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FATIGUE FAILURE ANALYSIS OF BIKE CRANK ARM USING SOLIDWORKS SIMULATION

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ABSTRACT

Fatigue analysis probes how cyclic random service loads can often lead to catastrophic structural failure of the component. In this research work the crank bar design of a Bike is validated for Fatigue analysis using SOLIDWORKS Simulation which enables designers to simulate Fatigue failure of the component using Stress Life (SN) method that is based upon standard material test to failure. Aluminum 6061 – T6 material is used in the design and Fatigue SN curve table data is taken from the SOLIDWORKS material library which is derived from material elastic modulus based on ASME Austenitic Steel curves. The crank arm length is 10 in and width is 1.5 in with overall constant thickness 0.8 in and crank mid-section thickness equals to 0.2 in. First the design is analyzed for Static strength by applying the bearing load of 350 lbs. The maximum VonMises stress calculated was 106.61 MPa which is below the allowable yield strength of the material 275 MPa. A fully reversible alternating stresses equivalent to static VonMises stress is loaded for 100,000 cycles which is the required life of the component. The total life calculated was 69,158 cycles which is less than 100,000 cycles and factor of safety is 0.93. The conclusion was the component has to be redesigned for Fatigue strength.

KEYWORDS

Fatigue Analysis, Static strength, VonMises Stress, Bearing load, SN Curve, Constant Amplitude, Load Ratio, Goodman diagram, Mean Stress, Load cycles.

1. INTRODUCTION

On January 10th 1954British Flight 781 from Overseas Airways Corporation crashed into Mediterranean Sea killing all 35 people including crew and passengers onboard. The reason for the crash was due to metal fatigue failure at forward ADF window of pressure cabin in Cockpit roof [1]. This was the wakeup call for engineers to design safe and strong products. Now a day's bikes are not only limited to riding on roads, but you can see these things in Bike stunts, Mountain bike ridings and Sports or many adverse situations. Since crank arm is the component on which balance of the rider lies while in motion, imagine a situation when someone loses balance while performing stunt or riding on a steep narrow mountain because of crank failure, it might cause a serious injury or death but point here is even one loss of life or a multiple lives in case of aircraft, the reason behind the loss of life will be the component failure due to fatigue. Fortunately, Solid works Simulation renders quick economic and authentic means of predicting and solving fatigue issues for engineers. In this paper the Fatigue failure analysis has been done for Bike crank arm made of aluminum alloy subjected to variable load. The typical Bike crank arm components are often vulnerable to fatigue loads and results in failure as shown in figure 1 below [2]. Fatigue failure is due to repeated or random varying loads which never causes failure in single application but in different phases, first - Creation of crack, second - extension of crack and third - fracture as shown in figure 2 below [3].

Figure 1: Typical bike crank arm failure due to fatigue

Many studies may be available for different bike crank arm components design using different software other than solid works, but using solid works, only couple of studies on bike crank is available and that too design, material and usage conditions differ from what we used in this study. Reason is because Solid works is not that widely recognized as FEA software compared to other dedicated FEA software available in the market. So we decided to carry out this analysis using Soliworks simulation to show its capabilities which is also less expensive than any other FEA software available in the market. Since Solid works FEA package is not that expensive, lot of small industries, education institutions and students use this for engineering validation of their design and can always refer back to our study for their reference.

