Optimization of a Two Wheeler Crankshaft Using Finite Element Analysis

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Abstract—**The crankshaft is one of the most critically loaded components as it experiences cyclic loads in the form of bending and torsion during its service life. Its disappointment will bring about genuine harm to the motor so its unwavering quality check must be performed. The primary goal of this study is to investigate mass lessening open doors for a creation crankshaft. This will involved performing a heap investigation. Along these lines, this study needs to managed two subjects, in the first place, stress investigation of the crankshaft, and second, enhancement for mass. In this anticipate, limited component investigation of single cylinder four stroke petrol engine of a two wheeler is taken as a case study which belongs to Suzuki Access 125. The CAD model is created in Creo 2.0. The FEA is carried out using Hypermesh as pre-processor and Optistruct as a solver. The project goes through two steps. In first behavior of different material is observed by performing finite element analysis and in the second stage the mass optimization of the crankshaft is performed. A mass reduction of 65.15% by using aluminium crankshaft and 2.115% of mass reduction is observed by shape optimization.**

Index Terms—**Crankshaft, Two Wheeler, Hypermesh, Optistruct, Optimization.**

I. INTRODUCTION

THE crankshaft is one of the largest components in the (IC) engine and has a perplexing geometry comprising of cylinders as bearings, and plates as the crank webs. The crankshaft comprises of the shafts, which rotate in the bearings, the crank pins to which the enormous finishes of the con rod are associated, the crank arms, which interface the crankpins, and the shaft parts. The crankshaft, contingent on the position of crank, might be isolated into the following two types.

A. In light of the position of the crank

i) Side crankshaft or overhung crankshaft.
ii) Centre crankshaft

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B. Based on the quataties of throw

i) Single throw crankshafts
ii) Multi throw crankshafts

Fig. 1 Suzuki Access 125 Crankshaft

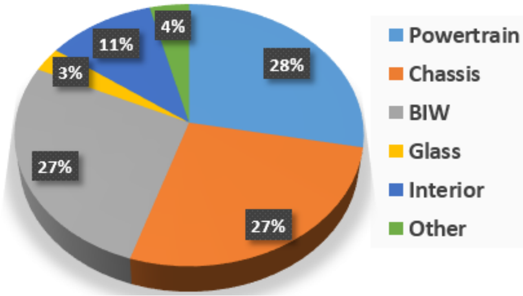
Crankshaft experiences large forces from gas combustion. This power is connected to the highest point of the cylinder and since the connecting rod interfaces the cylinder to the crankshaft, the power will be transmitted to the crankshaft. The greatness of the power relies on upon numerous elements which comprise of crank range, connecting rod dimensions, and mass of the connecting rod, piston, piston rings, and pin. ignition and inertia powers following up on the crankshaft cause two sorts of stacking on the crankshaft structure; tensional load and bending load.

This project is dealing with mass optimization of forged steel crankshaft.

II. PROBLEM STATEMENT

Due to growing competitive market worldwide, to increase the performance/efficiency of the vehicle is major challenge. In the worldwide, OEMs are imposing stringent design parameter to increase the performance/efficiency of the vehicle.

An analysis in mass distribution in vehicle as shown in below graph



Graph 1 Weight Distribution in Vehicles

One parameter to increase the Performance/efficiency of the vehicle is to design light weight vehicles. As Power-train occupies almost 28% weight of the vehicle, other hand bigger power-train and lightweight body design to achieve a performance target is not convenient option because a bigger and probably heavier power-train needs also more support from the body frame and therefore raises also the weight of the body, hence it is the need to design light weight power-train.

This study was motivated by a need for a of forged steel and ductile cast iron crankshafts, which are the most commonly used manufacturing processes for an automotive crankshaft. In addition, it was desired to develop an optimized geometry, material, and manufacturing procedure which will reduce the weight of the component for fuel efficiency and reduce the manufacturing cost due to high volume production of this component. Weight can be reduced through several types of technological improvements, such as advances in materials, design and analysis methods, fabrication processes and optimization techniques, etc. Another tool had been developed beside the CAD software which is CAE.

