A Review on Comparative Analysis of Crankshaft to Reduce its Weight by Using Alternative Material

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doi.org/10.64643/IJIRTV12I12-200749-459

***Abstract*—This study represents a comparative analysis of crankshaft to reduce its weight by using alternative materials. The conventional Forged Steel Crankshaft is modeled using Solidworks software and analyzed under structural load using Finite Element Analysis (FEA) Software (Ansys 2023 R2). A alternative materials, include Aluminium Alloy (6061-T6), Structural Steel are tested to evaluate their equivalent stress, Total deformation, maximum shear stress, Directional deformation x direction, Directional deformation Y direction, Directional deformation Z direction ratio compared to steel. Results indicated that replacing steel with lighter materials can reduce the overall crankshaft weight (by over 15-40%) while maintaining safety, leading to reduce inertial forces and enhanced engine performance.**

***Keywords*— Crankshaft, Weight Reduction, Finite Element Analysis (FEA), Alternative Materials, Structural Analysis (ANSYS 2023 R2), Forged Steel, Aluminium Alloy (6061-T6).**

I. INTRODUCTION

The crankshaft is arguably the most critical structural component of an internal combustion engine (ICE), serving as the mechanical bridge that translates the energy of combustion into usable kinetic power. In the hierarchy of automotive engineering, it functions as the "spine" of the engine assembly. Its primary purpose is to convert the reciprocating (up-and-down) linear motion of the pistons into rotational motion, which is subsequently transmitted through the drivetrain to the wheels of a vehicle or the rotor of a generator.

Mechanical Principles and Geometry -
The fundamental operation of a crankshaft is based on the principle of a crank mechanism. Each piston is connected to the crankshaft via a connecting rod. The end of the connecting rod attaches to a crankpin (also known as a connecting rod journal), which is offset from the central axis of rotation. As the air-fuel mixture ignites in the combustion chamber, the resulting pressure forces the piston downward. This linear force is applied to the offset crankpin, creating a moment or torque around the shaft’s center, thereby inducing rotation.

The geometry of the crankshaft is complex and dictates the engine's firing order, vibration characteristics, and overall balance. A standard crankshaft consists of:

- Main Journals: These serve as the pivot points for the shaft, resting in the engine block's main bearings.
- Crankpins: The attachment points for the connecting rods.
- Crank Webs: The structural walls that connect the crankpins to the main journals.
- Counterweights: Precisely machined masses integrated into the webs to balance the reciprocating mass of the pistons and rods, minimizing centrifugal forces.

Material Science and Manufacturing -
Because the crankshaft is subject to extreme torsional stress, bending moments, and cyclic loading, its material composition is a focal point of metallurgical research. In high-performance or heavy-duty applications, forged steel is the industry standard due to its superior fatigue strength and grain flow. For mass-produced passenger vehicles, ductile cast iron (nodular cast iron) is often preferred for its cost-effectiveness and excellent damping properties, which help absorb engine vibrations.
To further enhance the component's durability, surfaces such as the journals undergo specialized heat treatments like nitriding or induction hardening. These processes increase surface hardness and wear resistance while maintaining a ductile core capable of absorbing shocks without fracturing.

Dynamics and Balancing -
One of the greatest challenges in crankshaft design is managing harmonic vibrations. Every time a cylinder

fires, it delivers a "punch" of energy to the shaft, causing it to slightly twist and rebound. If these pulses align with the natural frequency of the shaft, it can lead to catastrophic torsional failure. To mitigate this, engineers employ torsional vibration dampers (harmonic balancers) at the front of the shaft and heavy flywheels at the rear to smooth out power delivery.

Research Significance-
In the contemporary era of "downsizing" and "high-power density," the crankshaft remains a central subject of academic study. Researchers are currently exploring the use of carbon-fiber composites and micro-alloyed steels to reduce the "rotating mass" of the engine. A lighter crankshaft allows the engine to rev faster and improves fuel efficiency by reducing parasitic losses. Furthermore, Finite Element Analysis (FEA) is now used to predict stress concentrations at the "fillet" regions (the corners where journals meet webs), allowing for optimized designs that provide maximum strength with minimum weight.

In summary, the crankshaft is not merely a rotating rod but a sophisticated piece of precision engineering. Its ability to endure millions of cycles under high temperature and pressure while maintaining micrometer - level tolerances is essential for the reliability and performance of modern mechanical systems.

II. LITERATURE SURVEY

Rao et al. (2015) – Comparative Study of Forged Steel and Cast Iron Crankshafts Rao and his team analyzed crankshafts made from forged steel and cast iron using finite element analysis (FEA). They found that forged steel crankshafts exhibited superior fatigue strength and durability due to their fine grain structure and higher tensile strength. However, the major drawback was the increased weight and manufacturing cost. Their study concluded that material optimization could play a key role in improving performance without compromising strength.

Patil and Kulkarni (2017) – Stress Analysis and Optimization Using ANSYS Patil and Kulkarni conducted static structural and modal analysis on a single-cylinder diesel engine crankshaft using ANSYS Workbench. The study identified high-stress zones near the crankpin fillet and main journal fillets. They optimized these areas by adjusting fillet radii and reducing sharp edges, which resulted in a 7–10% reduction in maximum stress while maintaining stiffness. This study highlighted the significance of geometric refinement in improving crankshaft performance.

Singh et al. (2018) – Weight Reduction through Material Substitution Singh and colleagues explored alternative lightweight materials such as alloy steels and metal matrix composites to replace traditional forged steel crankshafts. Using FEA simulations, they achieved 10–15% weight reduction with only minimal compromise in strength. However, the high cost and complex manufacturing process of composite materials made them less feasible for mass production. Their work emphasized the need for practical, cost-effective material alternatives.

Mehta et al. (2022) analyzed fatigue life improvement techniques and suggested using alternative materials such as EN8 and Ti-alloys, demonstrating better performance under cyclic loads while maintaining acceptable deflection limits.

Jadhav et al. (2024) – Lightweight Hybrid Material Design Jadhav and co-authors proposed a hybrid crankshaft combining a forged steel core with aluminum–silicon alloy counterweights. The hybrid model achieved a 14% reduction in weight and improved balance factor without compromising torsional stiffness. This research suggested that hybrid material combinations could be a promising direction for future lightweight crankshaft designs.

Park et al. (2021) – Comparative Study of Manufacturing Techniques Park's study compared traditional forging, precision casting, and additive manufacturing (metal 3D printing) methods for crankshaft production. Finite element analysis revealed that additive-manufactured prototypes could achieve similar stiffness to forged ones, with 10–12% lower mass. However, surface finish and residual stress control remain key challenges for AM-based crankshafts.

R. J. Deshbhratar et.al have designed crankshaft by using Pro-E and analysis was done by ANSYS software. The maximum stress is seen in the fillet area and also around the center of crank pin. At most of the times crankshaft deforms because of bending under natural frequency as the maximum deformation is observed on crankpin neck.

III. CRANKSHAFT DESIGN AND MATHEMATICAL PROCEDURE

Maximum Gas Force

$$F_g = \frac{\pi}{4}(0.1)^2 \times 6 \times 10^6 = 47{,}100 \text{ N}$$

$$F_g = 47.1 \text{ kN per cylinder}$$

3.4 Bending & Twisting Moments (per crankpin)

$$M_b = F_g \times r = 47{,}100 \times 0.046$$
$$= 2.17 \times 10^6 \text{ N/m}$$
$$M_t = F_t \times r = 14{,}100 \times 0.046$$
$$= 0.65 \times 10^6 \text{ N/m}$$

Equivalent Bending Moment

$$M_e = \sqrt{M_b^2 + M_t^2} = 2.27 \times 10^6 \text{ N/mm}$$

3.5 Crankpin Stress Check

(A) Bending Stress

$$\sigma_b = \frac{32M_e}{\pi D_p^3}$$

$$\sigma_b = \frac{32(2.27 \times 10^6)}{\pi(54)^3} = 14.8 \text{ MPa}$$

(B) Shear Stress (torsion)

$$\tau = \frac{16M_t}{\pi D_p^3} = 2.5 \text{ MPa}$$

Safe (allowable ≈ 80 Mpa for steel, FOS = 2.5).

3.6 Web (Crank Arm) Bending Stress

$$M_b' = \frac{M_b}{2} = 1.08 \times 10^6 \text{ N/m}$$

$$\sigma_w = \frac{6M_b'}{b_w t_w^2} = \frac{6(1.08 \times 10^6)}{15(38)^2} = 30.0 \text{ MPa}$$

Safe (allowable up to 70 MPa).

3.7 Bearing Pressure (per crankpin)

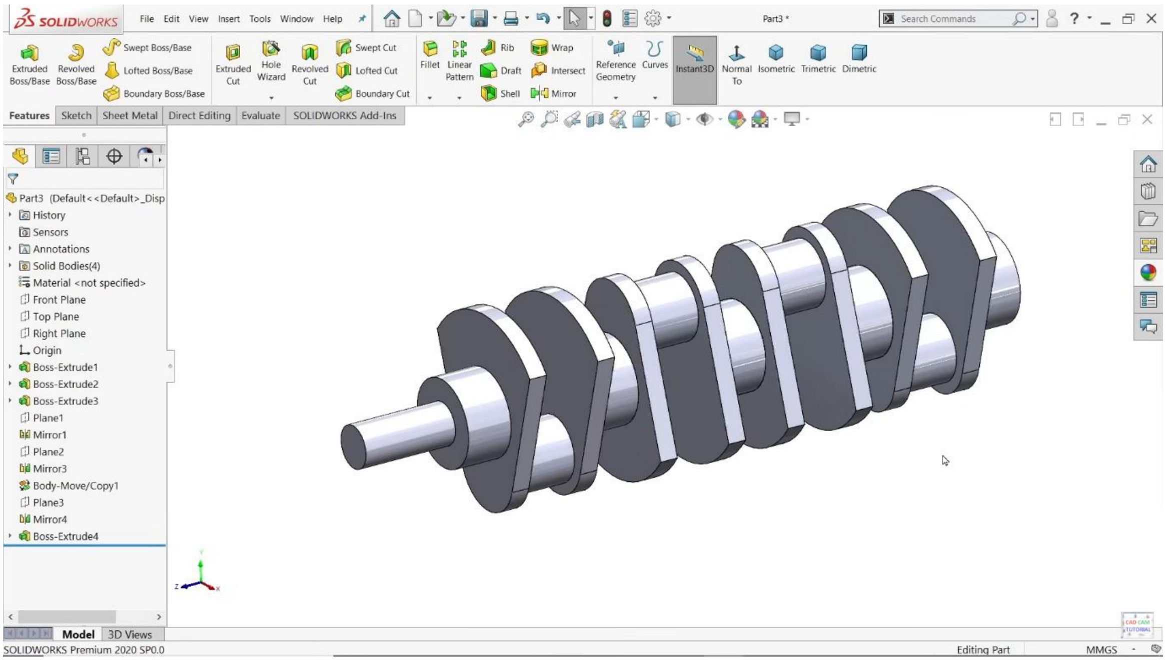
Assume bearing length $l_p = 38$ mm.

$$p_b = \frac{F_g}{l_p D_p} = \frac{47{,}100}{38 \times 54} = 22.9 \text{ N/mm}^2$$

