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Design, Materials, Production, FEM and Experimental Analysis of an I.C. Engine Crankshaft – A Review

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Abstract. A crankshaft can be called as the heart of any I.C. engine since it is the first recipient of the power generated by the engine. Its main function is to convert the oscillating motion of the connecting rod into rotary motion of the flywheel. Irrespective of having an intricate profile, crankshafts are mass produced. In this paper, the design considerations, finite element stress analysis and experimental stress analysis of the crankshaft are studied. The crankshaft of a mini truck, car and motorcycle was designed using standard design formulae, followed by the creation of its 3-D model using suitable design software like CATIA or PRO/E. Static and dynamic stress analysis was performed using ANSYS software to determine the values of total deformation and equivalent stress, based on which the areas susceptible to failure are identified. The analysis was carried out for commonly used materials for manufacturing a crankshaft, like cast iron and forged alloy steel. The work carried out by various researchers on design and FEM based analysis of a crankshaft is reviewed in this paper. Aspects such as materials, manufacturing processes, causes of failure, experimental stress analysis are also reviewed in this paper.
Keywords: **crankshaft, cast iron, design, dynamic loading, experimental, FEM, forged steel, finite element method, production, static loading, stress analysis**

1 Introduction

A crankshaft as shown in Fig. 1 can be considered as the heart of an I.C. engine, without which it cannot work. It allows the pistons to continuously reciprocate inside the cylinder by means of the unbalanced masses called crank webs. It has a intricate solid geometry. The crankshaft consists of three main parts namely the crank pin, crank web and shaft. The big end of the connecting rod is connected to the crank pin; the crank web connects the crank pin to the shaft portion which is rotated by the main bearings and transmits power to the outside source through the belt drive, gear drive or chain drive. Load of the gas forces inside the combustion chamber is transferred and distributed over each crank pin through the connecting rod. Every crank web is subjected to bending moment and twisting moment. There is a flywheel attached at the end of the crankshaft to bring uniformity in torque of a four-stroke I.C. engine by storing energy during the power stroke and releasing the same during the other three strokes. The crankshaft should have sufficiently high strength so as to sustain the gas force acting vertically downwards during the expansion stroke. Strength of the crankshaft should be enough to avoid bending failure. Hence, the crankshaft greatly affects the life and reliability of an I.C. engine.

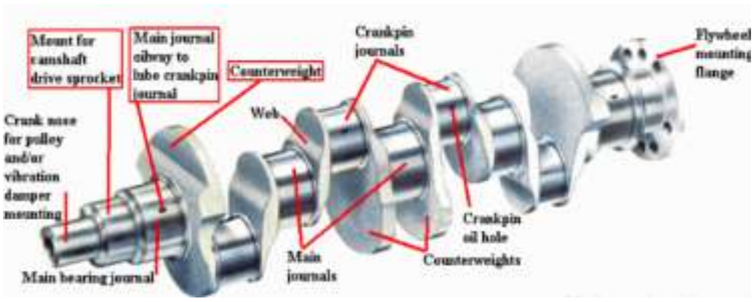


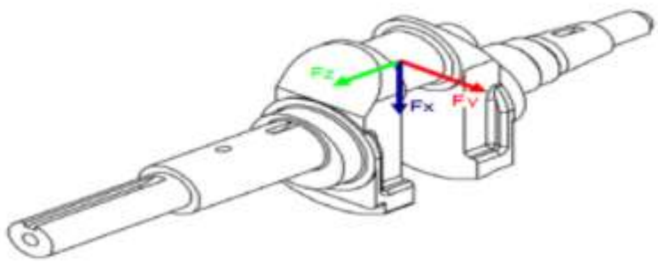
Figure 1. Nomenclature of crankshaft

An automobile should have a crankshaft which has maximum strength and minimum weight. Thus, there is an extensive research work conducted regularly to optimize the crankshaft by using optimized designs, new materials, and performing finite element analysis to identify the problems and rectify them. At the same time, saving cost should be focused on too.

2 Stresses in Crankshaft

Following stresses directly affect the crankshaft of an I.C. engine:-
1. Bending Stress: - The gas force generated by the burning of air-fuel mixture in the combustion chamber, above the piston head, forces the piston downwards. This force is transmitted to the crankpin bearing. It is a bending load, causing corresponding bending stress.
2. Torsional Shear Stress: - Crankshaft is a rotating component, and it runs at high speeds. Any rotating mass generates centrifugal force. Greater the engine speed, greater is the centrifugal force. Connecting rod also generates centrifugal force. Due to this, both, bending and torsional shear stress are developed in the crankshaft.

These are as shown in Fig. 2.



Crankshaft geometry and bending (F_x), torsional (F_y), and longitudinal (F_z) force directions

Figure 2. Forces acting on crankshaft

3 Materials and Manufacturing Processes

Nallicheri et al. (1991) [1] performed a wide-ranging study on finding out replacement materials for manufacturing automotive crankshafts. A study was performed on materials like SG iron, micro-alloy steel, austempered ductile iron and forged steel. They evaluated the costs of using these materials. They came to a conclusion that as the production volume increases cost of production decreases and vice-versa. The most cost-effective material was found out to be cast iron, but the properties offered by it were such that it could only be used in light duty applications. If there is a need of better mechanical properties, other materials shall be looked upon. Based on the production volume per year, material has to be selected. If the production volume is high (more than 200000 parts per year), micro-alloy steel was found out to be the best option. If the production volume is low (less than 200000 parts per year), the high cost of micro alloy steel was not justified. They concluded that, for forged steel, out of the total cost, around 30% and 47% were the raw material cost and the manufacturing cost respectively. The same for micro-alloy steel was 38% and 43% respectively. This showed that micro-alloy steel has higher raw material cost but lower manufacturing cost as compared to forged steel. A further reduction in a cost of about 3.5% of the total cost was found out for micro-alloy steel, on account of it not needing heat treatment.

