Design and Analysis of Crankshaft of Single Cylinder Four Stroke Engine Using ANSYS Software

Santosh Kumar Yadav, Earnest Vinay Prakash

Abstract— Crankshaft is one of the large components with a complex geometry in internal combustion engine which converts the reciprocating displacement of the piston into a rotary motion. The study was undertaken with the objective of analysis of single cylinder four stroke engine of Super Splendor Crankshaft using ANSYS Software for different materials and optimize the best materials for crankshaft. The three materials used were Structural Steel, Aluminum Alloy and Nickel Chromium Molybdenum Steel. The measurement of crankshaft of bike engine was taken from bike workshop and model was generated in SolidWorks which was finally imported in ANSYS for Analysis. The stress analysis and total deformation was criteria for optimization of crankshaft materials. The comparative study was done by comparing both analytical as well as software generated results. The value of von-misses stresses of analysis is less than the material yield stress so this design is safe. From this work, the maximum stress appears at the area between crank journal and crank cheeks. By comparing von-misses stress values, Aluminum Alloy has higher strength and shows lower stress value (146.28 MPa) than other materials. Because of the more strength, Aluminum Alloy crankshaft can withstand load and is best materials for crankshaft among three.

Index Terms— Crankshaft, SolidWorks, ANSYS, Stress Analysis, Super Splendor

I. INTRODUCTION

Crankshaft is one of the critical components of IC engine with complex geometry that converts the reciprocating displacement of piston into a rotatory motion [4]. Crankshaft consists of different parts like journal bearing, crank pin, crank web and shaft parts. The Shaft parts which revolve in the main bearings, the crank pins to which the big end of the connecting rod are connected, the crank arms or webs which connect the crank pins and shaft parts [1]. **Ismail al-Jazari** was the first Arabic mechanical engineer to invent crankshaft [2] . The crankshaft is subjected to the function of bending torsional loads by the centrifugal force, periodic change of inertial force and reciprocating inertial force of the rotational mass [6]. Therefore, the crankshaft must have sufficient strength and stiffness, the surface of the shaft neck need to wear, work evenly, and good balance. The reliability and life of internal combustion engine mainly depend on the strength of the crankshaft [5]. A large value of the coefficient of thermal expansion can be a problem when choosing materials for crankshafts. Ductile iron, forged steel, and titanium are commonly used as materials for manufacturing shafts like in the Prosche GT3 RS. Crankshafts made of aluminum composites reinforced with SiC and graphite are in the development stage [7].

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II. OBJECTIVES

- **i.** To model single cylinder crankshaft using modeling Software SolidWorks.
- **ii.** To analyze a single cylinder engine crankshaft using ANSYS Software.
- **iii.** To analyze the crankshaft with different materials for crank web and crankpin
- **iv.** To optimize the existing crankshaft and provide optimum design.

Fig 1. Typical Crankshaft of hero Splendor taken from Workshop

III. DESIGN CALCULATION FOR CRANKSHAFT

The Design calculation of single cylinder petrol engine crankshaft with specific two wheeler Hero Super Splendor 124.7 CC bike. The engine specification and dimension are given below in tabulated form:

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Table 1. Engine Specification

Parameter	Value
Engine Type	4 Cycle, 1 Cylinder, Air Cooled
Valve System	OHC, 2 VALVE
Cylinder Bore	52.4 mm
Stroke	57.8 mm
Displacement	124.7 cm3
Compression ratio	10:1
Maximum Power	11.20 PS @ 7500 rpm
Maximum Torque	11 NM @ 6500 rpm

Table 2. Engine Dimension

Symbol	Parameter	Value
D	Piston Diameter	52.4 mm
l_c	Length of crankpin	40 mm
d_c	Diameter of crankpin	28 mm
L	Stroke	57.8mm
d_s	Shaft Diameter	22 mm
T	Thickness of crank web	30 mm
W	Width of crank web	30 mm
R	Shaft center to web center	29 mm

Mathematical derivation of Von misses stress and total deformation using formulas are given below:

- **Pressure Calculation**

Density of petrol (CgH18):
ρ = 750 kg / m3
Molecular mass of petrol:
$M = 114.228 \times 10^{-3}$ kg / mole
= 750 × 10-9 kg / mm3
Operating Temperature:
$T = 20\ ^0C$
= 20 + 273.15
$= 293.15\ ^0k$
Gas constant for petrol:
$R = 72.7868 \times 10^3$ J / kg / mo l K

Mass of displacement:
$m = \rho \times V$
$= (750 \times 10^{-9}) \times (124.7 \times 10^3)$
= 0.0935 kg Where,
ρ = Density
V= Volume

We know that PV = mRT
$P \times 124.7 \times 10^3 = 0.0935 \times 72.7868 \times 10^3 \times 293.15$
$$P = \frac{0.093X\ 72786.8X293.15}{12470}$$
P=16.003 MPa

- **Design Calculation for Gas force**

Design of crankshaft when the crank angle is at the angle of maximum bending moment
Gas force (F_p) =?

We have
F_p = P X A
$=16.003X\ (\frac{\pi}{4} XDXD)$
=16.003X (0.7854X52.4X52.4)
=34.51 KN

Distance between two bearings is given by
b = 2D = 2X52.4= 104.8 mm
b1=b2=52.4 mm

Due to the piston gas load (Fp) acting horizontally there will be the two horizontal reactions H_1 and H_2 at the bearings 1 and 2 respectively, such that

$H_1 = H_2 = F_p/2 = 17.255$ KN

- **Design of crankpin**

Moment on crankpin =
$$M_{max} = \frac{Fp}{2} X \frac{Lc}{2}$$
$= 17.255X10^3$ X 20
$= 345.1X10^3$ Nmm

Torque obtained at Max. Power of hero splendor

$$P = \frac{2X\pi XNXT}{60}$$
$$11.2X10^3 = \frac{2\pi X7500XT}{60}$$
T= 14.26 Nmm

Von- misses stress

$$\sigma_{von} = \frac{Meq}{Z}$$
Where,
M_{eq} = Equivalent bending moment
So, Equivalent bending moment is given by
$$M_{eq} = [(K_b\ X\ M_{max})^2 + \frac{3}{4}(K_t\ X\ T)^2]^{1/2}$$
Here, K_b = Combined shock and fatigue for bending = 1
K_t = Combined shock and fatigue for torsional = 1
M_{max} = Bending moment
$$M_{eq} = [(1X345.1X10^3)^2 + \frac{3}{4}(1X14.26X10^3)^2]^{1/2}$$
$M_{eq} = 345.32X10^3$ Nmm

Section modulus of crankpin

$$Z = \frac{\pi}{32}\ X\ d_c\ X\ d_c\ X\ d$$
=0.098175X 28X28X28
$=2155.132\ mm^3$
Now,
$$\sigma_{von} = \frac{345320}{2155.19664}$$
= 160.227 MPa

Equivalent twisting moment

$$T_{eq} = (\ M_{max}{}^2 + T_2)^{1/2}$$
$$T_{eq} = [\ (345.1X10^3)^2 + (14.26X10^3)^2]^{1/2}$$
$T_{eq} = 345.48X10^3$ Nmm

Now,
$$T_{eq} = \frac{\pi XdcXdcXdcX\tau}{16}$$

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$$345.48X10^3 = \frac{\pi X 28 X 28 X 28 X \tau}{16}$$

$$\tau = 80.15\ N/\ mm^2$$

Stain for Structural Steel

$$\varepsilon = \frac{\sigma von}{E}$$

$$= \frac{160.227}{200000}$$

$$= 0.00225$$

Stain for Aluminum Alloy

$$\varepsilon = \frac{\sigma von}{E}$$

$$= \frac{160.227}{200000}$$

$$= 0.00225$$

Strain for Nickel Chromium Molybdenum Steel

$$\varepsilon = \frac{\sigma von}{E}$$

$$= \frac{160.227}{200000}$$

$$= 0.00080113$$

IV. DESIGN METHODOLOGY

A. *Procedure for Static Analysis*

First, we modeled the crankshaft in SolidWorks and saved it as .IGES file format for Analysis of crankshaft in ANSYS software. The imported .IGES model is simulated in ANSYS Workbench.
The dimension of crankshaft taken from workshop is modelled in SolidWorks software. The modeled assembly of crankshaft is shown below:

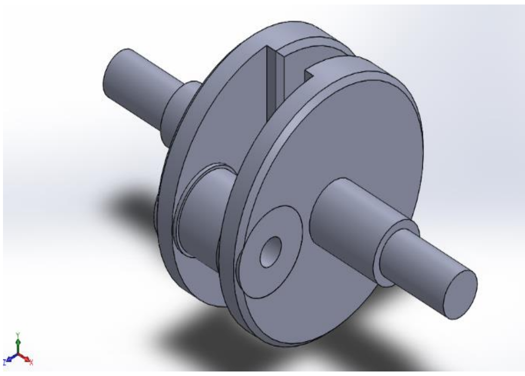

Fig 2. Crankshaft assembly modeled in SolidWorks

B. *Loading and boundary condition*

Boundary condition play important role in FEA[9]. Here we have taken fixed support at both bearing. The given below illustrate the boundary condition of crankshaft. The force of 34.51 KN is applied in Crankpin of crankshaft. The blue colour mark illustrate fixed support and red coulur illustrate application of gas force as given in fig. 3

C. *Meshing of crankshaft*

Meshing is the most important part in any of the computer simulations, because it can show drastic changes in results you get. Tetrahedral meshing is done because the tetrahedral meshing methodology is utilized for the cross section of the strong district geometry and meshing delivers fantastic cross section for boundary representation of solid auxiliary model.

Method: Tetrahedrons
Number of nodes: 16625
Numbers of elements: 9148

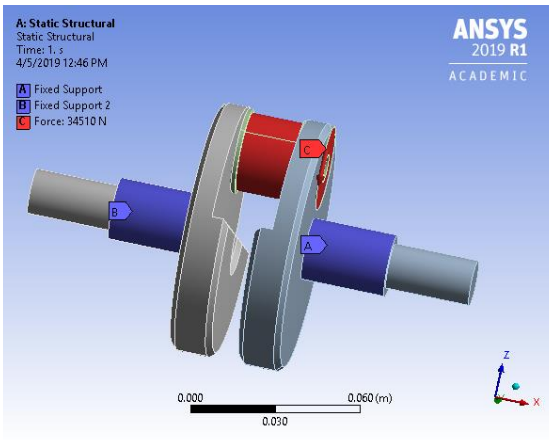

Fig 3 Application of Load and Gas Force

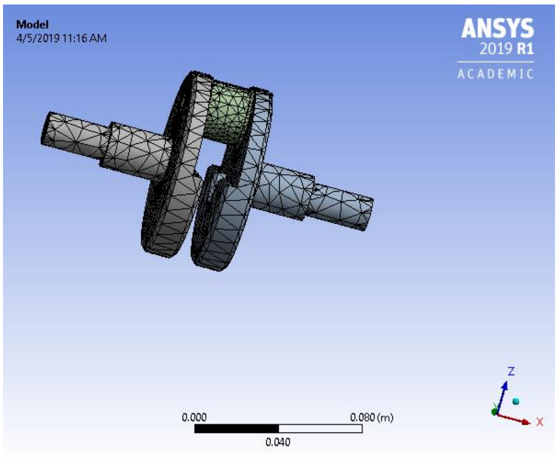

Fig 4. Meshing of crankshaft in ANSYS

D. *Application of Materials for Analysis*

There are total three materials are used for this solid model structural steel, aluminum alloy and nickel chromium molybdenum steel. The material properties of the crankshaft is given below:

I. Structural Steel

Density=7850 Kg/m^3
Yield Tensile Strength= 250 MPa
Poison Ratio= 0.3
Modulus of Elasticity= 200 GPa

II. Aluminum Alloy

Density=2770 Kg/m^3
Yield Tensile Strength=280Mpa
Ultimate Tensile Strength=310Mpa
Poison Ratio=0.33
Modulus of Elasticity=71 Gpa

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III. Nickel Chromium Molybdenum Steel

Density=7850 Kg/m^3
Yield Tensile Strength= 550 MPa
Ultimate Tensile Strength= 620 MPa
Poison Ratio= 0.285
Modulus of Elasticity= 200 GPa

E. Linear Static Analysis of Crankshaft

After the application of boundary condition and force, the next step is to perform static analysis in ANSYS software. We are mainly concern with the von mises stress and total deformation. The crankshaft is checked for von-misses stress and analytical calculation with different three materials for the validation of work.

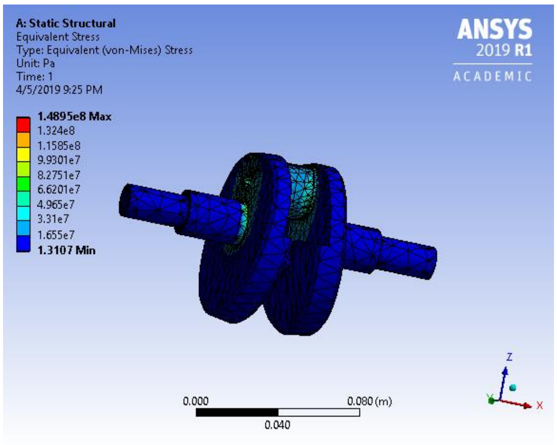

Fig 5 Von- misses stress for Structural steel

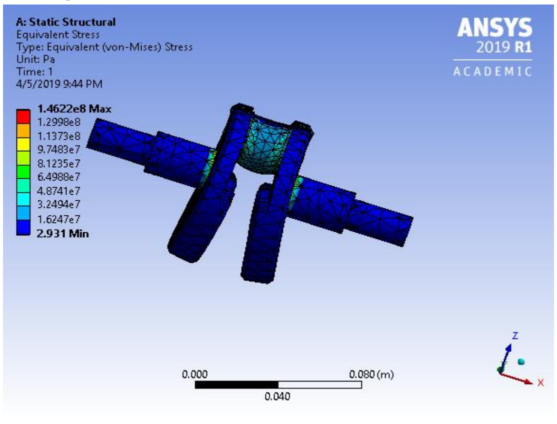

Fig 6 Von- misses stress for Aluminum alloy

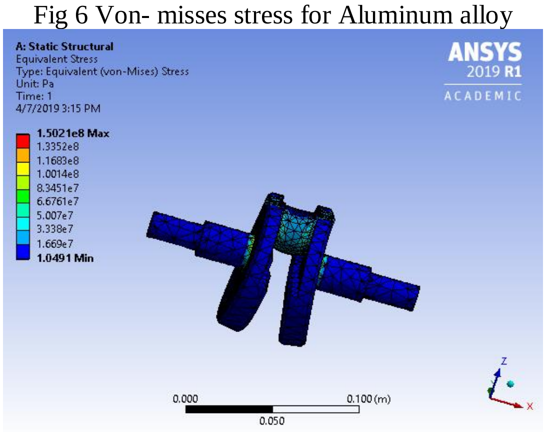

Fig 7 Von- misses stress for NCM steel

Since crankshaft consists of different parts like crank web, journal shaft, crankpin and main shaft. The crankpin is the important part of crankshaft assembly as gas force is indirectly applied to crankpin through connecting rod. So we have carried out our analysis by taking one material for crankpin and other materials for rest part of crankshaft assembly among three used materials for best result out of these combination.

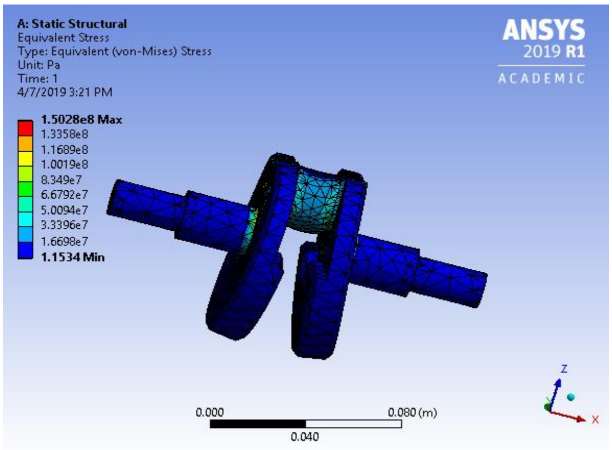

Fig 8. Web made of structural steel & crankpin made of NCM steel

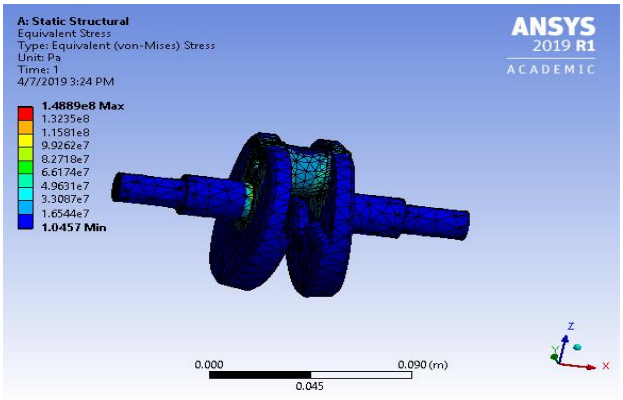

Fig 9. Web made of NCM steel & crankpin made of Structural steel

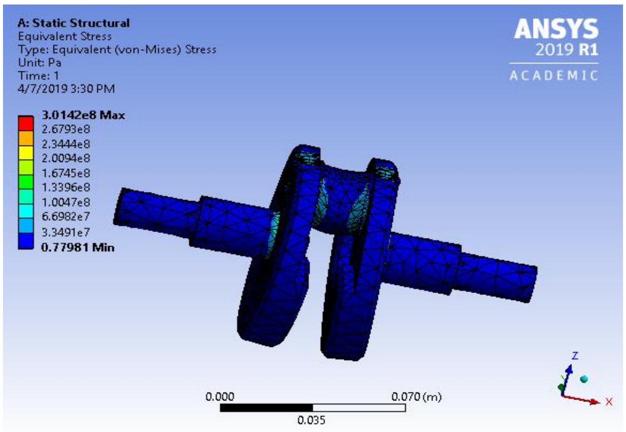

Fig 10. Web made of structural steel & crankpin made of Aluminum Alloy

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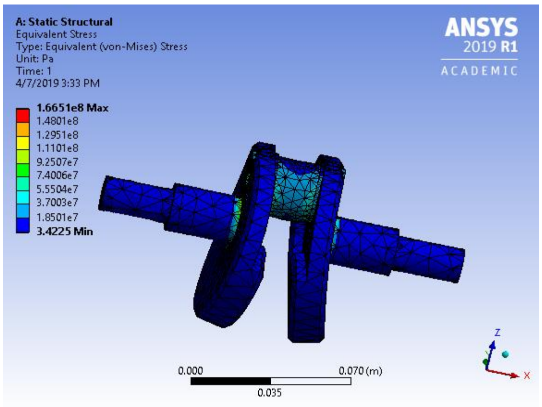

