Design Optimization of Bicycle Crank using Finite Element Analysis

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***Abstract*: The crank is an important part of bicycle as it converts the reciprocating motion of the pedal into rotary motion through the chain drive arrangement. A crank should have sufficient strength to withstand the bending and twisting moments to which it is subjected. This study describes the stress distribution and deformation of a carbon fiber , structural steel and aluminum cranks used in bicycle using commercial Finite Element Analysis (FEA) software ANSYS™ .The stress analysis results are significant to select the best material to design the bicycle crank.**

***Keywords*: Crank, ANSYS™ software, deformation, stress distribution. Note: All the deformation shown in figures are 4 times the actual scale.**

1. Introduction

In 1206, al-Jazari invented an early crankshaft, which he incorporated with a crank-connecting rod mechanism in his twin-cylinder pump. Like the modern crankshaft, Al-Jazari's mechanism consisted of a wheel setting several crank pins into motion, with the wheel's motion being circular and the pins moving back-and-forth in a straight line. The crankshaft described by al-Jazari transforms continuous rotary motion into a linear reciprocating motion, and is central to modern machinery such as the steam engine, internal combustion engine and automatic controls. He used the crankshaft with a connecting rod in two of his water-raising machines: the crank-driven saqiya chain pump and the double-action reciprocating piston suction pump. His water pump also employed the first known crank-slider mechanism. The crank set is the component of a bicycle that converts the reciprocating motion of the rider's legs into rotational motion used to drive the chain which in turn drives the rear wheel. It consists of one or more sprockets, also called chain rings or chain wheels attached to the cranks, arms, or crank arm to which the pedals attach. It is connected to the rider by the pedals, to the bicycle frame by the bottom bracket, and to the rear sprocket, cassette or freewheel via the chain. Bicycle cranks can vary in length to accommodate different sized riders and different types of cycling. Crank length is measured from the center of the pedal spindle to the center of the bottom bracket spindle or axle. The larger bicycle component manufacturers typically offer crank lengths for adult riders from 180 mm to 200 mm long in 2.5 mm increments, with 190 mm cranks being the most common size. A few small specialty manufacturers make bicycle cranks in a number of sizes smaller than 180 mm and longer than 200 mm. Some manufacturers also make bicycle cranks that can be adjusted to different lengths. While logic would suggest that, all other things being equal, riders with shorter legs should use proportionally shorter cranks and those with longer legs should use proportionally longer cranks, this is not universally accepted. However, very few scientific studies have definitively examined the effect of crank length on sustained cycling performance and the studies' results have been mixed. Bicycle crank length has not been easy to study scientifically for a number of reasons, chief among them being that cyclists are able to physiologically adapt to different crank lengths. Cyclists choose for typically more efficient pedaling cranks with which they have had an adaptation period. Several different formulas exist to calculate appropriate crank length for various riders.

2. Literature survey

A. Material optimization of crank

Ventzi G. Karaivanov and David A. Torick talked about the title of advancement of a bike wrench and bug utilizing limited component programming, portrays the development of a bike wrench and arachnid design.The pedal is appended to the bike wrench and the creepy crawly is the part that exchanges the torque delivered from the pedal and wrench a safe distance to the chain sprocket. They demonstrate the redirection and stress examination of a section level plan. Configuration change was to choose another material to diminish the heaviness of the wrench and creepy crawly assembly.They choosed a Glass Fiber Reinforced Plastic (GFRP). This material has a Young's Modulus of 26 GPa and a Poisson's Ratio of 0.28. This material change caused a generous decline in absolute mass of the model. The assessed weight for the wrench/creepy crawly get together diminished from 265grams (for Aluminum composite) to 176.6 grams. Be that as it may, our most extreme worry of 75 MPa is a lot nearer to the yield worry of 125 MPa for GFRP. The diversion of the finish of the wrench arm has likewise expanded by a factor of three from 0.66 mm to 2.1mm. Filets all through the model are important to keep away from pressure fixations and wounds from sharp edges.

B. Weight reduction case study of crank

Sean Sullivan from Chris Huskamp, IBC Advanced Alloys

International Journal of Research in Engineering, Science and Management
Volume-2, Issue-5, May-2019
www.ijresm.com | ISSN (Online): 2581-5792

(2013) talked about the contextual analysis of weight decrease of a superior street bike wrench arm set by actualizing Beralcast 310. The initial segment of the examination concerns the immediate substitution of 7050-T651Al with Beralcast 310. As referenced already, the wrench arms are empty forgings however the inner geometry isn't known and was in this way not displayed. Chart diagrams the last aftereffects of the substitution of Beralcast 310.

The emphasis is on the relative contrasts between the two materials, thusly the majority of the outcomes are appeared as a percent distinction. The figure demonstrates the graphical portrayal of weight decrease of existing wrench.

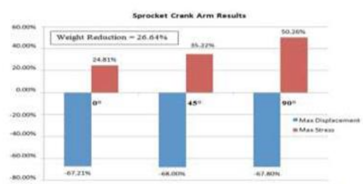

Fig. 1. Sprocket crank arm results

From the second piece of the examination, the model of the standard Dura-Ace straight wrench arm was altered in five one of a kind approaches to demonstrate the potential weight funds. The figure demonstrates the pictorial portrayal of elective structure options. The weight decrease by shaped through cut is over 20%, the best out of the five one of a kind plans. It is important that each plan has few pressure fixations. Anyway the focal point of this examination isn't to make refined generation quality plans but instead demonstrate the positive characteristics of utilizing Beralcast 310 for the Dura-Ace wrench set. In such manner, the 310 is an improvement over the 7050-T651 Al. For every one of the five plan emphases; the general feelings of anxiety are beneath yield, the weight decrease levels are 10 to 20% over the deliberate load of the real part, solidness increments by as meager as 5% and as much as 64%

C. *Stress analysis of bicycle paddle*

S. Abey Gunasekara and T.M.M. Amarasekara talked about the pressure investigation of bike paddle and upgraded by limited component technique, portrays and proposed enhancements of structures with respect to limit the weight, cost and ideal factor of security. Disappointment of oar wrench implies the dynamic of abrupt weakening of their mechanical quality as a result of stacking impact. Oar make materials demonstrated distinctive properties therefore numerous focal points just as inconveniences. Anyway material quality ought to have capacity to withstand a connected worry without disappointment. For the most part, wrenches are made of an aluminum combination, titanium, carbon fiber, chromyl steel or different more affordable steel. The pedal power is changing each second during the time spent turning the pedal and size and heading of pedal power is distinctive as per diverse riding stance. First 50% of the round weight is certain and second half weight is negative. Most extreme burden is coming vertically descending and greatness is relying upon the street condition, slant of the street and just as weight of the rider. In this writing considered 95 % man's weight of the populace is about 116Kg. This is the greatest burden following up on pedal just as wrench in descending. Because of this heap bowing worry in wrench and it will make winding of the wrench. The most extreme twisting pressure gives the heap acting toward the finish of the pedal. From this writing, we found that there is a most extreme worry in sharp edges in the wrench close to fixed gap so need to apply a few filets on sharp edges and more thickens close to fixed opening than the pedal fixing gap by including material. Continuously it is expected to keep identical worry as much as low. It will profit to toughness of the segment.

D. *Conclusion of literature review*

From the survey of writing introduced over, coming up next are the real ends: I) Weight decrease of wrench helps the genuine cyclist and racers for quick driving. A weight decrease of 90 grams will influence the plan to be appealing. In the event that we utilize substitute material, significant increment in avoidance. Utilization of GFRP had a generous increment in avoidance. A few top of the line wrench congregations should be benchmarked to decide whether the redirection is satisfactory. On the off chance that the benchmarked wrenches have comparable redirections the plan ought to be worthy to the top of the line customer. ii) Directly substituting the Beralcast 310 builds the part's firmness by around 67% and diminishes the weight by 26.6%. Weight decrease of 10 to 20% is conceivable with an expansion in firmness upto 64%. iii) In reference to bike cranksets, weight and solidness are both critical attributes. Weight decrease implies the rider can acquire more prominent speeds and separations utilizing less vitality. More noteworthy wrench arm firmness takes into account increasingly pedal power to be exchanged to the bike's back wheel as opposed to distort the arm. iv) Fatigue is the dynamic auxiliary harm that happens when materials are exposed to cyclic stacking. Worry because of burden on the wrench was expanded to greatest and diminishing to least. Comparable pressure ought to be decreased and need to keep it in a normal incentive for strength.

