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Structural Analysis of Crank Arm for Quadracycle

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Abstract–**The crank arm is the component of the bicycle that transfers the force exerted on the pedals to the crank set. Crank arms can crack in a number of places. Sometimes a crack will develop between the pedal mounting hole and the end of the arm. This research is basically deal with to analyse the structural analysis of crank arm by using the three different materials.The problem to be dealt for this work is to design and simulate using SolidWorks software for the optimization of the crank arm with constraints of stiffness and strength is considered for design safety.The crank is analyzed in static condition. Distribution of different stress components and the maximum von Misesstress have been ascertained. The maximum von-Mises stress 106.6MPa and maximum deflection is 0.282mm found that on the alloy steel material. So alloy steel is the suitable material of the crank arm for Quadracycle.It has been found that the maximum von Mises stress in the crank is 106.6 MPa which is below the yield strength of the crank material (620.42 MPa**).

Keywords – **Crank Arm, Static condition, von-Mises stress, stiffness, Structural Analysis**

I. INTRODUCTION

A crank is an arm attached at a right angle to a rotating shaft by which reciprocating motion is imparted to or received from the shaft. It is used to convert circular motion into reciprocating motion, or vice versa. The arm may be a bent portion of the shaft, or a separate arm or disk attached to it.A crack alsowill develop at the crotch of the chaining-mounting arms (spider arms) and the crank arm. Attached to the end of the crank by a pivot is a rod, usually called a connecting rod. The end of the rod attached to the crank moves in a circular motion, while the other end is usually constrained to move in a linear sliding motion [3].

The term often refers to a human-powered crank which is used to manually turn an axle, as in a bicycle crank set or a brace and bit drill. In this case a person's arm or leg serves as the connecting rod, applying reciprocating force to the crank. There is usually a bar perpendicular to the other end of the arm, often with a freely rotatable handle or pedal attached. Crank length can be measured from the centre of the pedal spindle to the centre of the bottom bracket spindle or axial. Crank are constructed of either an aluminium alloy, titanium, carbon fibre, chromyl steel, or some less expensive steel [10]. Figure 1 illustrates the component of bicycle crank arm.

Figure 1. Crank Arm [3]

II. THEORY BACKGROUND

A bicycle arm is a critical component of the drive mechanism as it transmits the force generated by the rider and his or her weight to the crankshaft on which the chain wheel is mounted. The concentrated load acting on crank arm.

A. Design Consideration of Crank

The loads imposed on the crank arm of a light commercial vehicle due to normal running conditions are considered. There are two basic load cases to be considered.

B.Bending Case

This is loading in a vertical plane, the x–z plane to be construct the weight of components distributed along the crank which cause bending about the y-axis.

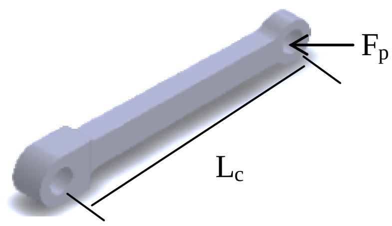

Figure 2. Load on Crank Arm

Figure 2 shows the total load distribution on crank arm.

C. Torsion Case

The crank arm is subjected to a moment applied at the axle centre lines by applying upward and downward loads at each axle in this case.
Torsional moment,
$T = F_p \times L_c$(1)

III. Stresses In Crank Arm

The stress involves the proper sizing of a beam to safely withstand the maximum stress which is induced within the beam when it is subjected separately or to any combination of bending, torsion, axial or transverse loads.

A. Bending Stress

A beam is a member that carries loads transverse to its axis. Such load produce bending moments in the beam which result in the development of bending stress. Bending stresses are normal stresses that is either tensile or compressive.

$$\sigma = \frac{M\,y}{I} \qquad (2)$$

B.Area Moment of Inertia

The area moment of inertia is a property of shape that is used to predict deflection, bending and stress in beams. Area moment of inertia for bending around the X axis can be expressed.

$$I_{CG} = \int_A y^2 dA \qquad (3)$$

For the moment of inertia of the channel section with respect to the neutral axis about the x axis from the equation,

$$I = I_{CG} + Ad^2 \quad (4)$$

C. Shear Stresses and the Principal Stresses of Crank Arm

The shear stress τ in the web of the beam at distance y_1 from the neutral axis is

$$\frac{\tau}{V} = \frac{Q}{It} \quad (5)$$

The principal stress is the maximum normal stress on a particular plane can have at its some point.The principal stress at the point of the beam is

$$\sigma_{1,2} = \frac{1}{2}(\sigma_y + \sigma_x) \pm \frac{1}{2}[(\sigma_y - \sigma_x)^2 + 4\tau^2]^{\frac{1}{2}} \quad (6)$$

The von-Mises stress is

$$\bar{\sigma} = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2]} \quad (7)$$

D. Beam Deflection of Macaulay's Method

Macaulay's Method is a means to find the equation that describes the deflected shape of a beam. From this equation, any deflection of interest can be found.

General deflection equation from the Euler-Bernoulli Theory of Bending, at a point along a beam,

$$\frac{1}{R} = \frac{M}{EI}$$

Mathematically, it can be shown that, for large R:

$$\frac{1}{R} = \frac{d^2y}{dx^2}$$

Hence, the fundamental equation in finding deflections is:

$$\frac{d^2y}{dx^2} = \frac{M_x}{EI_x}$$

In which the subscripts show that both M and EI are functions of x and so may change along the length of the beam.
Going back to basic formula, to find the deflection :

$$\frac{d^2y}{dx^2} = \frac{M(x)}{EI} \qquad (8)$$

$$y = \iint \frac{M(x)}{EI} dx \qquad (9)$$

IV. Design Consideration On Crank Arm

TABLE I

SPECIFICATION DATA OF CRANK ARMFOR QUADRACYCLE

No.	Design parameter	Symbols	Value	Units
1	Pedalling force	F	377	N
2	Length of crank arm	L_c	0.165	m
3	Height of crank arm	h	0.02	m
4	Width of crank arm	b	0.014	m

Table I shows the specification data of crank arm for Quadracycle.

TABLE II

COMPARISON OF THEORETICALANDNUMERICALRESULT OF CRANK ARM

Type of component	Theoretical Result		Numerical Result	
	$\bar{\sigma}$ (MPa)	y (mm)	$\bar{\sigma}$ (MPa)	y (mm)
Crank arm (Alloy steel)	95.66	0.288	106.6	0.282

Table II shows the comparison of numerical and theoretical result of crank arm. In the comparison of theoretical and numerical results, the deviation of von-Mises stress is 10.31% and deflection is 2.08% inalloy steel.

V. Structural Analysis For Crank Arm

Crank arm can measure all the visible dimension manually with specified measuring instrument to create accurate and scaled model. The simulation involves the discretization called meshing, boundary conditions and loading.

TABLE III

SPECIFICATION OF MATERIAL

Material Properties	Alloy Steel	Stainless Steel	Cast alloy steel	Unit
Density	7700	7800	7300	kg/m^3
Modulus of elasticity	210	200	190	GPa
Passion ratio	0.28	0.28	0.26	-
Yield strength	620.4	172.3	241.3	MPa
Tensile strength	723.8	513.61	448.1	MPa

Table III shows the specification of material used for research.

A. Creating a Solid Model

To create the model of crank arm, firstly are surveyed the existing crank arm of Quadracycle from market and many available sources for reverse engineering. And then, measure all the visible dimension manually with specified measuring instrument to create accurate and scaled model. The simulation involves the discretization called meshing, boundary conditions and loading. For simulation, the material is selected from table III.The first step was to prepare a solid model of crank arm. This was carried out by using SolidWorks 2017 software.

B. Structural Analysis

Structural analysis is probably the most common application of the method with SolidWorks 2017.

C. Boundary Conditions

For stress analysis, force is applied with point load on the upper surface of the crank arm where the left hole of the crank arm is supported with the fixed support.

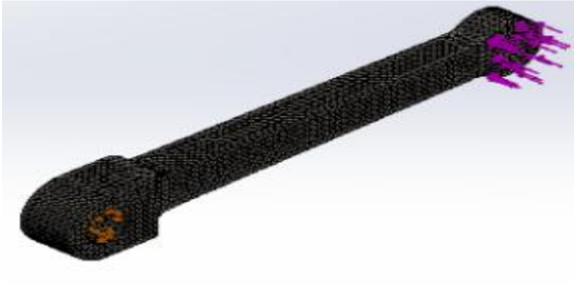

Figure 3. Meshing of Crank Arm

This geometry model was meshed with high smoothing. This meshed model was imported for the structural analysis of the crank arm.The generated mesh of crank is shown in Figure 3. The generated mesh is done by fine position to obtain the good quality of mesh.