The most commonly used materials for the manufacturing of automobile crankshafts are Nodular Cast Iron, Cast Steel and Forged Alloy Steel, depending upon the end application, whether it is used for two wheelers, passenger cars or heavy commercial vehicles. The volume of production also matters. Some special materials like Aluminium-Silicon composite, Inconel X-750 have also been used for exotic applications like racing cars, where performance outdoes cost reduction.

Prajakta Pawar et al. (2015) [2] evaluated various crankshaft manufacturing methods. According to them, there are mainly three processes which are used for manufacturing a metal crankshaft, namely forging, casting,

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and machining. Forging is but shaping of metal by plastic deformation. Various stages in forging are as shown in Fig. 3.

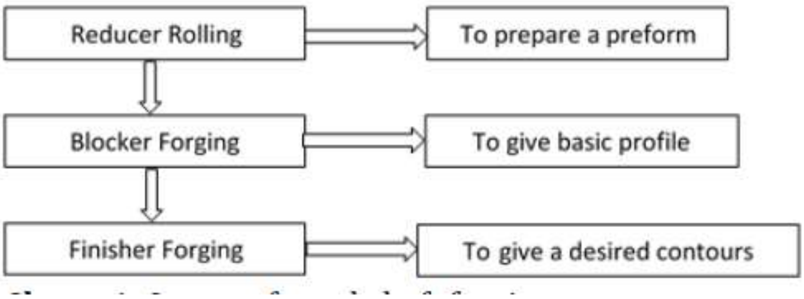

Figure 3. Stages in crankshaft forging

In forging, deformation is induced in each stage to guarantee the metal flow in to the die cavity in both top and bottom dies. The workpiece moves in a particular direction in each stage with a specific velocity. Metal flow pattern fills the complete die cavity to produce a complete forging. This is the most widely used method of manufacturing crankshafts nowadays since the crankshafts get highest mechanical and fatigue strength and become light in weight. This process is followed by a number of other processes as shown in Fig. 4.

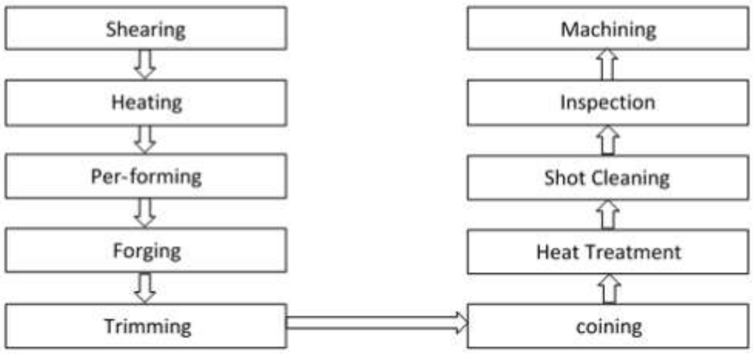

Figure 4. Forging process for manufacturing crankshaft

In casting, the metal is heated and poured in moulds in molten state to achieve the desired product. This is followed by machining. The main advantage of casting is that mass production can be achieved in less time and it is a low cost process compared to forging. But the main limitation is that crankshafts manufactured by casting have the lowest mechanical and fatigue strength, are brittle and heavy. Hence they are preferred for light duty applications. Heat treatment and surface treatment is required after casting. Various stages in casting are as shown in Fig. 5.

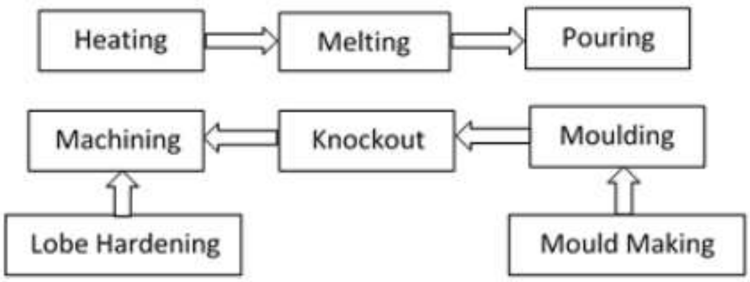

Figure 5. Casting process for manufacturing crankshaft

Machining is a material removal process from a billet with a required diameter. In this process the part is machined from a billet. Flexibility in design can be achieved using machining. The billet process makes it much easier to locate the counterweights and journals webs exactly where the designer wants them to be. This process requires machines and tools like Lathe machine, Shaper, Precision Drills, Milling machine, etc. This is a costly and time consuming process and is only used for special purpose applications. Flow chart for machining is shown in Fig. 6. Comparison of these three manufacturing processes is as shown in Table 1.

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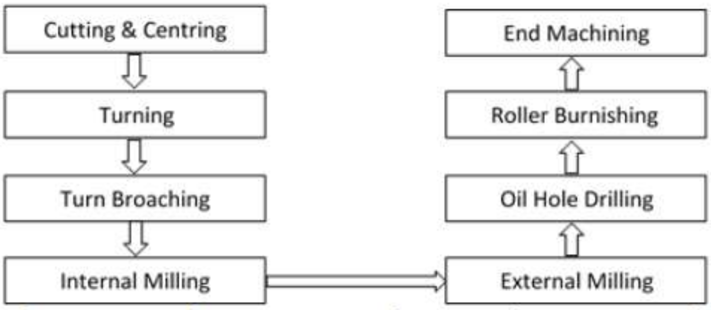

Figure 6. Machining process for manufacturing crankshaft

Table 1. Comparison of crankshaft manufacturing processes

Sr No	Parameter → / Method ↓	Material	Time	Material Cost	Labour Cost
1	Forging	Forged steel	Less	High	Less
2	Casting	Cast Iron	More	Less	More
3	Machining	Alloyed Steel	More	More	Less

4 Theoretical Design Calculations of Crankshaft

Sujata Satish Shenkar and Nagraj Biradar (2015) [3] in their work, theoretically designed the crankshaft of a single cylinder engine of a mini tempo truck, followed by static structural analysis using ANSYS software. The design of crankshaft was made by taking into account two different positions of crank.

Crank is located at the dead centre. This is the position of the crank at which it is acted upon by highest gas forces of combustion, on the piston head. This force gets transferred to the crankpin through the connecting rod. This would cause bending of the crank pin. Hence, at this position of the crank, the crankshaft will experience the highest bending moment and no torsional moment. The authors also studied the action of forces on the crankshaft. It is as shown in Fig. 7.