3. Problem Statement

This project will focus on selecting the best design and material for manufacturing of the bicycle crank out of the following materials:

- Structural steel
- Carbon fiber cranks
- Aluminum cranks

By obtaining the results of stress distribution and deformation when a constant force is applied on the different materials, using finite element analysis (FAE) software ANSYS™

A. Objectives

1. To determine the best design for manufacturing of the bike crank (out of the four proposed designs.)
2. To determine the best material for manufacturing of the bike crank Using the finite element analysis method (using ANSYS^{TM})

B. Crank specifications

A roadster bicycle is a type of utility bike which was once common worldwide, and still common in Asia, Africa, Latin America, and some parts of Europe. During the past few decades, traditionally styled roadster bicycles have regained popularity in the Western world, particularly as a lifestyle or fashion statement in an urban environment.

Fig. 2. Crank specifications

The general specifications of the selected bicycle are as follows:

- Dura tuf steel brazed frame and fork/nylon tyres
- 48 teeth chain wheel crank and 20 teeth freewheel
- Frame Height: 22 inch and 24 inch
- Centre and side pull braking system
- Wide and thin barrel hubs kindly note, this product will be shipped in a semi assembled/dismantled state

Fig. 3. Bicycle crank

C. Dimension of the bicycle crank

- End to End distance = 20cm
- Radius of the rivet hole on the left = 0.75cm
- Radius of the semicircular region on the left = 1.25cm
- Square section towards left = 2.5X2.5 cm^2
- The circular region towards right has diameter = 2.4cm
- Radius of the rivet hole on the right = 0.6cm
- Thickness of the crank = 1.2cm
- Breadth of the crank = 1.6cm

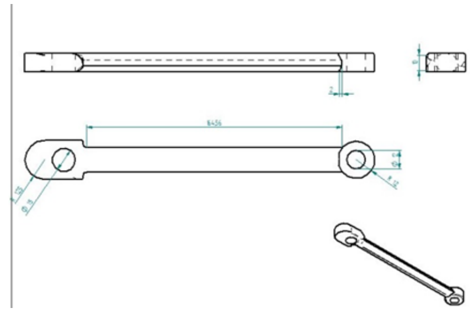

Fig. 4. Crank specifications

The dimension of the bicycle crank of the selected bicycle are shown in the above figure.

D. Structural analysis: Standard crank made of structural steel

Fig. 5.

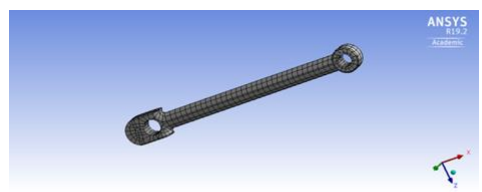

Fig. 6.

Figure 5 displays the 3-D diagram of the standard design of the crank used in the Hercules Roadster model and the Figure 6 displays the meshing of it.

The left part of the crank is fixed using the Rivet of the same material used in the crank. Upon constant load application of 800N (80 kg approximately) on the right end of the crank(which depects the force acting on the crank by the cyclist when the cyclist is cycling), it deforms in the following fashion.

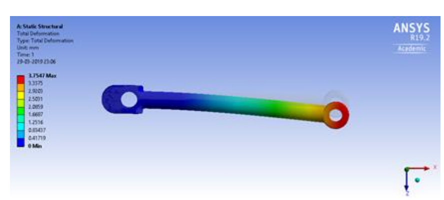

Fig. 7.

Figure 7 displays the deformation of the crank form its mean position. The material being structural steel undergoes a maximum deformation of 3.7547mm.

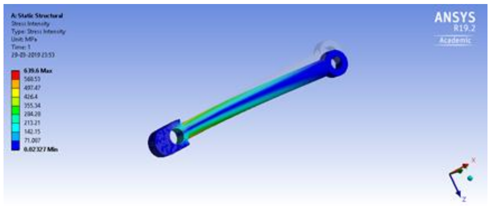

Fig. 8.

The figure 8 explains the stress distribution on the model when a constant force of 800N is applied on it. The crank shows a maximum stress concentration of 639.6 MPa highlighted by the area in red.

E. Improvised model 1 made by structural steel

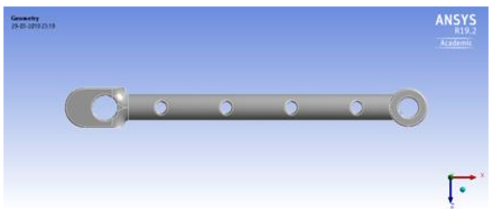

Fig. 9.

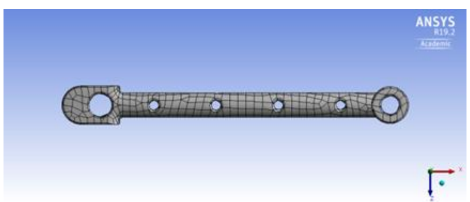

Fig. 10.

Figure 9 shows the 3-D model of the improvised design and the Figure 10 displays the meshing of it. that helps in reducing the net deformation of the model and also the maximum stress concentration. The left part of the crank is fixed using the Rivet of the same material (structural steel) used in the crank. Upon constant load application of 800N (80kg approximately) on the right end of the crank, it deforms in the following fashion:

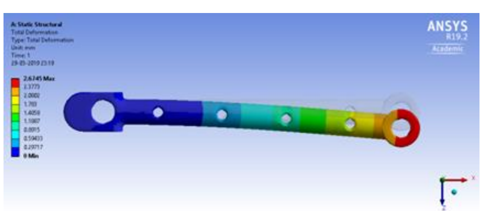

Fig. 11. Displays the deformation of the crank form its mean position.

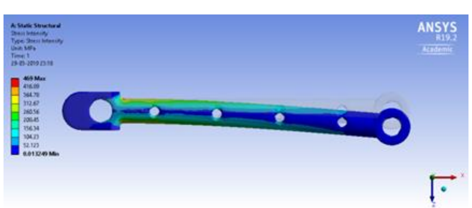

Fig. 12.

The material being structural steel undergoes a maximum deformation of 2.6745 mm. This is a net reduction in the deformation by 28.769% which is very effective and it also has reduction in the material quantity used as it has holes drilled in it.

The figure 12 explains the stress distribution on the model when a constant force of 800N is applied on it. The crank shows a maximum stress concentration of 469 MPa highlighted by the area in red. Thus this design is better and lighter to manufacture than the standard model.

F. Improvised model 2 made by structural steel

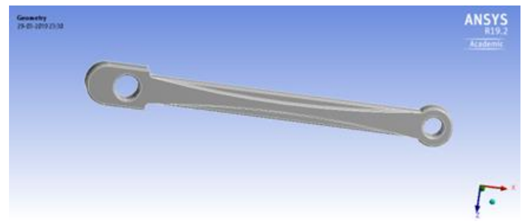

Fig. 13.

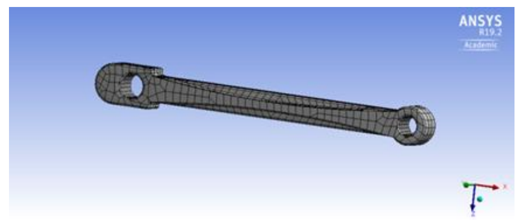

Fig. 14.

Figure 13 shows the 3-D model of a more improvised design and the Figure 10 displays the meshing of it that helps in reducing the net deformation of the model even more and also the maximum stress concentration. The left part of the crank is fixed using the Rivet of the same material (structural steel) used in the crank. Upon constant load application of 800N (80 kg approximately) on the right end of the crank, it deforms in the following fashion.

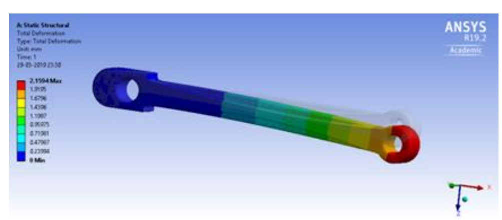

Fig. 15.