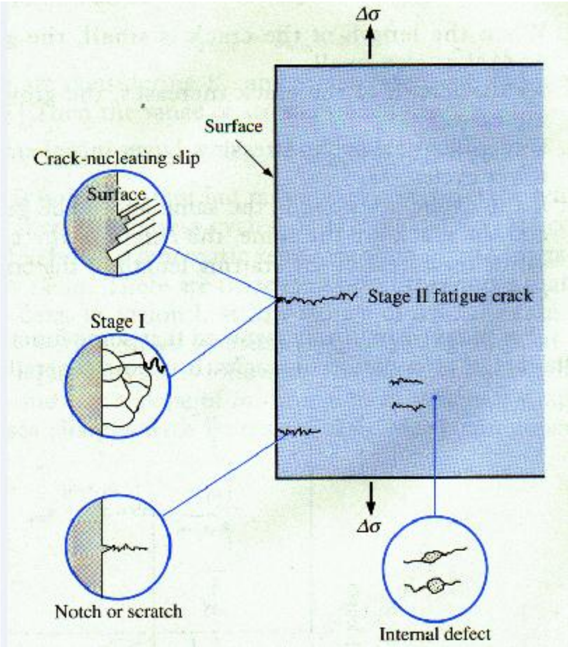


Figure 2: Stages of crack growth

There are two variables that decide the time it takes to initiate crack and sufficiently grow to an extent that causes failure. Those two variables are 1. Material of the component and 2. Magnitude of the stress field. There are three different methods to evaluate fatigue life, 1- Using (SN) Alternating Stress vs Number of load cycles called stress life, 2 - Using Alternating Starin vs Reversals (EN) method 3- Using Linear Elastic Fracture Mechanics (LEFM) method.In this paper SN method is used for fatigue analysis. This method predicts fatigue life of structure established on genuine test data of the material. The result doesn't follow three stages of cracking but gives a total life. This method is widely used in industries and suitable for high cycle fatigue (generally above 10000 cycles or the point in material curve where slope suddenly falls as shown in figure 3 [4].

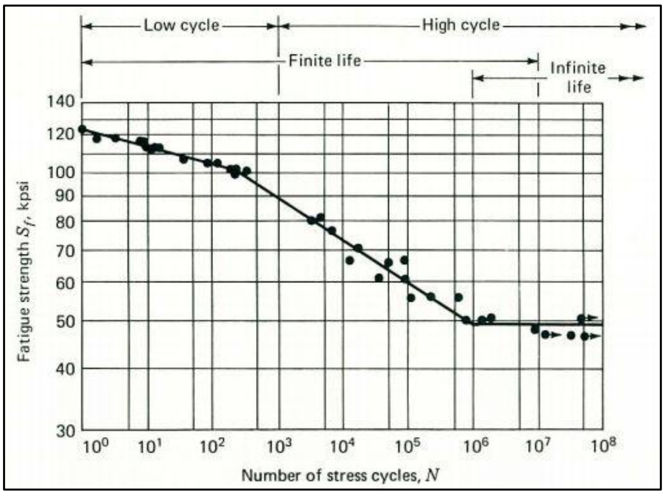


Figure 3: Typical SN curve cycle classification

2. COMPUTER AIDED DESIGN

The 3D model is designed in the Solid works part design workbench as shown in the figure 4 and material assigned is Aluminum 6061 T6 from the design library as shown in figure 6. Just like any other CAD software Solid works also provides Sketcher, Design features and Drafting workbenches. All these workbenches are used in designing the component. All the dimension units are in Inches and fillet radius in the model is R0.15 inch. The spider end which has five bolt holes as shown in figure 4 is fixed to crank plate with square opening aligned to the crank shaft. The other end of the design is where the pedal is fixed.