Material: Alloy Steel

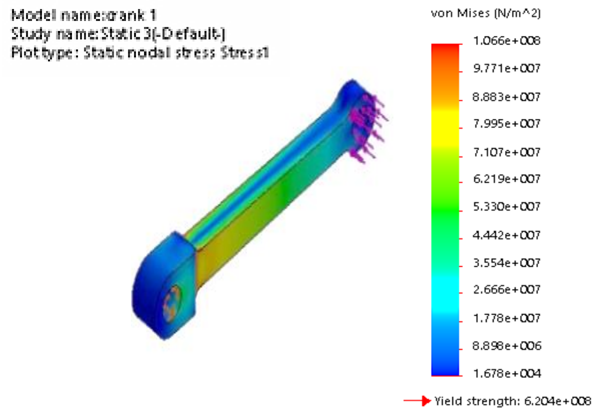

Figure 4. Maximum Von Mises Stress

Figure 4 showsthe analytical results for the maximum von Mises stress in crank arm for alloy steel material.The magnitude of maximum von Mises stress is 106.6 MPa.

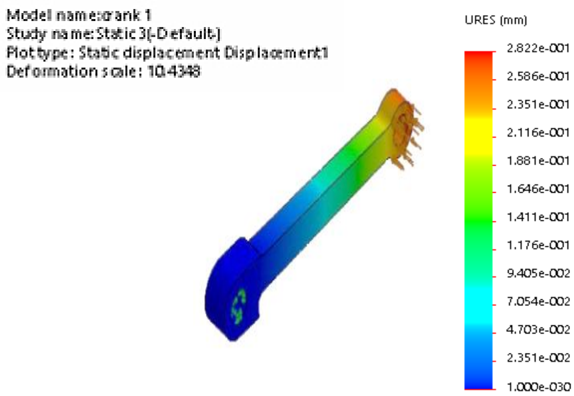

Figure 5. Total Deformation

Figure 5 showsthe analytical results for the total deformation in crank armfor alloy steel material.The magnitude of maximum total deformation is 0.282mm.

Material Stainless Steel

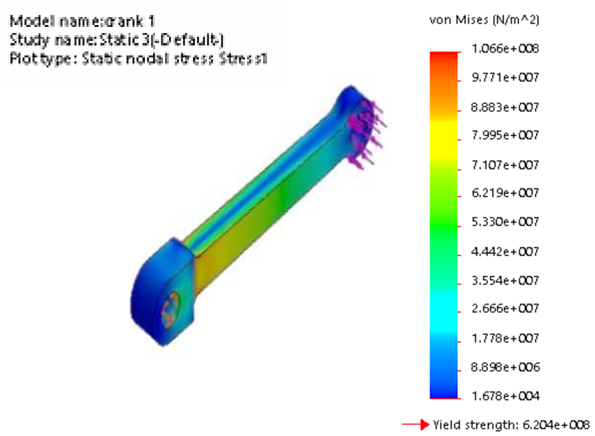

Figure 6. Maximum Von Mises Stress

Figure 6 shows the analytical results for the maximum von Mises stress in crank arm for stainless steel material.The magnitude of maximum von Mises stress is 106.6 MPa.

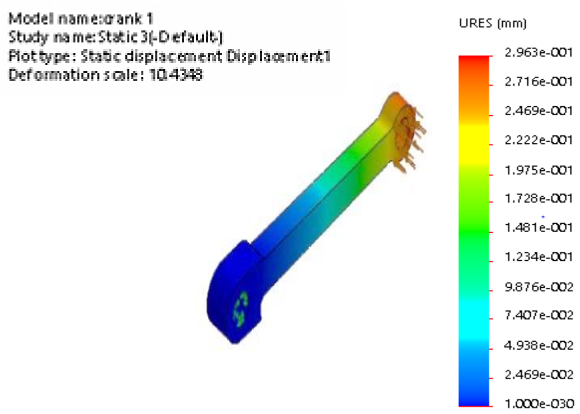

Figure 7. Total Deformation

Figure 7 shows the analytical results for the total deformation in crank arm for stainless steel material. The magnitude of maximum total deformation is 0.296mm.

Material Cast Alloy Steel

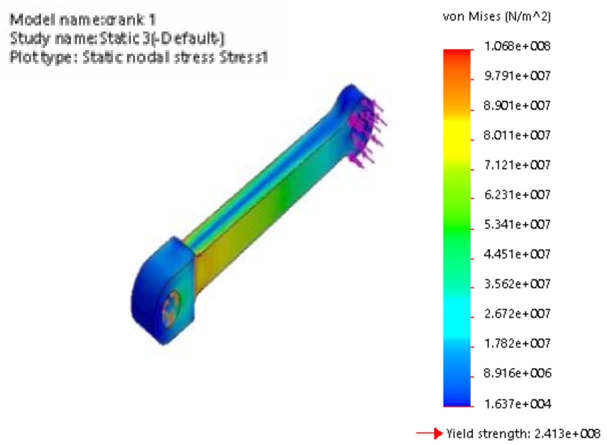

Figure 8. Maximum Von Mises Stress

Figure 8 shows the analytical results for the maximum von Mises stress in crank arm for cast alloy steel material.The magnitude of maximum von Mises stress is 106.8 MPa