Figure 15 displays the deformation of the crank form its mean position. The material being structural steel undergoes a maximum deformation of 2.1594 mm. This is a net reduction in the deformation by 42.488 % which is very effective and it also has reduction in the material quantity used as it has embossing on all the sides of its structure. It is lighter and cheaper and more effective in reducing the deformation as compared to other designs.

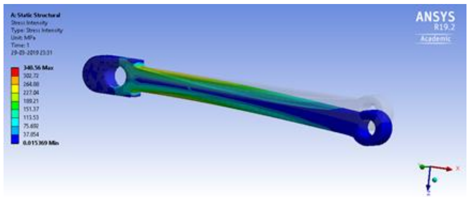

Fig. 16.

The figure 16 explains the stress distribution on the model when a constant force of 800N is applied on it. The crank shows a maximum stress concentration of 340.56 MPa highlighted by the area in red.

Thus this design is better and cheaper to manufacture than the standard model. It is lighter more effective in reducing the stress concentration as compared to other designs.

G. Improvised model 3 made by structural steel

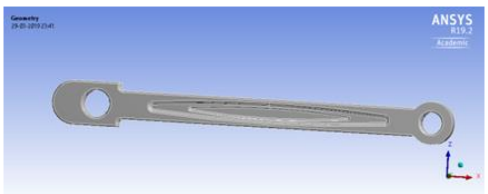

Fig. 17.

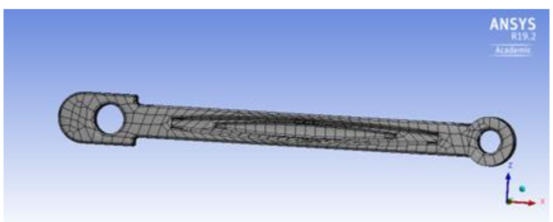

Fig. 18.

Figure 17 shows the 3-D model of a more improvised design and the Figure 18 displays the meshing of it. that helps in reducing the net deformation of the model even more and also the maximum stress concentration. The left part of the crank is fixed using the Rivet of the same material (structural steel) used in the crank. Upon constant load application of 800N (80 kg approximately) on the right end of the crank, it deforms in the following fashion.

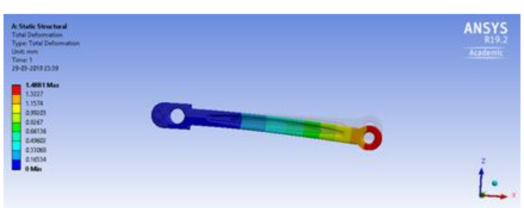

Fig. 19.

Figure 19 displays the deformation of the crank form its mean position. The material being structural steel undergoes a maximum deformation of 1.4881 mm. This is a net reduction in the deformation by 60.367% which is very effective and it also has reduction in the material quantity used as it has embossing on all the sides of its structure in the form of concentric oval shaped structure machined to a certain depth. It is lighter and more effective in reducing the deformation as compared to other designs.

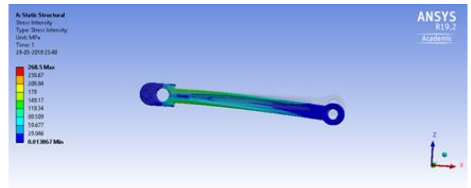

Fig. 20.

The figure 20 explains the stress distribution on the model when a constant force of 800N is applied on it. The crank shows a maximum stress concentration of 268.5 MPa highlighted by the area in red.

Thus this design is better and lighter to manufacture than the standard model. It is lighter and more effective in reducing the stress concentration as compared to other designs. As the above design has the least deformation and stress acting on it parts, thus we are analyzing it for other material to get better results.

1) Structural analysis on crank made of Aluminium alloy

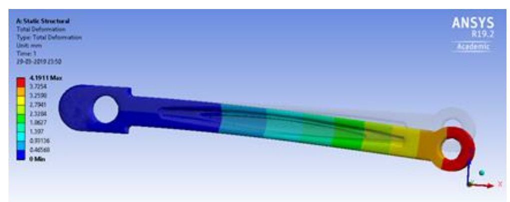

Fig. 21.