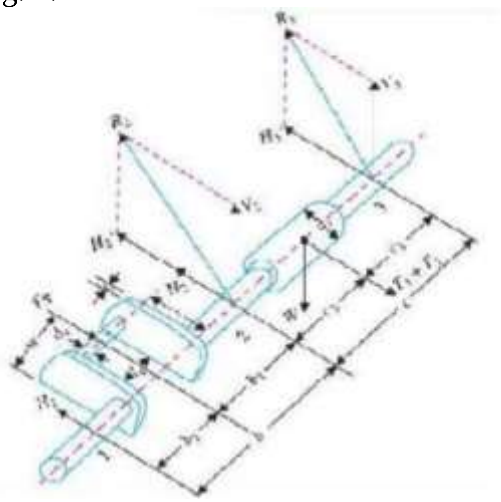

Figure 7. Forces acting on crankshaft when it is at the dead centre

Bearing reaction at bearing 3 was not considered, but more focus was given on bearing reactions at bearing 1 and 2. The theoretical calculations for this position of the crank are as follows:-

i. Force on the Piston (Fp)

Fp = Area of the bore x Max. Combustion pressure

$= \pi/4 \times D_2 \times Pmax$

ii. Bearing reactons (H_1 and H_2)

Due to piston gas load, there will be two equal horizontal reactions H1 & H2 at bearings 1 and 2 respectively.

$H_1 = F_p / 2 = H_2$

Lengths of the bearings are assumed to be equal.

$c_1=c_2=c/2$

iii. Crankpin

The crankpin was subjected to bending and twisting. The bending moment was given as follows:-

$Mc = H_1 * b_2$

$Mc = \pi / 32 * (d_c)^3 * \sigma b$

(Where d_c = Diameter of the crank pin)

Length of crank pin $l_c = F_p/(d_c*p_b)$

iii. Left Hand Crank Web

It is designed taking into account eccentric loading. The crank web is acted upon by two stresses namely bending stress and compressive stress. Both were due to the piston force (Fp). These stresses are given as follows:-

Thickness of the crank web is,

$t = 0.65 *d_c + 6.35$ mm

Width of the crank web is,

$w = 1.125 * d_c +12.7$ mm

Maximum bending moment acting on crank web is,

$M_{max} = H_1 (b_2 – l_c/2 - t/2)$

Length, thickness and width of the crank Maximum bending moment acting on crank web is,

Mmax = H1 (b2 – lc/2 - t/2)

Section Modulus

$Z = 1/6 * w * t_2$

Bending Stress $\sigma_b = M/Z$

The compressive stress acting on crank web is,

$\sigma_c = H_1/(w * t)$

Finally, the total stress (σ) is found out using the formula,

$\sigma = \sigma_b + \sigma_c$

It is compared with the allowable stress to ensure safety of the design.

iv. Right Hand Crank Web

For perfect balancing, the thickness and width of the right hand crank web were made equal with that of the left hand crank web.

Crank is subjected to maximum twisting moment when it is at some angle. Due to this, the tangential force on the crankshaft is the highest. The angle at which this occurs is about 30 to 40 degrees in diesel engines.

5 Literature Review

Amit Solanki and Jaydeepsinh Dodiya (2014) [4] performed a static simulation on the crankshaft of a 4-stroke diesel engine having a single cylinder. In their work, they designed a crankshaft using standard design formulae. After this, a 3-D model of the crankshaft was prepared using Pro/Engineer software. This model was imported in ANSYS software as shown in Fig. 8 and meshed using tetrahedron 10 elements as shown in Fig. 9. Boundary conditions were applied, fixing the bearing supports at both ends.

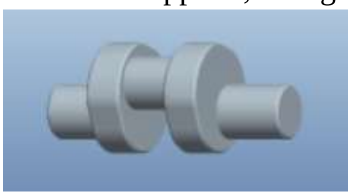

Figure 7. Crankshaft imported in ANSYS

Figure 8. Meshed crankshaft in ANSYS

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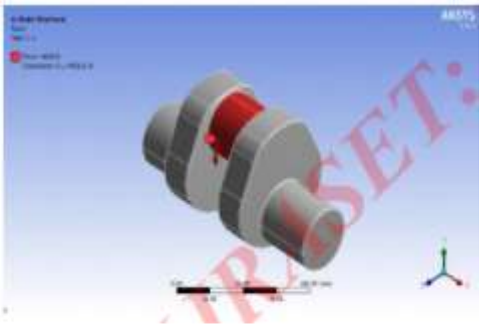


Figure 9. Tangential load applied

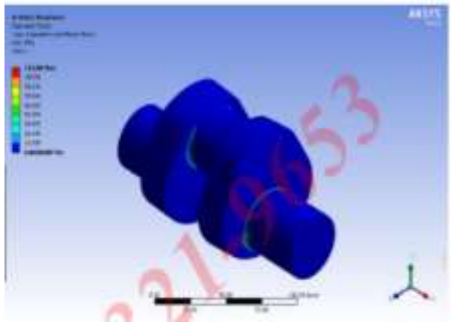


Figure 10. von-Mises stress

Load was applied as shown in Fig. 9 and the analysis was run after applying material as cast iron. The values of von-Mises stress as shown in Fig. 10 and shear stress were found out and compared with the theoretical values of the same for validation purpose. It was found that centre of the neck surface of crank pin had the highest deformation. The transitional surface between the journal of the crankshaft and cheek of the crank, called as fillet, showed the highest intensity of stresses. In addition to this, main journal edge was also a critical area. The analytical value of von-Mises stress was very less as compared to the material yield stress, which ensured a safe design.