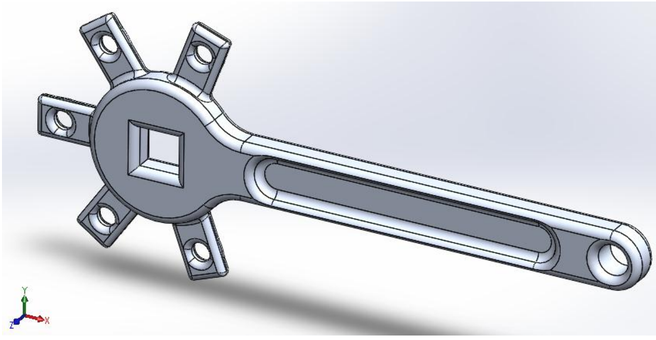


Figure 4: Bike crank arm CAD model

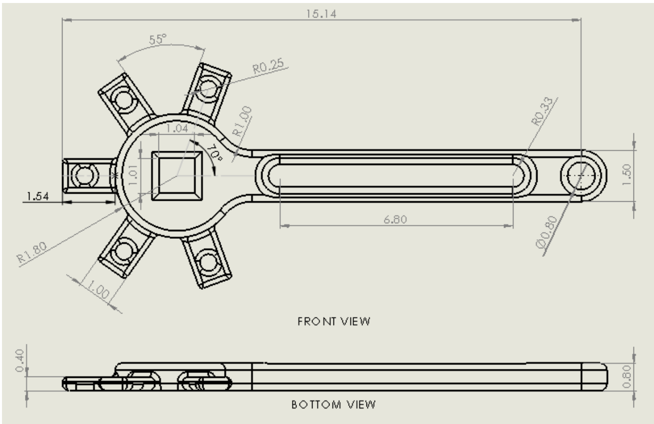


Figure 5: Bike crank arm overall dimension in Inches

Property	Value	Units
Elastic Modulus	10007604	psi
Poisson's Ratio	0.33	N/A
Shear Modulus	3770981.2	psi
Mass Density	0.1	lb/in^3
Tensile Strength	44961.7	psi
Compressive Strength		psi
Yield Strength	39885.38	psi
Thermal Expansion Coefficient	1.333333333e-005	/°F
Thermal Conductivity	0.00223225	Btu/(in·sec·°F)
Specific Heat	0.214006	Btu/(lb·°F)
Material Damping Ratio		N/A

Figure 6: Aluminum 6061-T6 material properties

3. METHOD OF ANALYSIS

For fatigue analysis to be done, first the model is run for static load and then the resulting static stresses are used to derive the fatigue loads in terms of constant amplitude fully reversal cycles and the fatigue life of the component is obtained from Solid works.

3.1 Finite Element Model

The model is meshed automatically in Solid works with 3D hexahedron elements as shown in figure 7. The meshed model details are shown in figure 8. Mesh convergence study has been done using three different element sizes of 0.4, 0.3 and 0.2 inches and the difference in the static Von Mises results vary only 1%.

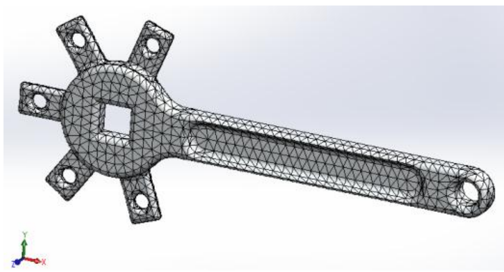
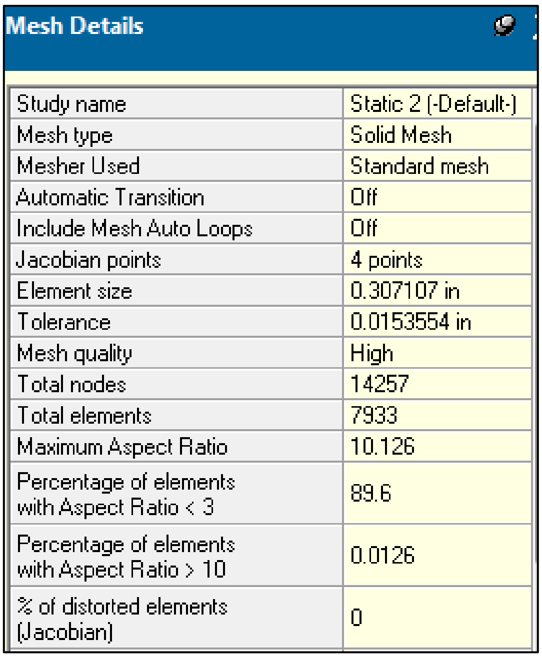


Figure 7: Bike crank arm finite element model


Mesh Details

Study name	Static 2 (-Default-)
Mesh type	Solid Mesh
Mesher Used	Standard mesh
Automatic Transition	Off
Include Mesh Auto Loops	Off
Jacobian points	4 points
Element size	0.307107 in
Tolerance	0.0153554 in
Mesh quality	High
Total nodes	14257
Total elements	7933
Maximum Aspect Ratio	10.126
Percentage of elements with Aspect Ratio < 3	89.6
Percentage of elements with Aspect Ratio > 10	0.0126
% of distorted elements (Jacobian)	0

Figure 1: Bike crank arm finite element model details

3.2 Boundary Conditions and Load For Static Analysis

Six degrees of freedom arrested at five places and bearing load of 350 lbs or 1556.88 Newton is applied at the end of the crank arm as shown in Figure 9. Then the model is solved for static analysis.

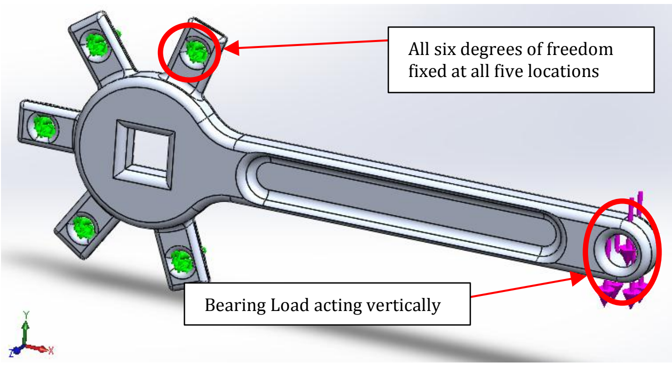


Figure 2: Bike crank arm boundary conditions

3.3 Static Analysis Results

The maximum Von Mises stresses obtained is 106.61 N/mm^2 or MPa at the fillet or neck region indicated in red color as shown in the figure 10.

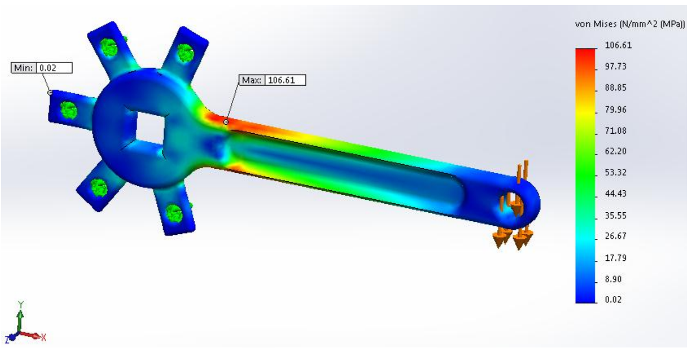


Figure 10: Maximum Von Mises stress plot

3.4 Fatigue Analysis

Stress life SN curve method is used to predict the fatigue life of the component in this paper. The finite element model and the boundary conditions remain same as that of static analysis. But the fatigue analysis requires SN curve of the material similar to the one discussed above in figure 13. The SN curve for Aluminum 6061-T6 is as shown in figure 11.

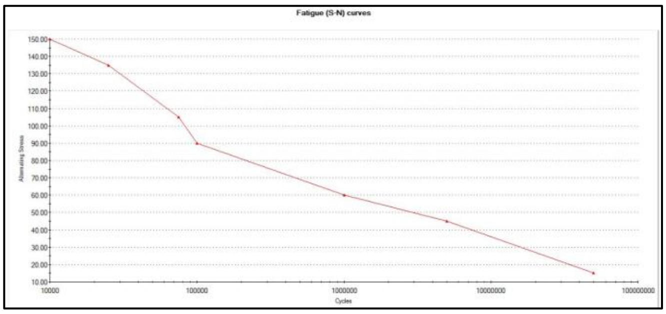
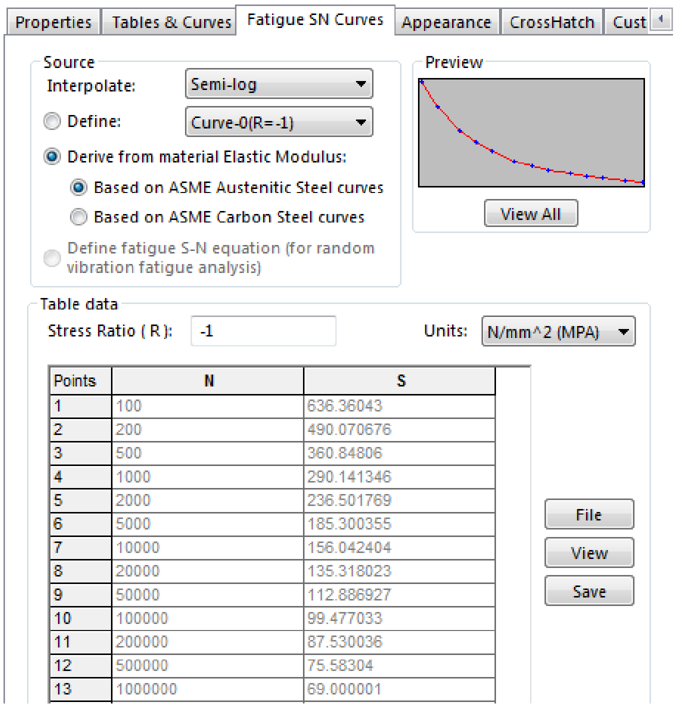


Figure 11: Alternating Stress vs Cycles (SN) curve for Aluminum 6061-T6



Points	N	S
1	100	636.36043
2	200	490.070676
3	500	360.84806
4	1000	290.141346
5	2000	236.501769
6	5000	185.300355
7	10000	156.042404
8	20000	135.318023
9	50000	112.886927
10	100000	99.477033
11	200000	87.530036
12	500000	75.58304
13	1000000	69.000001

Figure 11: Typical (SN) curve data for Aluminum 6061-T6 in Solidworks material library

The fatigue life of the component is determined or predicted by referencing the above graph where required alternating stress and the number of required cycles are provided as the input to the Solid works fatigue analysis solver.

3.5 Fatigue Loads

The fatigue loads are repetitive or cyclic loads with constant or variable amplitudes. In this analysis constant amplitude as shown in Figure 13 Failure of part during accident on traffic road by ayoub el amri," n.d.). With fully reversal cyclic loads are used.

Where,

Minimum stress, $\boldsymbol{\sigma_{min}}$ Maximum stress, $\boldsymbol{\sigma_{max}}$Stress range, $\boldsymbol{\sigma_r}$Alternating stress, $\boldsymbol{\sigma_a}$Mean stress, $\boldsymbol{\sigma_m}$Stress ratio, **R**(Fatemi, n.d.)

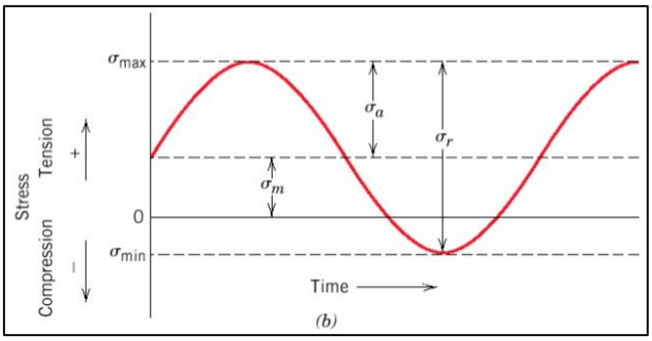


Figure 13: Typical constant amplitude loading

Stresses can be replaced with load, moment, torque, strain, deflection, or stress intensity factors.

R= -1 and R= 0 are two common reference test conditions used for obtaining fatigue properties.

- R= -1 is called the fully reversed condition since, σ_{min}= -σ_{max} and
- R = 0, where σ_{min} = 0, is called pulsating tension.

Unit cycle is the littlest section of stress vs time history that is recurred periodically.

- The statement of one cycle is not clearly defined in variable amplitude loads and therefore the stresses are frequently reversed.
- But in case of loads for constant amplitude, one complete cycle is equivalent to two turnarounds.

In this analysis, Minimum stress,σ_{min}= **-350 lbs or -1556.88 N**

Maximum stress, σ_{max}= **+350 lbs or +1556.88 N**

Therefore, Stress ratio, R = $\sigma_{min}/\sigma_{max}$ = -1, Number of cycles applied = 100000 cycles

3.6 Fatigue Analysis Results

After running the fatigue analysis, the predicted life of the component was found to be 69,158 cycles which is below the requirement of 100000 cycles at fillet or neck region of component indicated in red color as shown in the figure 15.

Understanding fatigue plots: Consider the typical SN curve for any given material as shown in Figure 14 [5]. The Solid works program finds the rectified alternating stresses on each nodal stress value in static study established on loading ratio. ΔN = Cycles range and Δσ = stress range [6].

- Fatigue failure is predicted at a position, where the green point with respect to figure 14, lies above the red curvature.
- Fatigue failure does not happen at the location where the green dot dwells below the curve.
- If the green point lies beyond the SN curve range. then the prominent adjusted alternating stress in the model should be within the SN curve stress range. Moreover, the number of cycles, N must lie within the SN curve cycle range. If not, the solid works program uses SN curve's end point rather than the intersection point.

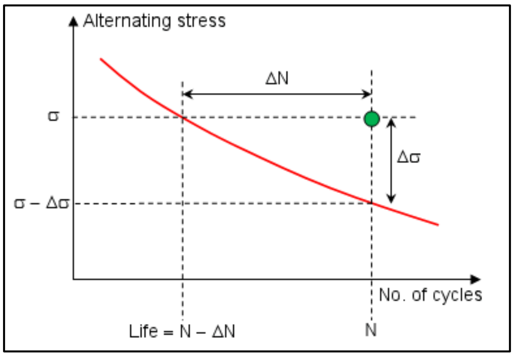


Figure 14: Typical SN curve for any given material

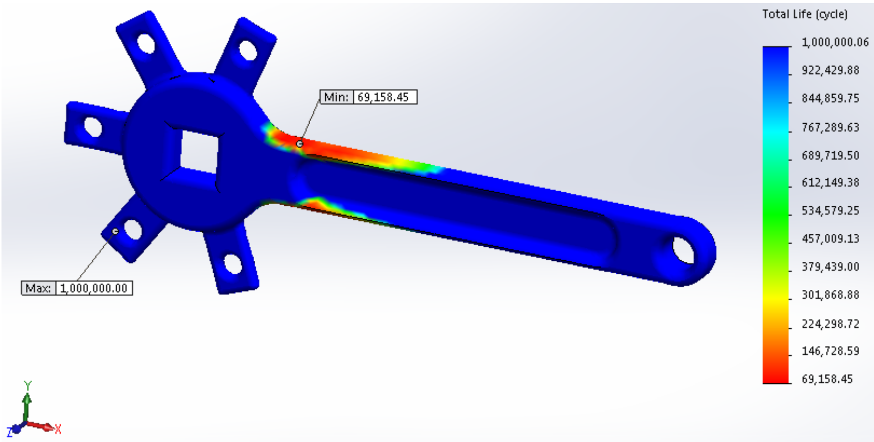


Figure 15: Plot of total life of component and failure affected area

Total life is the total number of cycles that leads to failure at a location in a model [7]. In the graph figure 13, the location is the convergence point between Stress which is a horizontal line and SN curve. Life = N – ