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INTERNATIONAL JOURNAL OF RECENT TECHNOLOGY SCIENCE & MANAGEMENT

“STRUCTURAL PERFORMANCE ENHANCEMENT OF HEAVY-DUTY ENGINE CRANKSHAFTS THROUGH GEOMETRIC OPTIMIZATION AND MATERIAL SELECTION”

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ABSTRACT

Crankshafts are critical components of heavy-duty automotive engines, responsible for converting the reciprocating motion of pistons into rotational motion and transmitting engine power. With the increasing demand for higher engine performance, improved durability, reduced component weight, and enhanced fuel efficiency, crankshaft design requires careful consideration of geometric parameters and material properties. Heavy-duty crankshafts are subjected to complex cyclic loading, which can result in excessive deformation, stress concentration, fatigue damage, and premature failure. Therefore, optimizing crankshaft geometry and selecting suitable materials are essential for improving structural performance and operational reliability. The present study focuses on enhancing the structural performance of a heavy-duty engine crankshaft through geometric optimization and material selection. A crankshaft associated with an Ashok Leyland Hino engine is considered for the investigation. A three-dimensional CAD model is developed, and selected geometric parameters, including crankpin diameter, main journal diameter, web thickness, and fillet radius, are considered for optimization. Structural analysis is proposed using Finite Element Analysis (FEA) to evaluate von Mises stress, total deformation, factor of safety, and fatigue performance under representative engine loading conditions. The performance of conventional ductile cast iron and AISI 4140 alloy steel is compared to assess the influence of material selection on strength, stiffness, durability, and weight. The combined evaluation of geometric modifications and material properties is intended to identify a suitable crankshaft configuration that provides an effective balance between structural strength, fatigue resistance, and component weight. The findings of this investigation are expected to provide useful guidance for the design and development of reliable, lightweight, and high-performance crankshafts for heavy-duty automotive applications.

Key Words: Heavy-duty engine, crankshaft, geometric optimization, material selection, Finite Element Analysis, AISI 4140 alloy steel, von Mises stress, fatigue life.

I. INTRODUCTION

The automotive industry continuously strives to improve engine performance, fuel efficiency, reliability, and durability while reducing component weight and manufacturing costs. The development of heavy-duty vehicles has increased the demand for engines capable of delivering higher power and torque under severe operating conditions. In this context, the structural design and performance of critical engine components have become increasingly important. The crankshaft is one of the most essential components of an internal combustion engine because it converts the reciprocating motion of the pistons into rotational motion and transmits the generated power to the transmission system. Its structural integrity directly influences engine performance, operational reliability, and service life. During engine operation, a crankshaft is subjected to combined bending and torsional loads generated by gas pressure, reciprocating inertia forces, and rotating components. These loads vary continuously with engine speed and operating

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conditions, resulting in cyclic stresses that can initiate fatigue cracks and ultimately cause component failure. Stress concentrations commonly occur around crankpin fillets, main journals, and crank webs because of changes in cross-sectional geometry. In heavy-duty engines, these regions require particular attention because the crankshaft must withstand repeated loading while maintaining dimensional stability and adequate fatigue strength. Therefore, improving the structural performance of a crankshaft requires an integrated approach involving geometric design, material selection, and numerical analysis.