P. Preetham and S. Srinivasa Prasad (March 2016) [5] presented a case study on a six cylinder four stroke engine crankshaft. Their main objective was to evaluate the principal shear stress and equivalent (von-Mises) stress in the crankshaft by means of ANSYS Workbench software. They performed static structural and modal analysis on traditional crankshaft made from structural steel and a newly modelled crankshaft using material Inconel X-750. They created a 3-D model of crankshaft using Solidworks software as shown in Fig. 11 This model was imported in ANSYS 14.5 Workbench software and meshed using Tetrahedron elements as shown in Fig. 12. After meshing, boundary conditions were applied, keeping both ends of the crankshaft fixed as shown in Fig-13. A gas pressure of 3.5 N/mm^2 was applied above the top centre of the crankpin was applied as shown in Fig. 14.

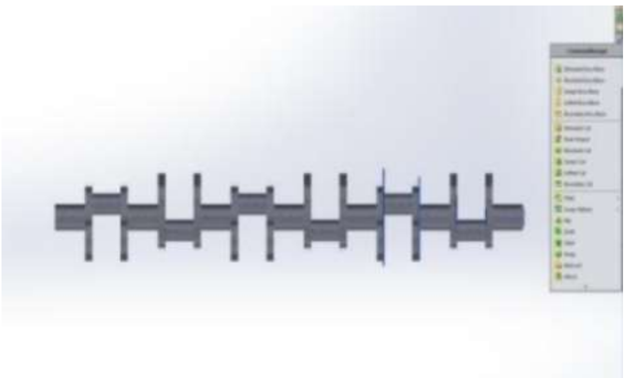


Figure 11. Crankshaft model

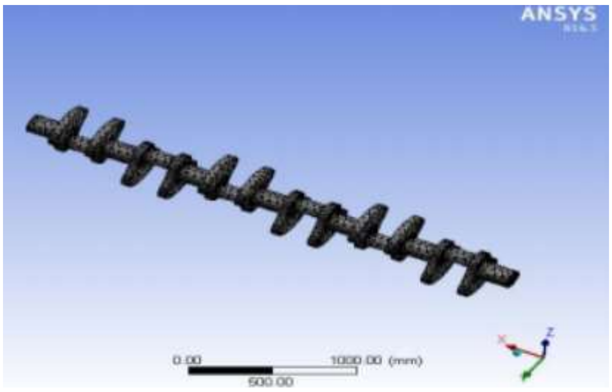
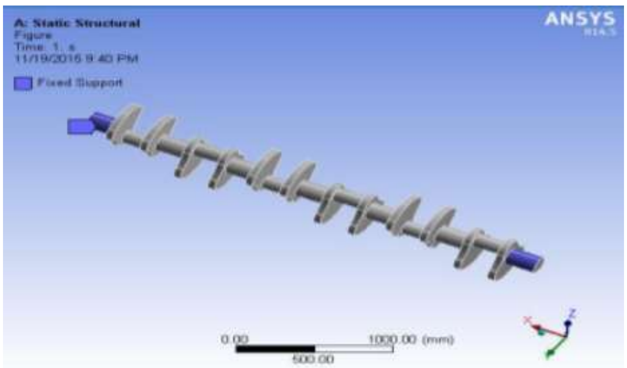


Figure 12. Meshing in ANSYS



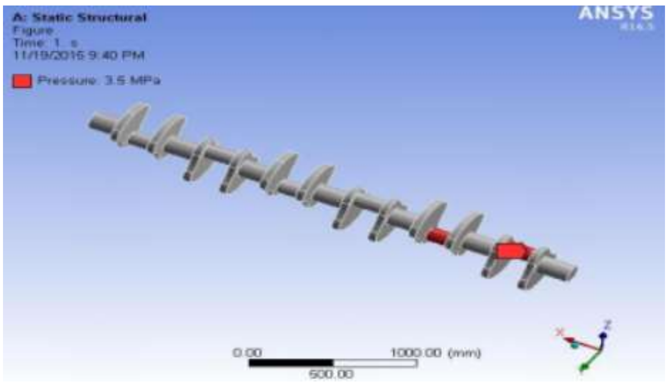


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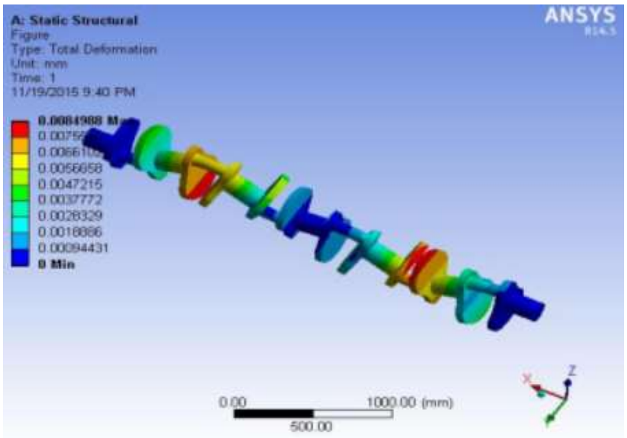
Figure 13. Boundary conditions   Figure 14. Loading of $3.5 N/mm^2$

Von-Mises stress and total displacement values were determined applying structural steel and Inconel X-750 as the materials, using static structural analysis as shown in Fig. 15, Fig.16, Fig. 17 and Fig. 18 respectively for structural steel and Inconel-X750.



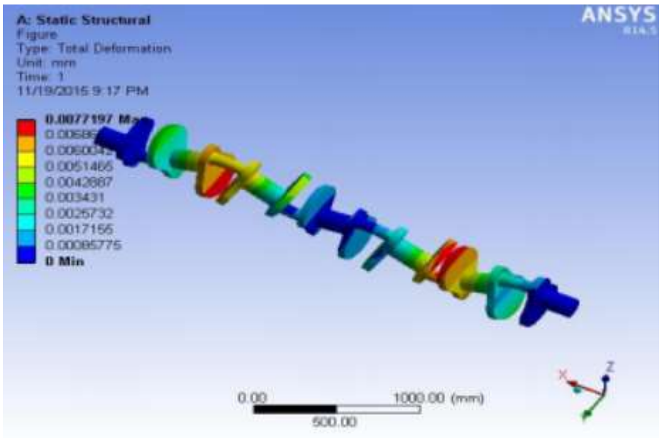
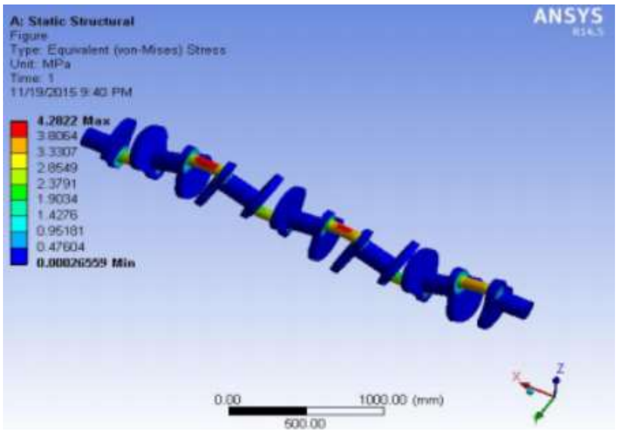