Figure 21 displays the deformation of the crank form its mean position.

The material being aluminium alloy undergoes a maximum deformation of 4.1991 mm. The design is still very reliable than the basic design but is not stronger because aluminium has less modulus of rigidity when compared to structural steel thus it can't be considered ideal for manufacturing.

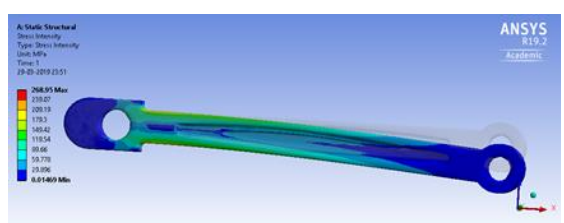

Fig. 22

The figure 22 explains the stress distribution on the model when a constant force of 800N is applied on it. The crank shows a maximum stress concentration of 268.95 MPa highlighted by the area in red.

2) Structural analysis on crank made of Carbon fiber

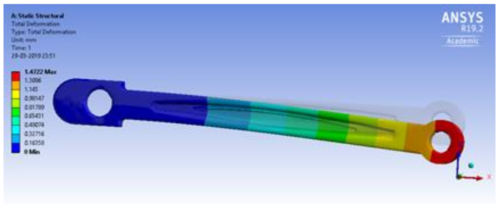

Fig. 23.

Figure 23 displays the deformation of the crank form its mean position. The material being carbon fiber undergoes a maximum deformation of 1.4722 mm. The design is still very reliable than the basic design and is stronger because carbon is very light compared to structural steel thus it can be considered ideal for manufacturing but carbon fiber is very expensive to use. Thus can be used for high performance bicycle.

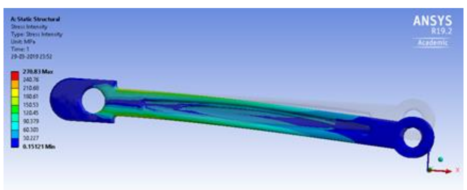

Fig. 24.

The figure 24 explains the stress distribution on the model when a constant force of 80 kg is applied on it. The crank shows a maximum stress concentration of 270.83 MPa highlighted by the area in red.

Analysis of the results:

Table 1
Model, strain and stress

1	Sample	Max. Strain(mm)	Max. Stress(Mpa)
2	Standerd Model	3.7547	639.6
3	Improvised Model 1	2.6745	469
4	Improvised Model 2	2.1594	340.56
5	Improvised Model 3	1.4881	268.5
6	Improvised Model 3(carbon fiber)	1.4722	270.83
7	Improvised Model 3(Aluminium)	4.1911	268.95

The above table 1, shows the quantitative stress and strain behavior of all the designs that we have considered.

Table 2
Various mechanical properties of the different elements

1	Sample	density(kgm^-3)	Young's Modulus	Poisson's Ratio	Shear Modulus
2	Aluminium	2770	7.10E+10	0.33	2.67E+10
3	Carbon Fiber	1.80E-09	2.30E+05	0.2	900
4	Structural Steel	7850	2.00E+11	0.3	7.69E+10

The above table 2, shows the various mechanical properties of the different elements.

4. Conclusion

From the tests conducted thoroughly by the finite element analysis (FEA) we concur the following:

1. Out of the three improvised structure the best design for manufacturing of the crank is the improvised design 3 as it is hollow thus it has more structural rigidity, and develops the least deformation.

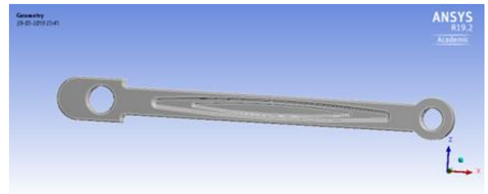

Fig. 25.

2. We can use structural steel or carbon fiber or aluminium for its manufacturing. The carbon fiber shows the least deformation when used but it is expensive thus it is only used for manufacturing of high end bicycles and in general structural steel can be used.

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