III. OBJECTIVE

A. The main objective of this study is to explore weight reduction opportunities in the design of a crankshaft

B. The study analysis includes the determination of forces acting on the crankshaft and finding out the maximum stress induced in the crankshaft

C. To change the existing crankshaft material can be replaced with a new material & the same performance can be expected in terms of component durability

D. To do the structural optimization by changing the geometry of the crankshaft

E. CAD modeling of crankshaft with the using Pro-E creo 2.0 software

F. Application of mesh strategy on CAD model in FEA Software

G. Weight optimization of crankshaft with the use of FEA Software

H. FEM approach for structural analysis using FEA Software

I. Calculation of the stress using analytical method

J. Comparison of the analytical result & software solution result(FEA)

IV. LITERATURE REVIEW

An extensive literature review on crankshafts was performed by Zoroufi and Fatemi (2005). Their study presents a literature survey focused on fatigue performance evaluation and comparisons of forged steel and ductile cast iron crankshafts. In their study, crankshaft specifications, operation conditions, and various failure sources are discussed. Their survey included a review of the effect of influential parameters such as residual stress on fatigue behavior and methods of inducing compressive residual stress in crankshafts. The common crankshaft material and manufacturing process technologies in use were compared with regards to their durability performance. This was followed by a discussion of durability assessment procedures used for crankshafts, as well as bench testing and experimental techniques. In their literature review, geometry optimization of crankshafts, cost analysis and potential cost saving opportunities are also briefly discussed.

Karan S Tembre and Satish M Margutti "Life Assessments and Failure analysis of Crankshaft" [3] The main objective of this paper is to investigate the behavior of crankshaft under the different loading conditions. Crankshaft from the 110 CC engine is selected for testing. Finite element analysis performed to obtain the variation of stresses at critical locations in the crankshaft. Bending and twisting analysis has done on the crankshaft. In static structural analysis bending and twisting forces are applied on crankshaft and maximum equivalent stresses on crankshaft are evaluated. Crankshaft is meeting static acceptance criteria, so we can go for the fatigue life calculations using the bending stress because bending stress is only the alternating stress in crankshaft. Experimentally it is found that stress values are within the limits in crankshaft. Simulation has been performed by using ANSYS software. The simulated results validated by actual crankshaft testing. In future modal analysis can be done to investigate the possibility of resonance.

Momin Muhammad Zia Muhammad Idris[1] "Optimization of Crankshaft using Strength Analysis" This paper presents results of strength analysis done on crankshaft of a single cylinder two stroke petrol engine, to optimize its design, using PRO/E and ANSYS software. The three dimensional model of crankshaft was developed in PRO/E and imported to ANSYS for strength analysis. This work includes, in analysis, torsion stress which is generally ignored. A calculation method is used to validate the model. The paper also proposes a design modification in the crankshaft to reduce its mass. The modal analysis of modified design is also done to investigate possibility of resonance.

A study was performed by Hoffmann and Turonek to examine the cost reduction opportunities associated with forged steel in which the raw material and machinability were the primary factors evaluated [9]. Materials evaluated in their study included medium carbon steel SAE 1050 (CS) and medium carbon alloy steel SAE 4140 (AS) grades using a sulphur level of 0.10%, (CS-HS and ASHS), and two micro-alloy grades (MA1 and A2). The material selection was based on fatigue strength requirements and potential cost benefits. The micro alloy grades that were evaluated offered cost

reduction opportunities over the original materials. The micro-alloy grade could reduce the finished
cost by 11% to 19% compared to a quenched and tempered alloy steel (SAE 4140), and by 7% to 11% compared to a quenched and tempered carbon steel (SAE 1050). In addition, the micro-alloy grades met or exceeded the fatigue strength of the original materials for the applications studied and had better machinability characteristics.

Rajkumar Ashok Tekale Patil, D. D. Date "Optimization through CAE Practices for Forged Crankshaft of a Two - Wheeler to Effect Mass Reduction" [4]. The main objective of this study was to investigate mass and cost reduction for forged crankshaft of two wheeler. Every stroke of the engine subjected to its adjacent components to cyclic loading that pulls and pushes the components like piston, connecting rod and crankshaft. The crankshaft, in turn, is connected to the transmission system and is a critical component from the design perspective. The design of the crankshaft can be done in a justifiable manner if an attempt is made to identify the effects of the operating loads on the component in the form of the type of stress induced with its peak value and the location of these stresses over the component. This study consists of two major sections, Finite Element Analysis and Optimization for mass reduction. In this dissertation work, 3-D finite element analysis is planned to be carried out by virtue of static stress analysis of crankshaft. Alternatives for Design would be suggested while attempting to modify the geometry of the Crankshaft by changing the different parameter. The load was applied to FE model in Hypermesh, and boundary conditions were applied according to engine mounting conditions. The no. of cycles of failure can be predicted using MSC Fatigue software.

Mr. Anant B. Khandkule "Comparative analysis of crankshaft in single cylinder petrol engine crankshaft by numerical and analytical method" [5]. The crankshaft considered here is of Pulsar 180 DTSi. It is a petrol engine crankshaft made from Alloy steel 41Cr4.Abnormal sound was heard in crankshaft while it is in operation. It was identified as failure of crankshaft. Severe wear has been observed at crankpin bearing location where the oil hole is provided. Here the analysis of the two wheeler crankshaft is done. Its results are then compared and verified numerically, then by the use of ANSYS software. The results compared here are Von Mises Stresses and the strain occurring on the crankshaft.

Park et al. (2001) [7] showed that without any dimensional modification, the fatigue life of a crankshaft could be improved significantly by applying various surface treatments. Fillet rolling and nitriding were the surface treatment processes that were studied in this research. Their study showed that the standard base sample had a fatigue limit of 10 kN, while fillet rolled specimens with 500 kgf load exhibited a 14 kN fatigue limit (i.e. 40% increase in fatigue limit). With 900 kgf rolling load, the fatigue limit increased to more than 18KN (i.e.80% increase in fatigue limit). These experimental data clearly indicate that fillet rolling can dramatically increase the fatigue performance of crankshafts. Although higher rolling force results in better fatigue strength as a result of inducing higher compressive stress on the fillet surface, the load should not be so high as to cause excess plastic deformation. The specimens prepared from the crankshaft in the Park et al. study found the optimum level of rolling force as experimentally to be between 700kgf and 900 kgf.

V. Methodology

The approach of the project is shown in figure 1 below.