Fig 11. Web made of Aluminum alloy& crankpin made of structural steel

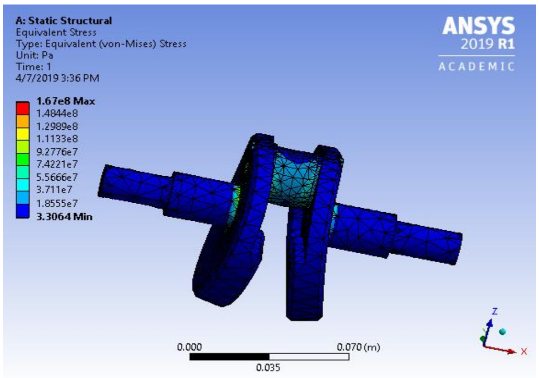

Fig 12. Web made of Aluminum alloy & crankpin made of NCM steel

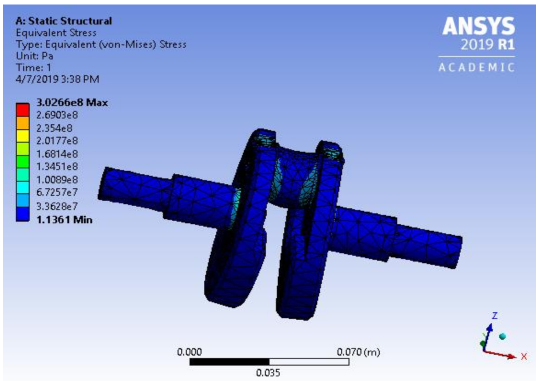

Fig 13. Web made of NCM steel & crankpin

The software result obtained with different materials for Von Misses stress in different condition of web and crankpin materials are given below:

Table 3. Von misses stress value for different materials

S.N.	Materials Condition	Von misses stress
1	Only Structural Steel	148.95
2	Only Aluminum Alloy	146.28
3	Only Nickel Chromium Molybdenum Steel	150.21
4	Webs made of Structural steel and crankpin as Aluminum alloy	301.42
5	Webs made of Aluminum Alloy and crankpin as structural steel	166.51
6	Webs made of NCMS and crankpin as aluminum alloy	302.66
7	Webs made of aluminum alloy and crankpin as NCMS	167
8	Webs made of NCMS and crankpin as structural steel	150.28
9	Webs made of structural steel and crankpin as NCMS	148.89

The total deformation obtained for different materials of crankshaft using ANSYS software are given below:

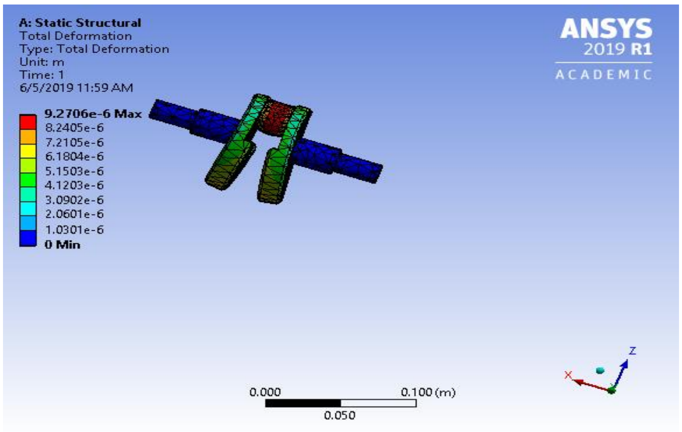

Fig 14. Total deformation for structural steel

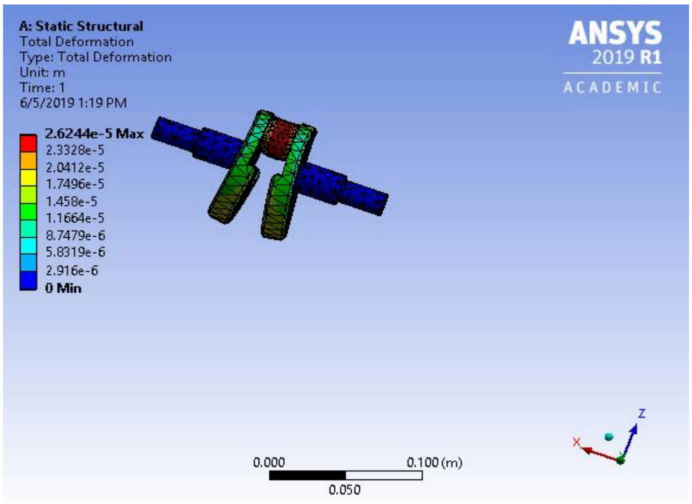

Fig 15. Total deformation for Aluminum Alloy

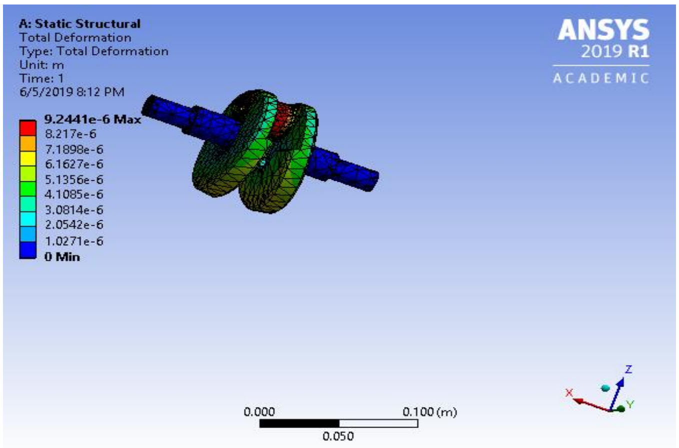

Fig 16. Total deformation for NCM steel

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Table 4. Total deformation for different materials

S.N	Materials Type	Software Results (m)
1	For Structural Steel	$9.27E^{-6}$
2	For Aluminum Alloy	$2.624E^{-5}$
3	For Nickel Chromium Molybdenum Steel	$9.244E^{-6}$

V. RESULT AND DISCUSSION

From above analysis we can see that there is total three materials used for analysis and got the different result with different parameters, from analysis it is found that the Aluminum alloy is best of them. Usually crankshaft is made from steel by using casting or forging but we can use aluminum alloy as a material for crankshaft making. We can see that crankshaft is made of combination of different parts like crank webs, crankpin, bearing supports, etc. among them crank webs and crankpin are important parts. Crank webs are used for weight balancing and crankpin are components were Pressure of gas is applied and is responsible for conversion of reciprocating motion into rotatory.

Thus we have used different materials for overall design of crankshaft as crankpin is made of one material and rest part are made of another one to check the von misses stress and total deformation under same condition of loading. From this analysis we get Webs made of structural steel and crankpin made from nickel chromium molybdenum steel is the second best combination for crankshaft design. Von misses stress for aluminum alloy is 146.28 MPa. The crankshaft chosen for this project is Hero Super Splendor 124.7 CC. Comparing chat of three materials is as below:

Table 5. Comparative table for Stress analysis

S.N.	Materials Condition	Analytical value (MPa)	Von misses stress
1	Only Structural Steel	160.227	148.95
2	Only Aluminum Alloy	160.227	**146.28**
3	Only Nickel Chromium Molybdenum Steel	160.227	150.21
4	Webs made of Structural steel and crankpin as Aluminum alloy	160.227	301.42
5	Webs made of Aluminum Alloy and crankpin as structural steel	160.227	166.51
6	Webs made of NCMS and crankpin as aluminum alloy	160.227	302.66
7	Webs made of aluminum alloy and crankpin as NCMS	160.227	167
8	Webs made of NCMS and crankpin as structural steel	160.227	150.28
9	Webs made of structural steel and crankpin as NCMS	160.227	**148.89**

Table 5. Comparative table for total deformation

S.N.	Materials Types	Analytical results (mm)	Software analysis Results (mm)
1	For Structural Steel	$8.0113E^{-4}$	$9.27E^{-6}$
2	For Aluminum Alloy	$2.257E^{-3}$	$2.624E^{-5}$
3	For NCM Steel	$8.0113E^{-4}$	$9.244E^{-6}$