Figure 15. Total deformation in steel   Figure 16. Total deformation in Inconel X-750



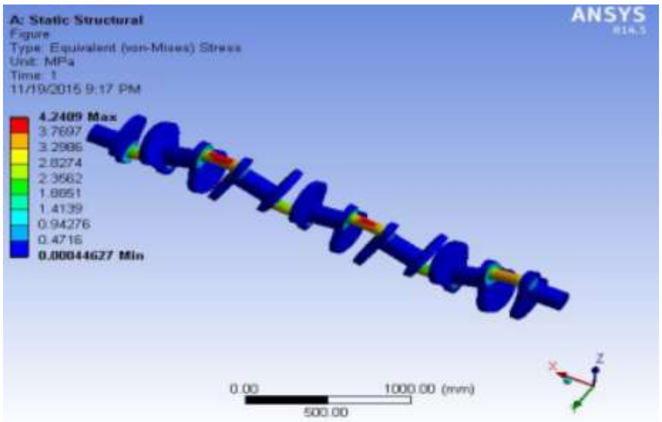


Figure 17. Von-Mises stress in steel   Figure 18. Von-Mises stress in Inconel X-750

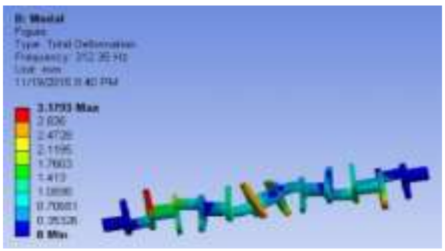
Comparison between the von-Mises stress and total deformation in structural steel and Inconel X-750 was done as shown in Table 2.

Table 2. Comparison between structural steel and Inconel X-750

MATERIAL	TOTAL DEFORMATION (mm)	EQUIVALENT STRESS (MPa)	SHEAR STRESS (MPa)
STRUCTURAL STEEL	0.0084988	4.2822	0.84067
INCONEL X750	0.0077197	4.2409	0.84445

Table 5.2.3: Results of structural analysis of two materials

Modal analysis was performed to calculate the frequencies of vibration, as shown in Fig. 19 and Fig-20.



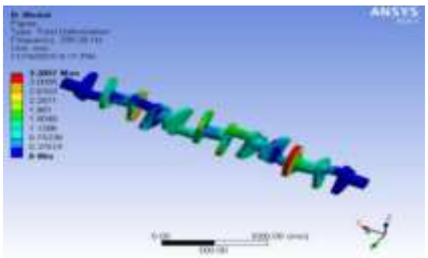


Figure 19. Modal analysis for steel   Figure 20. Modal analysis for Inconel X-750

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Results of the modal analysis for structural steel and Inconel X-750 were compared as shown in Table 3.

Table 3. Comparison of the results of modal analysis

MODES	1	2	3	4	5	6	7	8	9	10
STRUCTURAL STEEL	1.753	1.753	1.766	1.655	2.114	2.977	2.2866	2.3458	3.1889	3.1793
INCONEL X750	1.707	1.707	1.72	1.611	1.611	2.891	2.276	3.10	3.06	3.38
Table 5.3.3: Results Modal Analysis										

They concluded that Inconel X750 had less displacement or deformation than structural steel. Maximum displacement was found to be at top centre of the neck surface of the crank pin. Fillets on the crankshaft near the journal and cheek of the cranks were the areas of highest stresses.

Farzin H. Montazersadgh and Ali Fatemi (2007) [6] carried out a study on crankshaft applying dynamic loading. The analysis was conducted four-stroke engine crankshaft of a single cylinder engine. The values of stress and deformation at critical locations in the crankshaft were obtained using ANSYS software. The analytical results from ANSYS software were compared with the FEA results of simulation performed in ADAMS software. This analysis was conducted considering different engine speeds. The values of stress obtained for engine cycle and effect of fatigue were analyzed. An experimental analysis was also performed by attaching strain gauges at various critical locations in an actual crankshaft. These results were employed to calculate fatigue life of the crankshaft and to further optimize it. Materials considered for analysis were cast iron and forged steel. Results obtained from ANSYS software, ADAMS software and experimentation were compared with each other as shown in Table 4.

Table 4. Comparison of FEA, experimental and analytical results of crankshaft

Load (N)	Location a					Location b				
	FEA (MPa)	EXP (MPa)	Analytical (Mpa)	Diff-I* %	Diff-II+ %	FEA (MPa)	EXP (MPa)	Analytical (Mpa)	Diff-I* %	Diff-II+ %
-890	-61.6	-59.3	-72	3.80%	21.42%	86.9	81.4	72	6.40%	11.55%
890	61.5	65.5	72	6.50%	9.92%	-86.7	-90.3	-72	4.20%	20.27%
Load (N)	Location c					Location d				
	FEA (MPa)	EXP (MPa)	Analytical (Mpa)	Diff-I* %	Diff-II+ %	FEA (MPa)	EXP (MPa)	Analytical (Mpa)	Diff-I* %	Diff-II+ %
-890	-76.4	-71.7	-72	6.10%	0.42%	75.5	71.7	72	5.00%	0.42%
890	76.3	75.8	72	0.50%	5.01%	-75.6	-76.5	-72	1.30%	5.88%

In this study, they concluded that dynamic analysis gave realistic results as compared to static structural analysis. There was no effect of twisting load on the values of von-Mises stresses, even at the highly stressed areas. Torsion had a very small effect on the stresses. This made the authors to reach an important conclusion that the crankshaft analysis could be simplified by considering only bending load, without considering torsional load. Areas of the crankshaft geometry which were susceptible to failure were the ones having uneven or quick change in the gradient, such as fillets. These were found to have a high concentration of stresses.