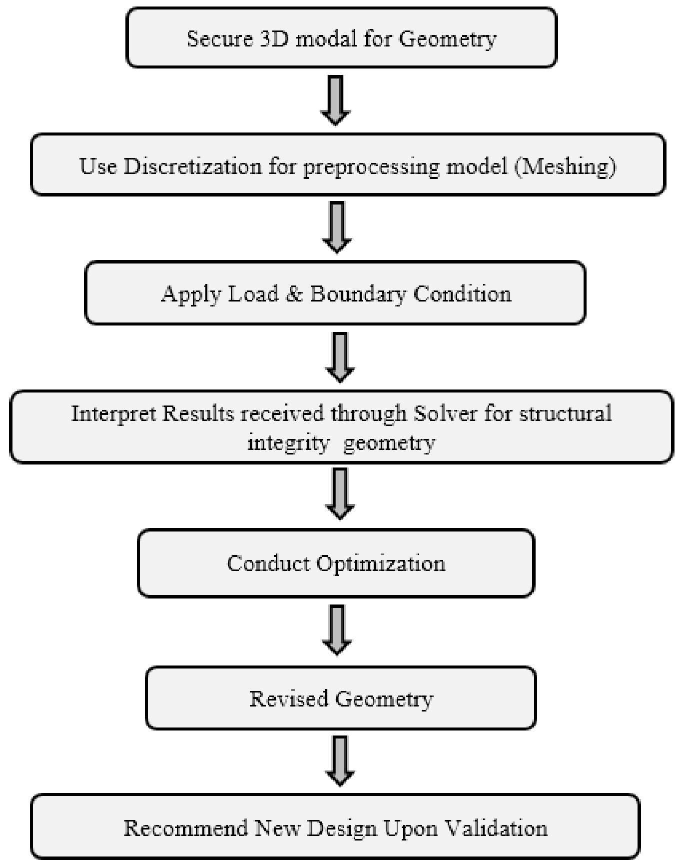


Fig. 2 Methodology

VI. Analytical Calculations

The design calculation of crankshaft performed for this study belongs to the two wheeler model Suzuki Access 125. The specification of engine is given below.

A. *Engine Specifications*

i) Capacity: 124cc
ii) Type: 4 Stroke, Single Cylinder, Air Cooled OHC
iii) Bore x Stroke: 54 x 53.5 (mm)
iv) Maximum Power: 6.4Kw@7000rpm(8.58hp@7000rpm)
v) Maximum Torque: 9.8Nm@5000rpm
(1.0kgm@5000rpm)

B. Pressure Calculations

Density of petrol (C_8H_{18}):
ρ = 750 kg/m3 = 750×10^{-9} kg/mm^3

Operating Temperature:
T = 20OC = 273.15+20 = 293.15^{O}K

As Mass = Density × Volume
Then m = $750 \times 10^{-9} \times 124 \times 10^3$
m = 0.093 kg

Molecular Mass of Petrol:
M = 114.228×10^{-3} kg/mole

4.4 Gas Constant for Petrol:

$$R = \frac{8314.3}{114.228 \times 10^{-3}}$$

R = 72.7868 x 10^3 J/kg/mol K

As pV = mRT
$p \times 124 \times 10^3 = 0.093 \times 72.7868 \times 10^3 \times 293.15$
Thus
p = 16.003MPa = 16.003 N/mm^2

C. Design Calculation

1) Gas Force (F_P):
F_P = Pressure (P) × Cross Section Area of Piston (A)
$F_P = 16.003 \times (pi/4)*53.5^2$
$F_P = 35.9566 \times 10^3$ N

2) Moment on the Pin

$$M_{max} = \frac{F_P}{2} \times \frac{l_c}{2}$$

$$M_{max} = \frac{35.9566 \times 10^3}{2} \times \frac{50}{2}$$

M_{max} = 449.468 x 10^3 Nmm

3) Section Modulus of Crankpin
Z = (pi/32) * d_c^3
Z = (pi/32) * 30^3
Z = 2649.375 mm^3

4) Torque Obtained at Maximum Power of Given Engine

P = (2*pi*N*T) / 60

$$6.4 \times 10^3 = \frac{2 * \pi * 7000 * T}{60}$$

T = 8.735 Nm
T = 8.735 x 10^3 Nmm

5) Von Mises Stress

Torque (T) = 8.735 x 10^3 Nmm
Bending Moment (M_{max}) = 449.468 x 10^3 Nmm
Combined shock & fatigue factor for bending (k_b) = 1
Combined shock & fatigue factor for torsion (k_t) = 1

Equivalent bending moment:

$$M_{ev} = \sqrt{(k_b \times M_{max})^2 + \frac{3}{4}(K_t \times T)^2}$$

$$M_{ev} = \sqrt{(1 \times 449468)^2 + \frac{3}{4}(1 \times 8735)^2}$$

M_{eq} = 449.532 x 10^3 Nmm
Thus

$$\sigma_{von} = \frac{M_{eq}}{Z}$$

$$6von = \frac{449.532x10^3}{2649.375}$$

σ_{von} = 170.183 MPa

VII. Software Analysis Calculations

A. Modelling of Crankshaft

Crankshaft of Suzuki Access 125, market available is selected for the present investigation. The dimensions of the selected crankshaft are found using vernier caliper. Crankshaft was modeled with the help of Pro-E Software.

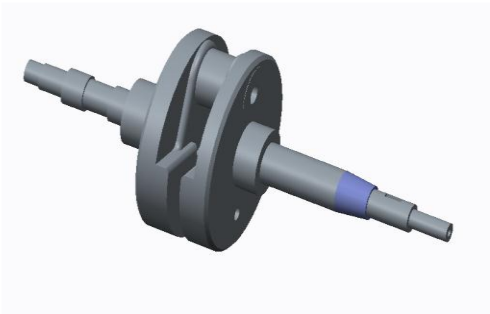


Fig. 3 CAD Model of Crankshaft

B. Define Material Property

The material medium carbon steel property of the crankshaft is given below in table format.

TABLE I
Material Attributes

Density	7.7×10^3kg/m3
Yield Tensile Strength	573.7 MPa
Ultimate Tensile Strength	410 MPa
Poisson’s ratio	0.29

Young's modulus	200000 MPa

C. Meshing

Here we have chosen tetrahedral mesh. The tetrahedral meshing methodology is utilized for the cross section of the strong district geometry. Meshing delivers fantastic cross section for boundary representation of solid auxiliary model

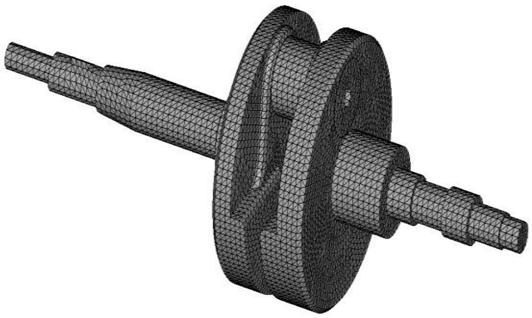


Fig. 4 Meshed Model of Crankshaft

D. Application of boundary conditions and loads

The shaft of the crankshaft is fixed form both side which is showed in green color in all the dof and load of 35956.6N generated due to maximum gas pressure is applied at the crankpin in vertical direction.

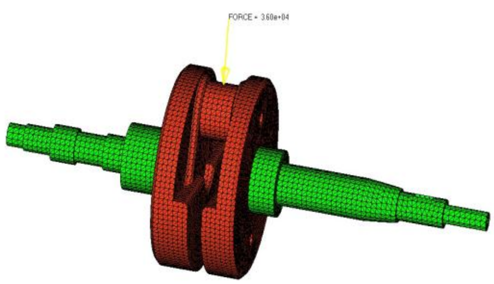


Fig. 5 Boundary Condition and Loading

E. Meshing Solution

Problem is solved for linear static behavior using OptiStruct as a solver. The crankshaft is checked for von mises strength and analytical calculation for validation of initial model.

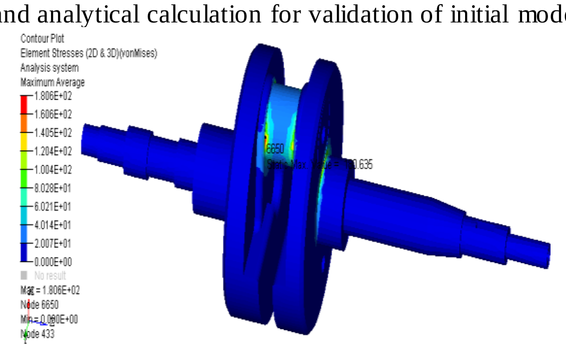


Fig. 6 Von Mises Stress in Original Crankshaft

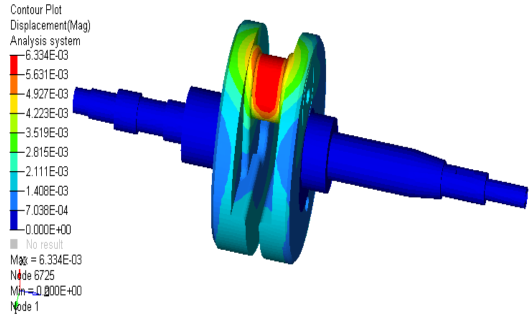


Fig. 7 Displacement in Original Crankshaft

TABLE II
RESULT TABLE

Parameter	Analytical	FEA	Percentage Error
Von mises (MPa)	170.183	180.6	5.5

A difference of 5.5% in the von mises stress is observed between the analytical and FEA result which is satisfactorily as 10% variation tolerance is set due to meshing technique and solution algorithm

The generated stress is below the yield stress of the material, hence the design is safe.

VIII. OPTIMIZATION OF CRANKSHAFT

Mass or mass lessening is getting to be critical issue in vehicles fabricating industry. Because of its extensive volume creation, it is just coherent that optimization of the crankshaft for its mass or volume will bring about vast scale reserve funds. In this paper first the material is by using different material like Aluminium and Nodular Cast Iron and second the mass reduction opportunity is shown without changing material.

A. Material Optimization

The behavior of each material is shown below and results can be seen in table which clearly shows that aluminium shows better result and can be opted as best material as it shows mass reduction of 65.18%.

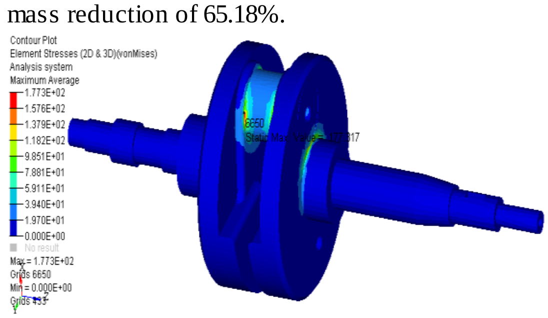


Fig. 8 Von Mises Stress for Aluminium Crankshaft

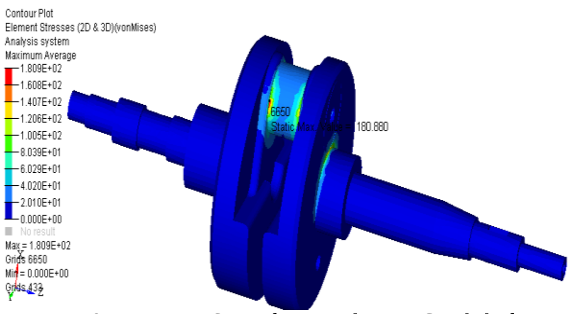


Fig. 9 Von Mises Stress for Ductile Iron Crankshaft

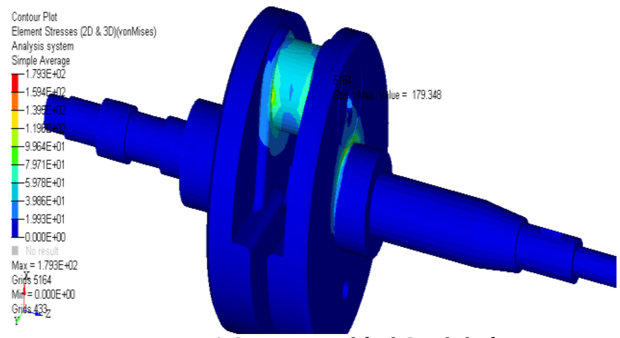


Fig. 10 Stress in Modified Crankshaft

TABLE III
MATERIAL OPTIMIZATION RESULT TABLE

Sr No	Material	Analytical Result	Software Analysis Result	Deformation	Mass
		Stress (MPa)	Stress (MPa)	(mm)	(kg)
1	Steel	170.183	180.6	6.34×10^{-3}	2.966
2	Aluminium	170.183	177.7	1.68×10^{-2}	1.032
3	Ductile Iron	170.183	180.8	7.92×10^{-3}	2.773

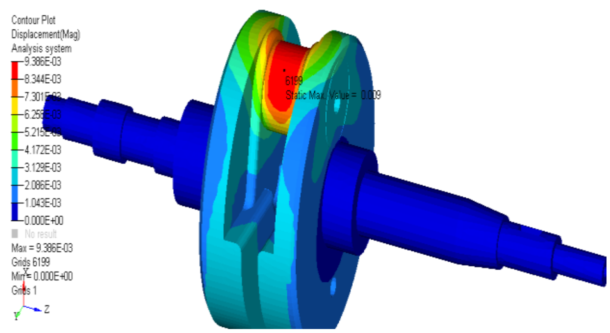


Fig. 11 Deformation in Modified Crankshaft

B. *Structural Optimization*

Optimization has been done by changing the parameter like web thickness of the crankshaft. As both web have different thickness, thickness is changed in one web only in 1st iteration and simultaneously change in web thickness is performed in subsequent iteration, different parameters are constraints. The outcome got by FEA are shown below.

TABLE IV
STRUCTURAL OPTIMIZATION RESULT TABLE

Iteration	Web1 Thickness (mm)	Web2 thickness (mm)	Stress (MPa)	Mass (kg)
1	18.5	21	188.05	2.934
2	**17.5**	**21**	**179.34**	**2.902**
3	16.5	20	197.0	2.840

From the table it can seen that there is a sudden increment in the stress in the third iteration hence the optimization is stopped and during structural optimization stress was design constraint hence iteration two can be taken as a best result out of all three. The stress pattern and deformation of modified crankshaft is shown in fig 10 and 11.

A. *Material Optimization Results*

A comparative results is shown below of various parameters out of which, this study focuses on mass and von mises stress as one shows the opportunity of cost saving and other show the opportunity of long durable life and increased strength of the component.

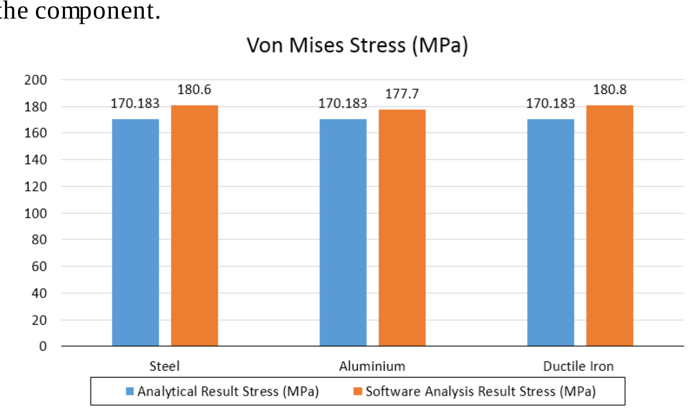


Fig. 12 Stress in Different Crankshaft Material

IX. RESULT AND CONCLUSION

This examination venture researched mass and cost diminution opportunities that different materials crankshaft offer. The crankshaft chosen for this project belonged to Suzuki Access 125.