Geometric optimization is an important method for improving crankshaft performance without unnecessarily increasing its overall dimensions or weight. Parameters such as crankpin diameter, main journal diameter, crank-web thickness, fillet radius, and crankshaft configuration influence stress distribution, deformation, stiffness, and fatigue resistance. Appropriate modifications to these parameters can reduce localized stress concentrations and improve the load-carrying capacity of the component. However, excessive material removal or unsuitable dimensional changes may reduce structural stiffness and increase the risk of fatigue failure. Consequently, geometric modifications must be evaluated systematically to achieve an effective balance between strength, durability, weight, and manufacturing feasibility. Material selection is another significant factor affecting crankshaft performance. Conventional ductile cast iron offers advantages such as good castability, vibration damping, and relatively economical manufacturing. Alloy steels, including AISI 4140, are also considered for demanding applications because their mechanical properties can be tailored through suitable heat treatment. The performance of these materials depends on properties such as yield strength, ultimate tensile strength, elastic modulus, density, hardness, and fatigue resistance. Selecting a material solely on the basis of strength may not provide the best overall solution, because component weight, manufacturing requirements, cost, and fatigue behaviour must also be considered. A comparative evaluation of candidate materials can therefore help identify a suitable material for heavy-duty crankshaft applications.

Computer-aided design (CAD) and Finite Element Analysis (FEA) provide effective tools for investigating crankshaft structural behaviour before physical manufacturing and testing. A three-dimensional CAD model enables accurate representation of the crankshaft geometry, while FEA can be used to estimate stress distribution, total deformation, and the factor of safety under specified loading and boundary conditions. Fatigue analysis can further support the assessment of durability under repeated engine loading. When combined with systematic geometric modifications and material comparisons, these techniques can reduce dependence on repeated physical prototypes and help identify promising design configurations. Nevertheless, the reliability of numerical predictions depends on the accuracy of the material properties, loading assumptions, mesh quality, contact definitions, and boundary conditions. The present study investigates the structural performance enhancement of a heavy-duty engine crankshaft associated with an Ashok Leyland Hino engine through geometric optimization and material selection. A three-dimensional crankshaft model is developed, and selected geometric parameters are evaluated to understand their influence on structural response. The comparative investigation considers ductile cast iron and AISI 4140 alloy steel, subject to confirmation of the exact material grades and their properties. Finite Element Analysis is used to evaluate von Mises stress, total deformation, factor of safety, and fatigue performance under representative engine operating loads. The overall objective is to identify a suitable combination of crankshaft geometry and material that improves structural reliability while maintaining an appropriate balance between component weight, strength, durability, and manufacturing considerations. The study is intended to provide a systematic engineering approach for improving crankshaft design in heavy-duty automotive applications. By considering geometric and material-related factors together, the investigation seeks to establish how design modifications influence the crankshaft's structural response and to identify opportunities for improved performance. The results may support future crankshaft design development and provide a foundation for further experimental validation under actual engine operating conditions.

II. PROBLEM IDENTIFICATION

The crankshaft is one of the most critical components of a heavy-duty internal combustion engine because it converts the reciprocating motion of the pistons into rotational motion and transmits the generated power. During engine operation, the crankshaft is subjected to cyclic bending and torsional loads caused by combustion pressure, reciprocating inertia forces, and rotating components. These loading conditions may produce high stresses, excessive deformation, and fatigue damage, particularly around crankpin fillets, main journals, and crank webs. Therefore, improving the structural strength and operational reliability of the crankshaft is an important engineering requirement. One of the major challenges in crankshaft design is achieving an appropriate balance between structural strength and

component weight. Increasing the dimensions of critical sections may improve load-carrying capacity but can also increase the overall weight, material consumption, and manufacturing cost. Conversely, reducing the dimensions to achieve weight savings may increase stress concentration and compromise stiffness and fatigue resistance. Therefore, suitable geometric modifications are required to improve the structural performance of the crankshaft without adversely affecting its durability and reliability.

Material selection also plays a significant role in determining crankshaft performance. Ductile cast iron is widely considered for automotive components because of its castability, vibration-damping characteristics, and manufacturing advantages, whereas alloy steels such as AISI 4140 offer high strength and the potential for improved fatigue performance when appropriately processed. However, the suitability of a material depends on its mechanical properties, density, heat-treatment condition, manufacturing requirements, and operating loads. A systematic comparison of candidate materials is therefore necessary to evaluate their influence on stress distribution, deformation, factor of safety, and fatigue life.