K. Thriveni and Dr. B. JayaChandraiah (2013) [7] in their work, performed an analysis of the crankshaft of a four-stroke engine having a single cylinder, under static loading conditions. They determined dimensions of the crankshaft using standard design formulae and created a 3-D entity of the crankshaft using CATIA software. This model was imported and meshed using tetrahedron elements in ANSYS software. Boundary conditons included fixing both ends of the crankshaft. A static structural analysis was carried out by applying cast iron as the material. A pressure of 3.5N/mm2 was applied at the top centre portion of the crank pin and the analysis was run. The values of von-Mises stress, maximum shear stress, elastic strain and total deformation were found out from the analysis. The theoretical values of von-Mises stress and shear stress were compared with the analytical ones, as shown in Table 5 to obtain validation.

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Table 5. Comparison of theoretical and ANSYS results

S.No	Type of stress	Theoretical	ANSYS results
1	Von-misses stress(N/mm^2)	19.6	15.83
2	Shear stresses (N/mm^2)	9.28	8.271

They concluded that the maximum displacement appeared at the neck surface of the crank pin, at its centre, whereas the highest stress appeared at the suddenly changing areas called as fillets, near the main journal and cheeks of the cranks. The crankshaft design was assumed to be safe since the values of von-Mises stress were obtained less as compared to the yield strength of the material.

Mallikarjuna Naraga, Babu Uppalapti (2016) [8] in their work, performed design optimization and stress analysis of a multicylinder diesel engine crankshaft. They created a solid geometry of the crankshaft using CATIA software. This model was imported and meshed in ANSYS 14.0 Workbench software. A static structural analysis was performed by applying structural steel, grey cast iron and copper alloy as the materials. The values of von-Mises stress and total deformation were determined from this analysis and the areas of high stresses were identified. These areas were modified in the model and the analysis was re-run. Finally, the values of von-Mises stress and total deformation prior to and after modification were compared with each other for the respective materials. It was found that structural steel had the minimum stress and deformation, to become the best material for manufacturing the crankshaft.

Sujata Satish Shenkar, and Nagraj Biradar (2015) [3] carried out design and static structural analysis of the crankshaft of a single cylinder engine of a mini Tempo truck. They found out dimensions of the crankshaft using standard design formulae and created a 3-D model of the crankshaft from these dimensions using Pro/Engineer software. This model was imported and meshed in ANSYS software using tetrahedron elements. Boundary conditions and loading was applied and static structural analysis was run using forged steel 40CrMo4 as the material. The values of von-Mises stress and shear stress were found out from this analysis and it was compared with the theoretical value of the same for the purpose of validation. It was concluded that the analytical value of stress was well below the yield strength of the material, making the design safe and giving a future scope for optimization. The maximum stress occurred at the joints besides the bearing region, which could be reduced by introducing a fillet.

Jian Meng, Yongqi Liu and Ruixiang Liu (2011) [9] presented a study on FEM analysis on the crankshaft of a four-cylinder diesel engine. A solid model was made using Pro/Engineer software. After this, they performed a stress analysis under static loading conditions, followed by a modal analysis using ANSYS software. Initially they found that the crankshaft of the four-cylinder engine was symmetrical and hence all the crankthrows were identical. Thus, to make the model simple, they considered one crankthrow model for performing the analysis. They prepared a 3-D model of one crankthrow as shown in Fig. 21. It was assumed that some tiny structural characteristics like rounding the chamfers and oil hole would have negligible effects on the simulation. Hence, these were not included in the model. This model was imported and meshed in ANSYS software as shown in Fig. 22. According to them, the defining factors for the accuracy of analysis were the boundary conditions. Boundary conditions like centrifugal force, gravity, bending moment and twisting moment were considered.

It was highlighted that ANSYS software considers the effects of gravity and centrifugal force by default, provided that acceleration due to gravity, angular velocity, density and physical dimensions are given as the input. Hence, the defining loading was the one applied on the surface of the crank pin. They mentioned that load distribution along the crankpin axis was a distribution of quadratic parabola type and that along the radial direction within an angle of 120° was a distribution of the cosine type. This is as shown in Fig. 23 The total load distribution in the crankpin was given in the equation shown in Fig. 24.

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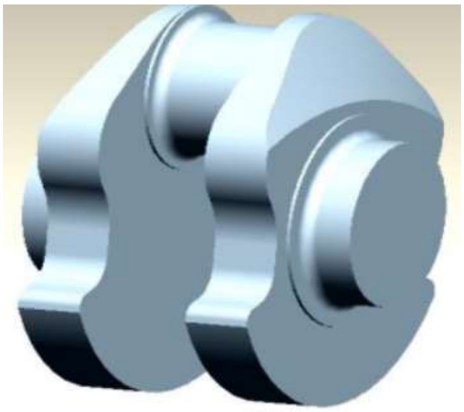