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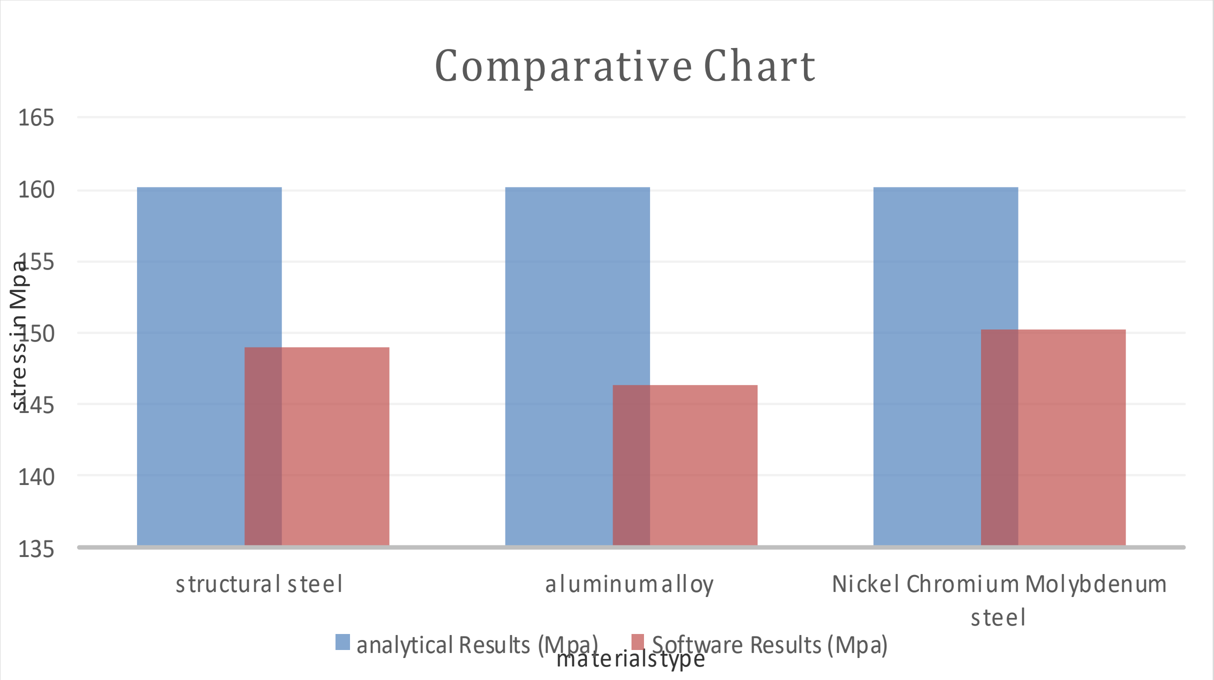

Chart 1. Von Misses Stress for different materials of Crankshaft

VI. CONCLUSION

The following conclusion can be drawn from the result of crankshaft analysis

a. Three different materials were used for the analysis of crankshaft as structural steel, aluminum alloy and Nickel Chromium molybdenum steel
b. The maximum stress appears at the area between crank journal and crank cheeks
c. The value of von-misses stresses of analysis is less than the material yield stress so this design is safe.
d. Crankshaft made of aluminum alloy has highest strength and show minimum value of von misses stress (146.28 Mpa)
e. Crankshaft is made of combination of different parts like crank webs, crankpin, bearing supports, etc. among them crank webs and crankpin are important parts.
f. Since, force is directly applied at the crankpin of crankshaft so a different combination of materials in same crankshaft is used to find best materials. we obtained Webs made of structural steel and crankpin made from nickel chromium molybdenum steel has least value of von misses stress (148.89 Mpa)

VII. FUTURE SCOPE

The analysis of crankshaft can be done in various way beside follows in this works. The design analysis can be explained by taking different constraints other static analysis and with different simulation software. The future scope of this works can be tabulated below:-

a. Analysis can be done with other materials of higher strength and low weight materials.
b. Vibration and fatigue analysis can be done to estimate life of crankshaft
c. Economic analysis for different combination of materials in single crankshaft can be in future.

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