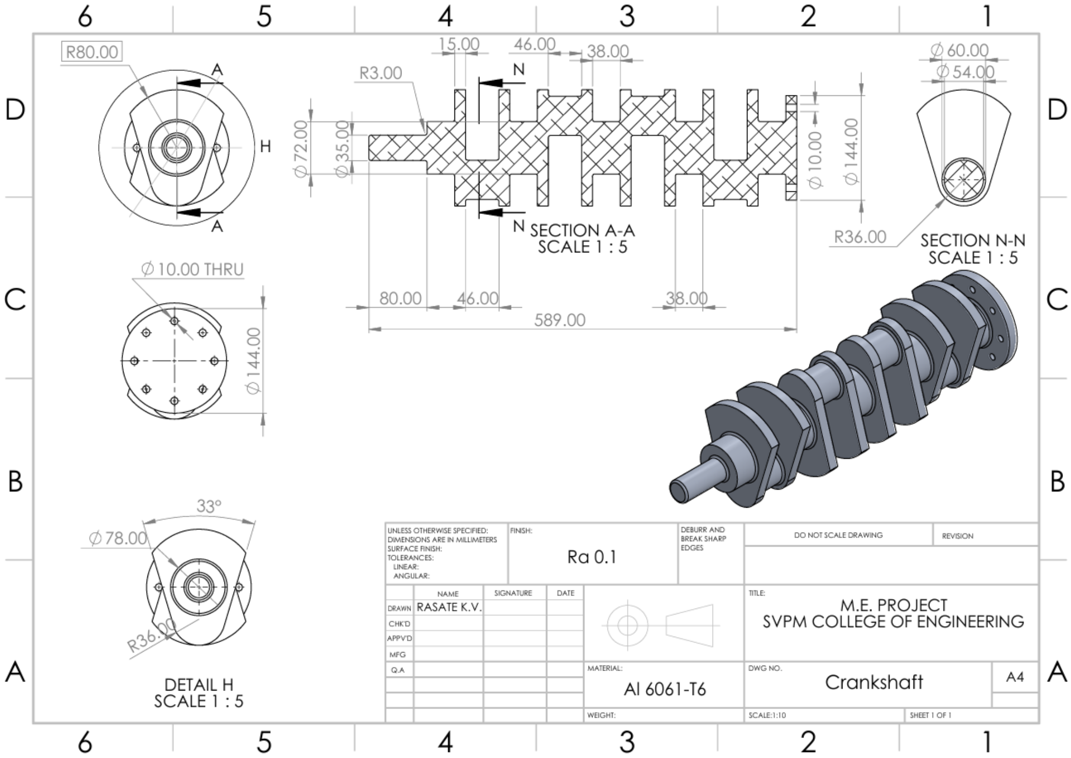
Safe (< 25 N/mm² for plain bearings).

Parameter	Symbol	Value
Main journal diameter	D_j	72mm
Crank pin diameter	D_p	54mm
Shaft end diameter	D_8	32mm
Crank radius	r	46mm
Web thickness	t_w	38mm
Web width	b_w	15mm
Fillet radius	R_f	3mm
Number of crank pin	n_p	4
Number of main journals	n_j	5

3.1 Crankshaft Isometric View



3.2 Crankshaft Detail Drawing



IV. CONCLUSION

The comparative analysis of the crankshaft demonstrates that significant weight reduction is achievable through the strategic application of alternative materials. By utilizing Finite Element Analysis (FEA) and Solidworks modeling, this study successfully evaluated the performance of lightweight materials such as Aluminium Alloy (6061-T6) against the industry-standard Forged Steel.

The primary findings of this research include:

- Weight Optimization: Replacing conventional forged steel with lighter alternative materials can reduce the overall weight of the crankshaft by 15% to 40%.
- Structural Integrity: Despite the reduction in mass, these alternative materials maintain a high standard of safety, as evidenced by the structural analysis of equivalent stress and total deformation.
- Performance Enhancement: A lighter crankshaft effectively minimizes inertial forces within the engine, leading to improved fuel efficiency and the ability for the engine to rev faster due to reduced "rotating mass".
- Geometric Precision: The study highlights that maintaining micrometer-level tolerances and optimizing high-stress zones—particularly at the crankpin and main journal fillets—is essential for ensuring reliability.

Ultimately, this research underscores that material substitution, supported by advanced computational tools like ANSYS, provides a viable pathway for modern automotive engineering to achieve higher power density and better mechanical performance.

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