Figure 21. Model of crankthrow

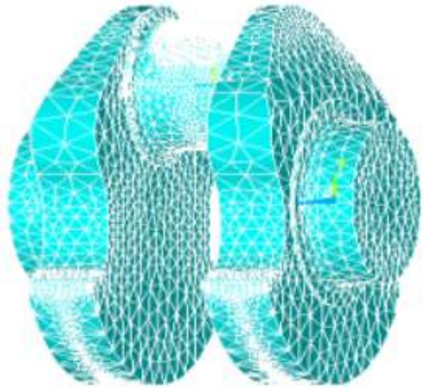

Figure 22. Meshed model of crankthrow

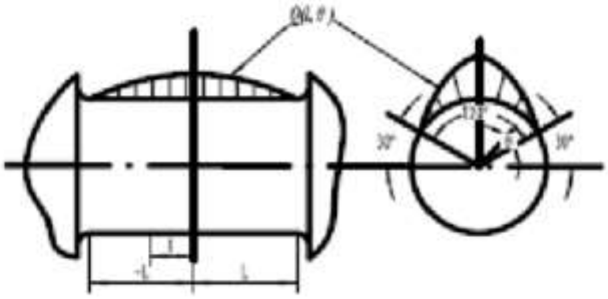

Figure 23. Distribution of load over the crank pin surface

$$Q(x,\theta)=\frac{9F_c}{16LR}(1-\frac{x^2}{L^2})\times\cos\frac{3}{2}\theta$$

Figure 24. Equation for load distribution

In the formula in Fig. 24, F_c was the load acting on neck surface of the crankpin, while x was the length along which the load acted. Other boundary condition applied was the restriction boundary condition in which the X, Y and Z direction degrees of freedom were locked at the end surface of the left crankthrow. X and Y direction degrees of freedom were locked at the right crankthrow end surface. After applying these boundary conditions, the analysis was started by using 42CrMn alloy steel as the material. The maximum deformation and von-Mises stress in the crankthrow was calculated as shown in Fig. 25 and Fig. 26.

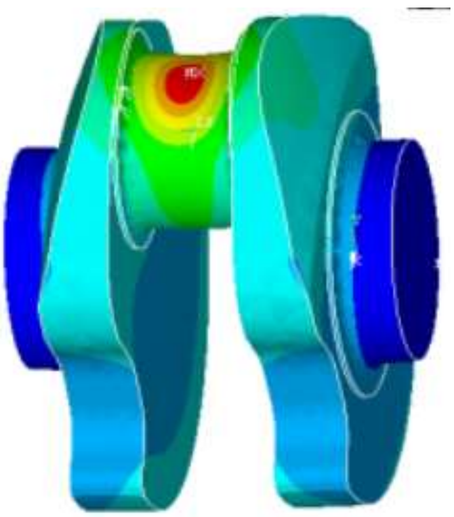

Figure 25. Total deformation in crankthrow

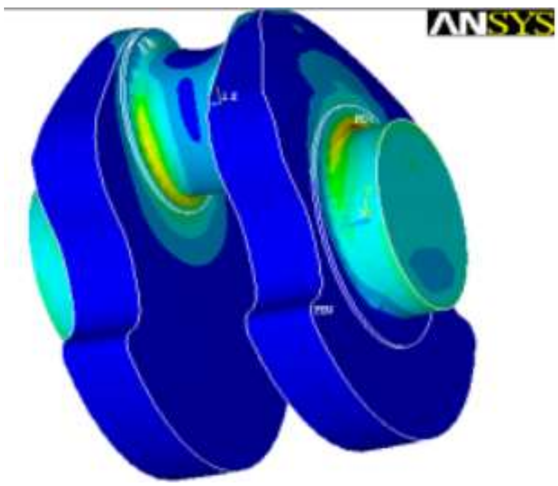

Figure 26. Von-Mises stress in crankthrow

The 3-D model of the entire crankshaft was prepared using Pro/Engineer software and meshed in ANSYS software.

Modal analysis was carried out to determine the vibrational frequencies. Conclusions were drawn as the maximum deformation occurred at the center of the crankpin neck surface and it was mainly due to bending load. Bending fatigue cracks could be developed in this area.

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B. Mounika and Madhuri .R .P (2015) [10] conducted a static structural analysis on the crankshaft of a single cylinder 4-stroke I.C engine. They calculated the dimensions of crankshaft using standard design formulae and prepared a 3-D model of crankshaft using these dimensions in CATIA-V5 software. This model was imported in ANSYS 16.0 and it was meshed using tetrahedron elements. Restriction boundary condition included the fixing of the two sides of crankshaft and load boundary condition included applying a pressure of 3.5 N/mm2 at the top of the crankpin at its centre. The static structural analysis was run for three materials such as cast iron, high carbon steel and alloy steel (42CrMn). The values of von-Mises stress, maximum shear stress and total deformation were determined from the analysis. Finally, the analytical values of von-Mises stress and shear stress were compared with the theoretical values of the same for validation purpose. This comparison is as shown in Table 6. Also, a comparison was made between the three materials on the basis of the von-Mises stress, shear stress and total deformation. This is as shown in Table 7.

Table 6. Comparison of stress results

S.No	Type of Stress	Theoretical Results	Ansys Results
1	Von-Misses stress (MPa)	32.58MPa	34.13MPa
2	Shear Stress (MPa)	15.71MPa	19.21MPa

Table 7. Comparison of three materials

Material	Equivalent Stress (MPa)	Shear Stress (MPa)	Total Deformation(mm)
Cast Iron	34.09	19.16	0.0035
High Carbon Steel	34.09	19.16	0.0030
Alloy Steel (42CrMn)	34.13	19.21	0.0031

They concluded that alloy steel (42CrMn) showed encouraging values of von-Mises stresses and shear stresses as compared to other two materials with little variation. The highest deformation took place at the central point of the neck surface of the crank pin.

Ashwin Kumar Devaraj (2011) [11] in his study, performed a finite element analysis on the crankshaft of a 4-stroke I.C. engine having a single cylinder. The main aim of his study was to evaluate the maximum stresses on a forged steel crankshaft at steady state condition occurring due to the gas pressure inside the cylinder. A 3-D entity of the crankshaft as shown in Fig. 27 was created using CATIA-V5 R14 software. This model was imported and meshed using SOLID95 elements in ANSYS software as shown in Fig. 28.