Another important problem is the interaction between crankshaft geometry and material properties. Parameters such as crankpin diameter, main journal diameter, crank-web thickness, and fillet radius influence the distribution of stresses and the overall structural response. Optimizing these parameters individually may not provide the best design because changes in one parameter can affect other regions of the crankshaft. Consequently, an integrated investigation combining geometric optimization and material selection is required to identify a suitable configuration for heavy-duty engine applications. In view of these challenges, the present study focuses on the structural performance enhancement of a crankshaft associated with an Ashok Leyland Hino engine using computer-aided design and Finite Element Analysis. Alternative geometric configurations and candidate materials, including ductile cast iron and AISI 4140 alloy steel, are evaluated under representative engine loading and boundary conditions. The analysis aims to identify a suitable combination of geometry and material that reduces critical stresses and deformation while maintaining an appropriate balance between strength, fatigue resistance, component weight, and manufacturing feasibility. The effectiveness of the proposed modifications will be established using the numerical results obtained from the structural and fatigue analyses.

III. RESEARCH OBJECTIVE

The primary objective of this study is to enhance the structural performance and fatigue resistance of a heavy-duty engine crankshaft through geometric optimization and material selection. The investigation focuses on comparing the performance of ASTM A536 100-70-03 ductile iron and AISI 4140 alloy steel (EN19) under specified loading conditions. The study also aims to evaluate the effects of crankshaft design modifications on stress distribution, deformation, factor of safety, fatigue life, component weight, and overall structural reliability.

The specific objectives of the present investigation are as follows:

1. To study the existing design and geometric configuration of a crankshaft used in a heavy-duty automotive engine.
2. To develop a three-dimensional CAD model of the crankshaft and evaluate two candidate materials: ASTM A536 100-70-03 ductile iron and AISI 4140 alloy steel (EN19).
3. To analyze the structural strength and deformation behaviour of the crankshaft using Finite Element Analysis under representative engine loading conditions.
4. To modify and optimize selected geometric parameters, including crankpin diameter, main journal diameter, crank-web thickness, and fillet radius, to improve structural performance.
5. To predict the fatigue life of the crankshaft numerically under cyclic loading conditions and identifies critical regions susceptible to fatigue failure.
6. To investigate the influence of material selection on von Mises stress, total deformation, factor of safety, fatigue resistance, and component weight.
7. To identify an optimized combination of crankshaft geometry and material that improves fatigue life and structural reliability while considering weight reduction and manufacturing feasibility.

IV. METHODOLOGY

The present study focuses on improving the structural performance of a heavy-duty engine crankshaft through geometric optimization and material selection. The methodology involves developing a three-dimensional CAD model of the Ashok Leyland Hino engine crankshaft using CATIA and evaluating its performance through Finite Element Analysis (FEA) in ANSYS Workbench. Initially, the existing crankshaft geometry is modelled by considering important parameters such as crankpin diameter, main journal diameter, crank-web thickness, and fillet radius. Two candidate materials, ASTM A536 100-70-03 ductile iron and AISI 4140 alloy steel (EN19), are selected for comparative analysis using their appropriate mechanical properties. The CAD model is imported into ANSYS, where meshing, material assignment, boundary conditions, and representative engine loads are defined. Static structural analysis is performed to determine von Mises stress, total deformation, and factor of safety. Fatigue analysis is subsequently conducted to estimate fatigue life under cyclic loading conditions. Finally, selected geometric parameters are modified, and the resulting configurations are analysed for both materials. The results are compared in terms of stress distribution, deformation, fatigue life, and component weight to identify a suitable crankshaft design with improved structural reliability and reduced weight, wherever feasible.

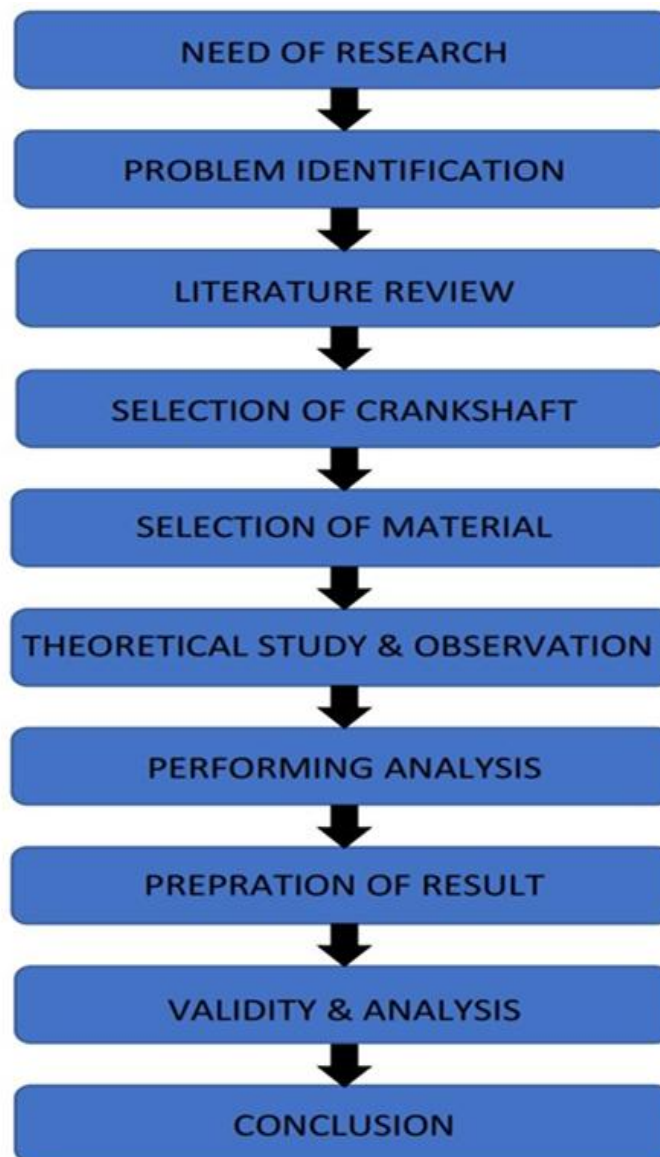


Figure 4.1 Methodology

5. MATHEMATICAL DATA AND STATISTIC

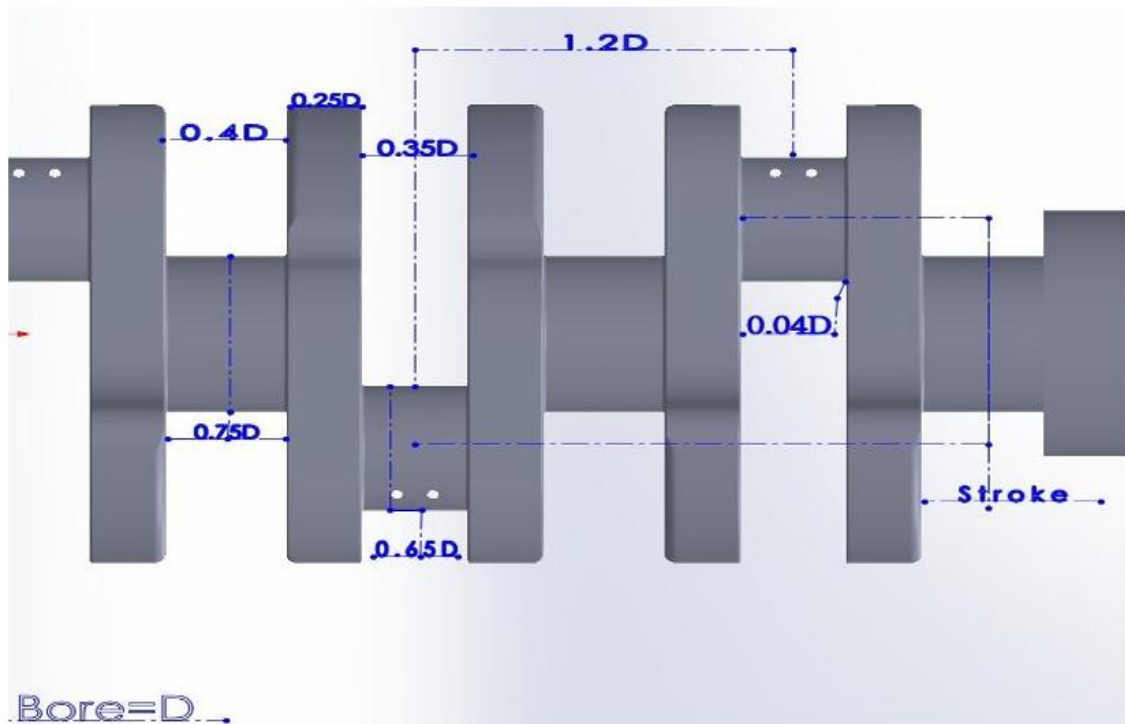


Chart 5.1 Crankshaft dimensional Nomenclature

Based on the cylinder bore diameter $D = 104$ mm, the preliminary crankshaft dimensions are calculated as follows:

1. Cylinder bore diameter, $D = 104$ mm
2. Cylinder centre distance $= 1.20 D = 124.8$ mm
3. Big-end journal diameter $= 0.65 D = 67.6$ mm
4. Main-end journal diameter $= 0.75 D = 78$ mm