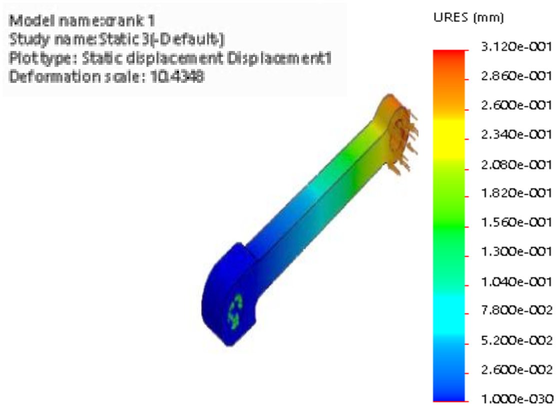

Figure 9. Total Deformation

Figure 9 shows the analytical results for the total deformation in crank arm for cast alloy steel material. The magnitude of maximum total deformation is 0.312mm.

VI. Result And Discussion

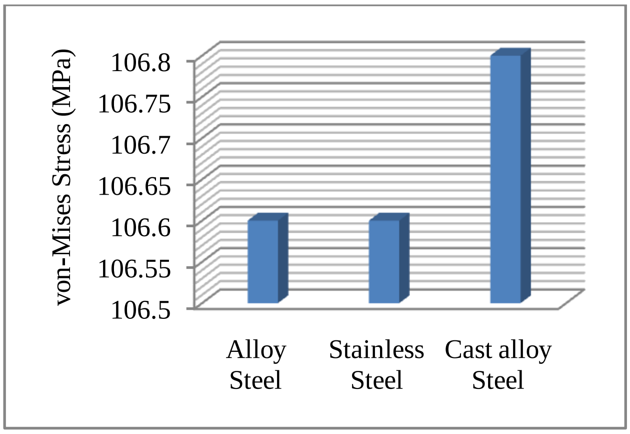

Figure 10. Comparison of Three Different Materials of Equivalent (von -Mises) Stress

Figure 10 shows the numerical result of comparison of three materials of equivalent (von Mises) stress.

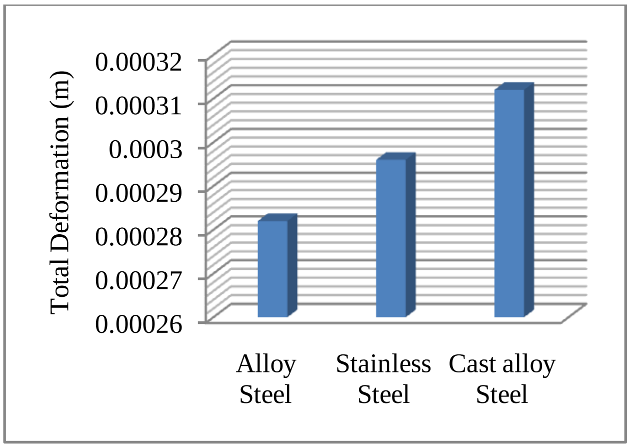

Figure 11. Comparison of Three Different Materials of Total Deformation.

Figure 11shows the numerical result of comparison of three materials of total deformation.

TABLE IV
NUMERICAL RESULT DATA OF CRANK ARM FOR THREE DIFFERENT MATERIALS

Materials	Maximum Equivalent Stresses (MPa)	Maximum Deformation (mm)
Alloy Steel	106.6	0.2822
Stainless Steel	106.6	0.2963
Cast Alloy Steel	106.8	0.312

Table IV shows the numerical results of maximum von Mises stress (equivalentstress) and maximum total deformation of crank arm for three materials.In the comparison of numerical results,the optimum von Mises stress and deformation of crank arm for Quadracycle are found in alloy steel as shown in Table IV.

VII. CONCLUSION

In the present work, the crank arm component of Quadracycle has been modelled and analysed in SolidWorks 2017 software. Based on the analysis results of the present work, the following conclusions can be drawn, the generated von Mises stress is less than the permissible value so the design is safe for all three materials. von Mises stresses were found minimum in alloy steel and maximum in cast alloy steel under given boundary condition. The deflection of crank arm using alloy steel is having least among the three types of materials at the given condition.

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