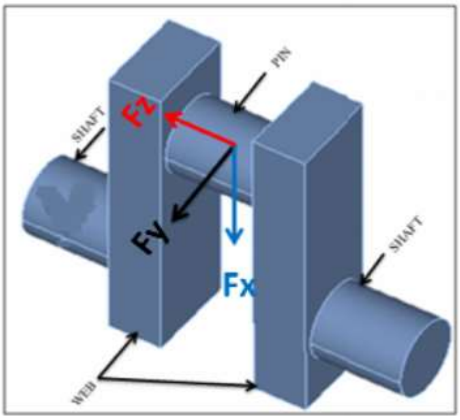

Figure 27. Crankshaft model in CATIA

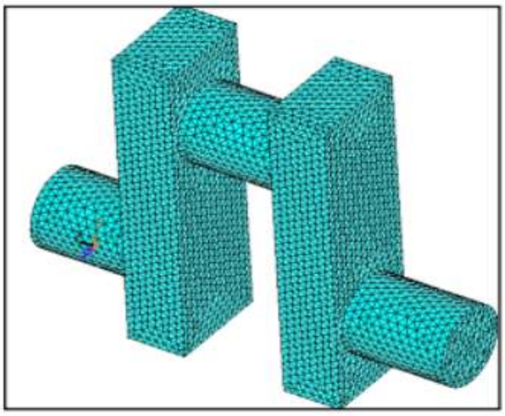

Figure 28. Meshed model in ANSYS

The bottom semicircular region of the crankshaft was fixed from both sides as the restriction boundary condition.A pressure of 9.23MPa was applied as the load boundary condition, at the top semicircular surface of the crankpin, at its centre. The static structural and modal analyses were run to find out the von-Mises stress and frequency of vibration of the crankshaft. They are shown in Fig. 29 and Fig. 30 respectively.

It was concluded that the critical stress locations on the crankshaft geometry were the regions corresponding to the interface between the shaft and the web and web and the crankpin. The fatigue cracks would start generating from critical stress locations. Hence, there was a need to perform fatigue analysis. He also added that by knowing the natural frequencies of the crankshaft, resonance problems could be avoided by keeping the excitation frequencies away from the natural frequencies of vibration to avoid dynamic failure.

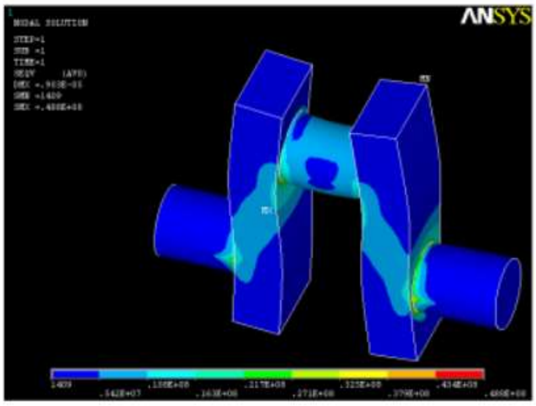

Figure 29. Von-Mises stress

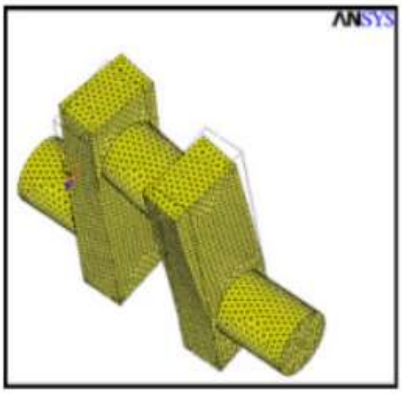

Figure 30. Mode shape

B.Kareem (2007) [12], has performed a study on the failure of crankshaft, looking into its different aspect. According to him, the failure of crankshaft can also take place due to factors other than stresses. In his case study, he gathered data from various sources like visiting different service stations, taking expert opinions and through questionnaires. The case study was related to Japanese automobile manufacturers like Nissan, Datsun, etc. He highlighted the various causes of crankshaft failure like oil leakages in engines, overloading, poor surface finish, misalignment, faulty thrust bearings, faulty oil pumps and poor quality of engine oils. In his solution, he stated that to avoid failure due to such causes, the crankshafts should be manufactured from locally stored materials, quality of manufacturing process should be improved by using tools like 6-Sigma, timely maintenance schedules, overall education to the consumers and improvement in the quality of roads and selecting the vehicle which is suitable for the operating conditions.

6 Conclusions

The researchers whose work has been reviewed in this paper highlight the loads, stresses, manufacturing processes, materials, modes of failure, theoretical design calculations, static structural stress analysis and dynamic analysis using finite element method, experimental analysis and case studies related to sustainability of automobile crankshaft. In order to perform stress analysis of a crankshaft, most of the researchers determined the crankshaft dimensions based on engine capacity, using standard design procedure or used readily available dimensions to create a 3-D model of the crankshaft using design software like CATIA-V5 and Pro/Engineer. This model was imported in ANSYS software to perform static structural analysis after applying boundary conditions and materials. The values of equivalent (von-Mises) stress, maximum shear stress and total deformation were determined from the analysis. These values were compared with the theoretical values of the same for the purpose of validation. Some researchers carried out dynamic analysis to evaluate the result of fatigue failure on crankshaft and to determine the natural frequencies of vibration, which are vital for avoiding failure on account of resonance. A few researchers carried out the finite element analysis by applying different materials like structural steel, cast iron, grey cast iron, forged steel, Inconel X-750, etc. to the crankshaft model. The values of stresses and deformation thus obtained were compared with each other for each material to select the best suited material for manufacturing the crankshaft. A few researchers performed optimization to the crankshaft geometry to reduce the intensity of stresses, save material, reduce weight and cost.

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Majority of the analyses show that the critical areas in a crankshaft are the crankpin neck surface and regions on the interface between the shaft and web. Highly stressed locations on the geometry of the crankshaft are found to be on the fillet areas due to elevated stress gradients. These lead to the concentration of high stresses. Due to stress concentration, cracks are initiated during the continuous rotation and cyclic operation of the crankshaft. This finally leads to fatigue failure. The static structural analysis gives conservative results as compared to dynamic analysis. Dynamic analysis gives more realistic results. FEA method is a good tool to simulate the effect of loads on crankshaft, saving the cost and time required for experimentation. The results listed in the research work will provide an excellent theoretical foundation for fatigue analysis and optimization in crankshaft geometry ensuring cost saving and increased life of a crankshaft.

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