5. Big-end journal width $= 0.35 D = 36.4$ mm
6. Main-end journal width $= 0.40 D = 41.6$ mm
7. Crank web thickness $= 0.25 D = 26$ mm
8. Fillet radius of journal and web $= 0.04 D = 0.04 \times 104 = 4.16$ mm
9. Crankpin overlap or eccentricity:

$$13.7 = \{(64.2 + 78) / 2\} - E$$

Therefore,

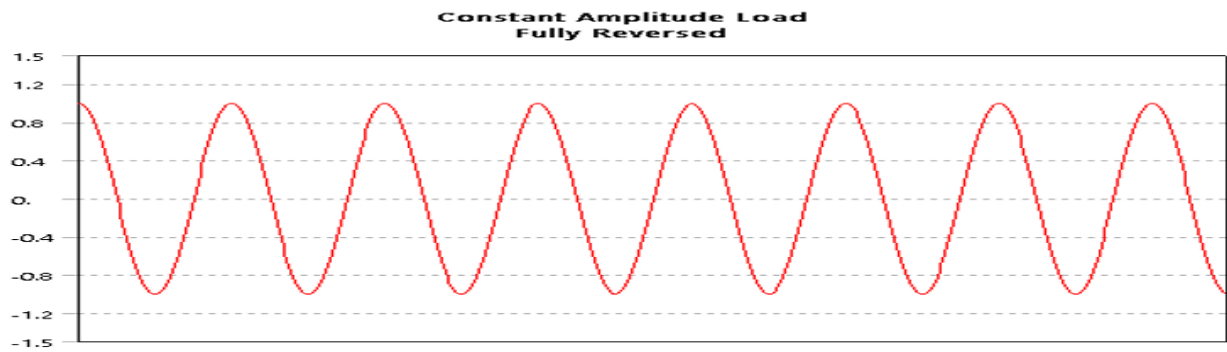
$$E = 57.4 \text{ mm}$$

Where,

E = Eccentric length or distance between the centre of the main journal and the crankpin.