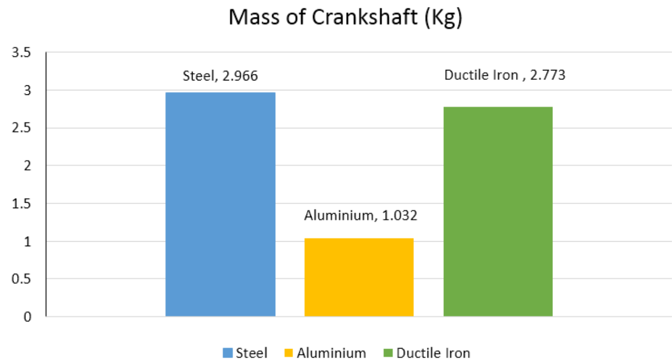


Fig. 13 Mass of Different Crankshaft Material

B. *Structural Optimization Results*

Mass reduction opportunity has been performed on crankshaft in various iteration. Out of all the iteration second iteration shows satisfying results.

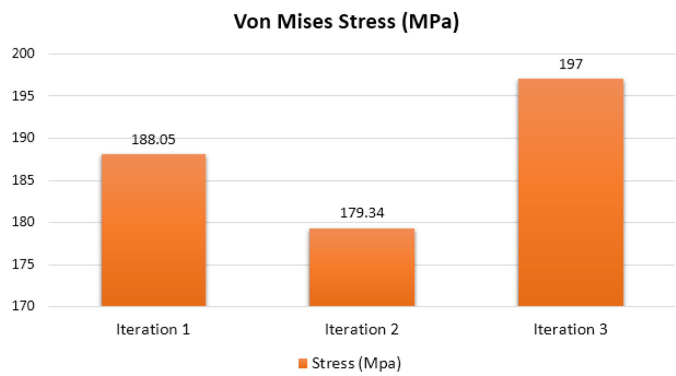


Fig. 14 Von Mises Stress for Structural optimization

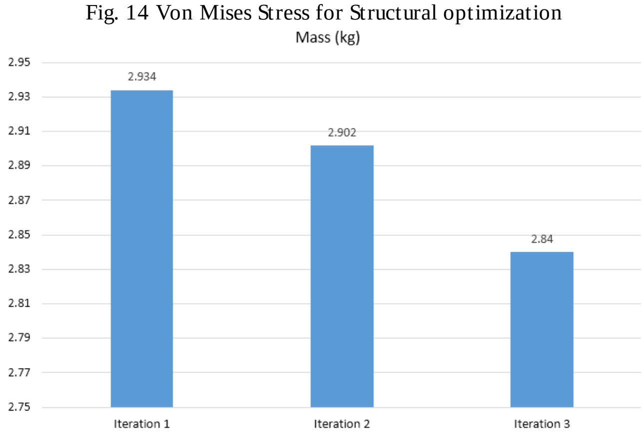


Fig. 15 Mass of Crankshaft

Form the results following points can be concluded

a) The existing and modified design is designed using modeling software and various parameters are obtained and the results are taken and compared
b) Structural optimization by varying the web thickness allowed three iteration out of which 2nd iteration can be applied as per the FEA results. 2.15% of mass reduction is observed in 2nd iteration as it give results a much more satisfying results than other two iterations. Changing the configuration parameters can yield better results. Since modified model gave best results. Therefore this design proved to be the best among others tested
c) From the result table show 7.2 above it can be seen that there is percentage reduction of 65.18% for Aluminium replacement and 6.44% for ductile iron crankshaft. So changing the material can be solution for mass reduction
d) Cost, fatigue, manufacturability and machinability may produce hurdle to aluminium replacement. But Nodular cast iron has the beneficial attributes of grey cast iron (that is, low melting point, great smoothness and castability, fabulous machinability, and wear resistance) and also the mechanical attributes of steel (that is generally high quality, hardness, durability, workability, and solidify capacity) which can serves as a superior replacement
e) Also 1.7 percentage of reduction in stress can be observed for aluminum crankshaft but there is negligible amount of change in stress for Ductile Iron

X. FUTURE SCOPE

i. Dynamic and vibration analysis of crankshaft can be done in future.
ii. Fatigue analysis can be performed to estimate the life of the component.
iii. Other factors for the failure can be considered.

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