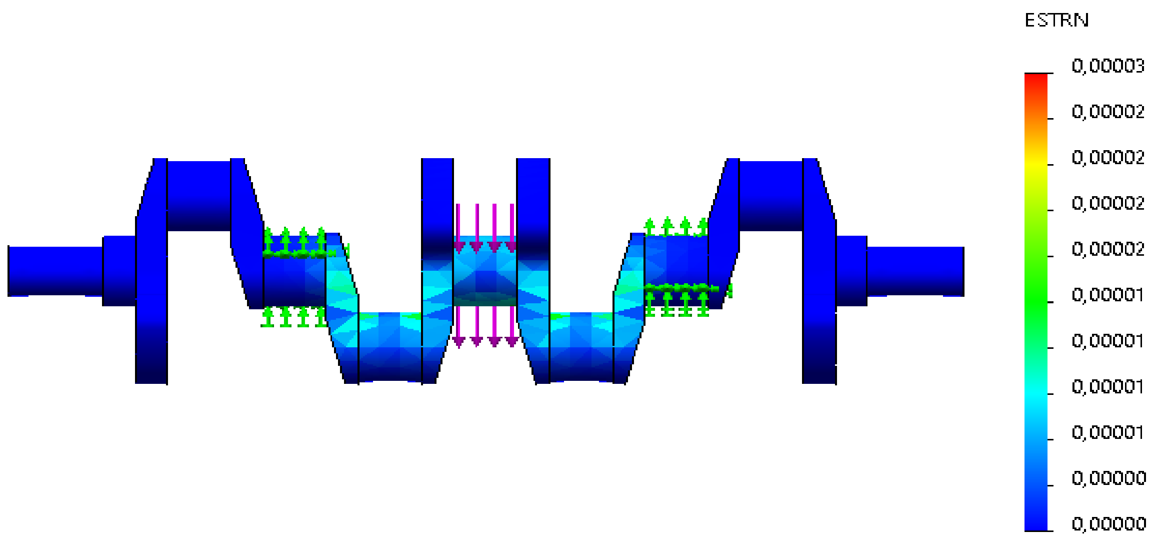

Figure 6: Static strain

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3.3 Displacement

The maximum value of the crankshaft displacement is obtained using Ductile Iron from the pressure deformation of the crankshaft, so the maximum value of 0.021 mm is obtained.

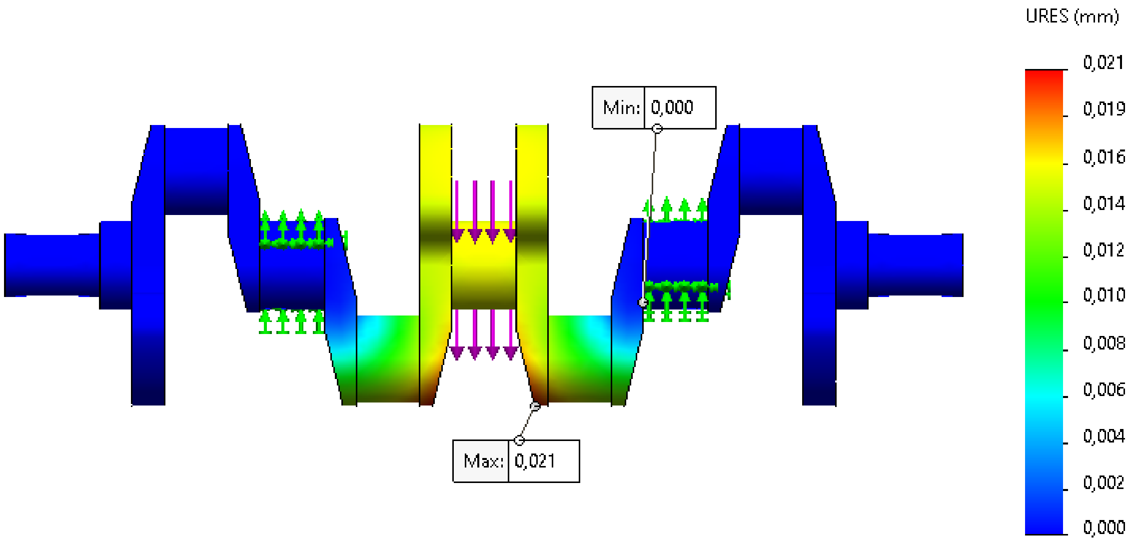

Figure 7: Displacement

3.4 Factor of safety

The Factor of Safety for the crankshaft is the ratio between the material strength of the crankshaft and the maximum stress it experiences during operation. This safety factor ensures that the crankshaft possesses adequate strength to withstand the applied loads. The Factor of Safety can be calculated by:

$$\frac{551{,}485}{4{,}658} = 118{,}4$$

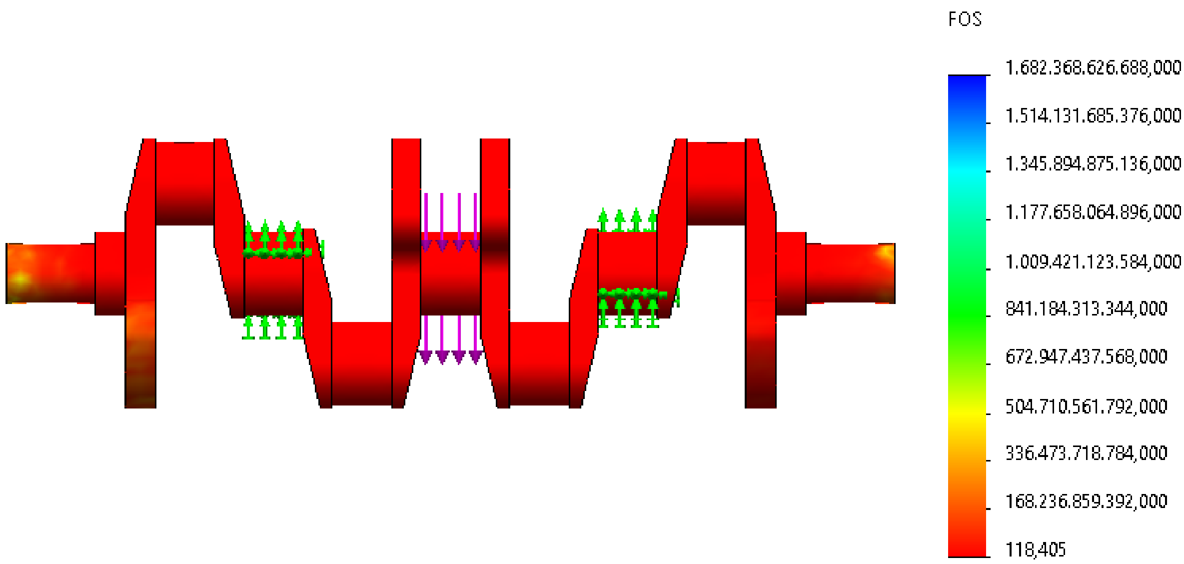

Figure 8: Factors of safety

From the above data, it is evident that von Mises stress significantly influences the safety of the crankshaft. It is known that the maximum yield strength of Ductile Iron material is 551.485 MPa, resulting in a factor of safety of 118.4. Hence, it is highly recommended that this material be utilized.

4. Conclusion and future work

This study highlights the pivotal role of the crankshaft in internal combustion engines, converting piston motion into rotation vital for automobiles. The complex geometry and dynamic forces pose significant challenges for analysis, necessitating comprehensive evaluations during design, including fatigue strength and durability considerations. Simulation results using SolidWorks software reveal a maximum von misses stress of 4.658 MPa and a crankshaft safety factor of 118.4. Material selection is crucial for sufficient strength and resistance to withstand engine loads and pressures. Ductile Iron's popularity for crankshaft manufacturing stems from its strength, durability, and cost-effectiveness, supported by research demonstrating its ability to enhance engine component performance and reliability—simulation technologies like SolidWorks aid in optimizing designs for more robust and more efficient components. Utilizing the Finite Element Method allows for detailed structural integrity and performance analysis under varied conditions, emphasizing the importance of material selection and design optimization in improving engine durability and safety.

For future research endeavors, further exploration into advanced simulation techniques and materials could yield valuable insights into crankshaft design optimization. Investigating alternative materials and their impact on crankshaft performance could offer new avenues for enhancing efficiency and reducing costs. Additionally, delving into the integration of emerging technologies like additive manufacturing processes in crankshaft production warrants exploration. Moreover, conducting experimental validations of simulation results could enhance the reliability and applicability of findings in real-world automotive applications.

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Conflict of interest statement

The authors declare no conflict of interest in this research and publication.

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