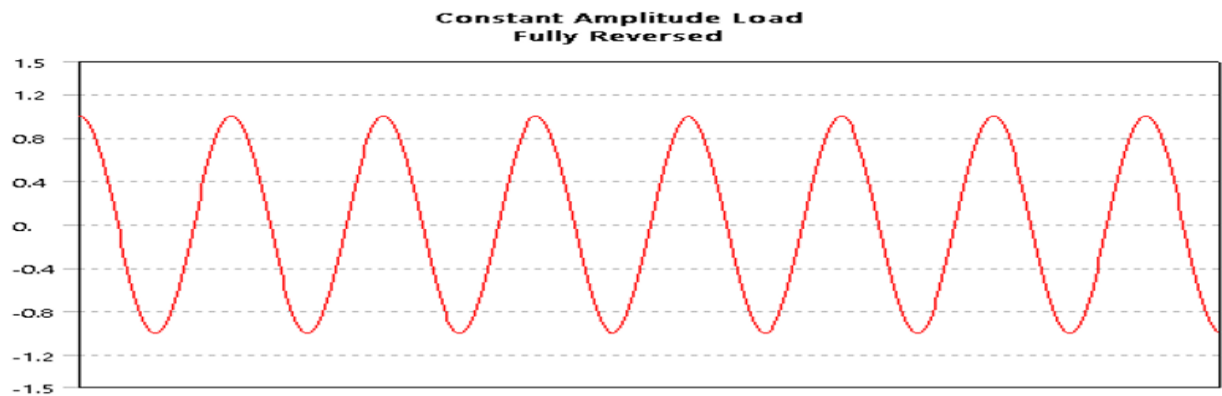
In V8 crankshafts, the counterweight is generally selected by considering the rotating and reciprocating masses. A common approach is to balance 100% of the rotating mass and approximately 50% of the reciprocating mass. In the present study, the counterweight is considered as 50% of the reciprocating mass for crankshaft balancing.

V. RESULT AND DISCUSSION



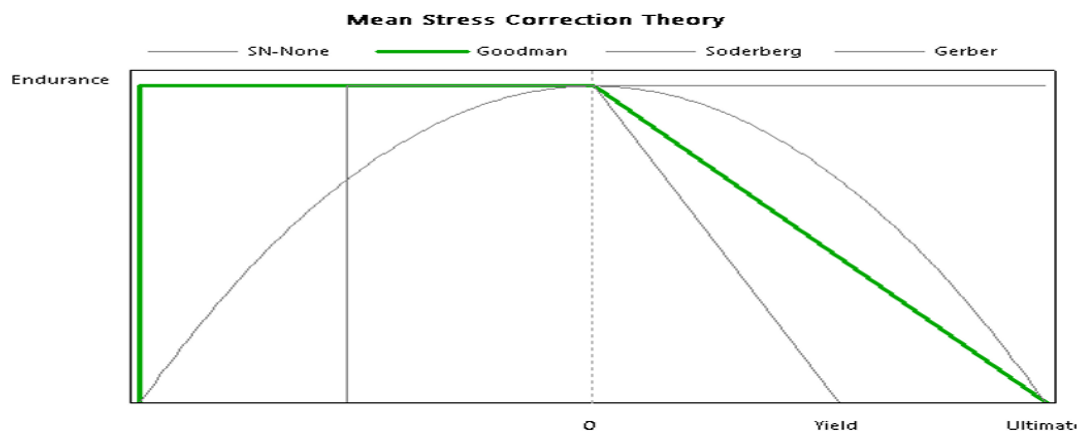
Graph 6.1 Amplitude of the force Material GGG 70

Here Graphs shows amplitude of forces for material GGG70 Conducted the impact studies on the dissimilar elements of AISI 4140 and AISI 304 and observed the carbon depletion at the weld interface of low alloy side. It was reported that AISI 4140 side should be pre-heat treated before welding for getting the better toughness.

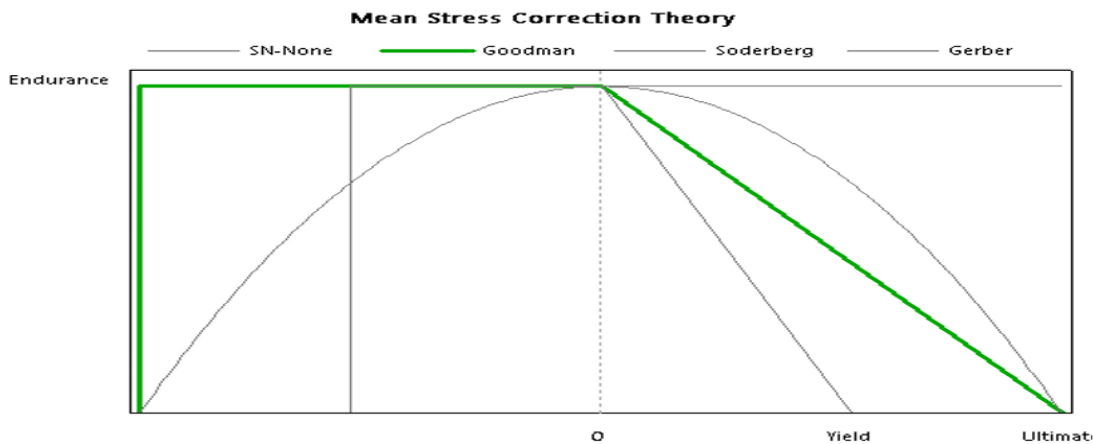


Graph 6.2 Amplitude of the force 1 Material AISI 4140

Here Graphs shows amplitude of forces for material AISI 4140 Mean stress is equal to the average of the maximum and minimum stress during a fatigue load cycle. Much of fatigue data is generated assuming a zero-mean stress, which means that the load cycle is completely reversed. The stress ratio, also referred to as R or R-ratio, is defined as the minimum stress over the maximum stress and is used to quantify the mean stress. A stress ratio of -1 represents a fully reversed loading.



Graph 6.3 Graph of correction theory Material GGG 70



Graph 6.4 Graph of correction theory Material AISI 414

Table.6.1 Results Comparison

ASTM A536 100-70-03 (GGG70)	AISI-4140
Heavier weight	Lighter weight
Possess low crankshaft qualities	Possess good crankshaft qualities
High measure of strain	less measure of strain
Same stress as AISI 4140	Same stress as GGG70
Deformation are almost constant	Deformation are almost constant
Low administration Life	High Administration Life
More Shear force	Low Shear force
Heap Conditions	Bring Down Dislodging
High Flexibility	High Rigidity
Tensile Strength=100000psi	Tensile strength=100000psi
Yield Strength=70000	Yield Strength=70000

VI. CONCLUSION

In this undertaking the appropriate substitute material has been AISI-4140 alloy steel (EN 19C) Steel distinguished and examined for the diesel motor camshaft rather ASTM A536 100-70 03 (GGG70) high ductile than material. The material is a heavier weight then ASTM A536 100-70-03 (GGG70) but Possess high crankshaft qualities. The high measure of strain is considerably high thus helping it to possess high administration Life. More Shear force, Heap Conditions, High Rigidity, Tensile Strength=100000psi, Yield Strength=70000. The outcomes got from Ansys test showed that the shear for exerted on the ASTM A536 100 70-03 (GGG70) high ductile than material is more as compared to AISI-4140 alloy steel (EN 19C) before enlistment solidifying. Effect test demonstrated that the weight of AISI-4140 alloy steel (EN 19C) is 3kg higher than ASTM A536 100-70-03 (GGG70). Moreover, ANSYS comes about demonstrated that AISI-4140 alloy steel (EN 19C) camshaft endured bring down dislodging than ASTM A536 100-70-03 (GGG70) camshaft for all heap conditions. From these outcomes it can be watched that AISI-4140 alloy steel (EN 19C) camshaft influenced utilizing has higher administration life.

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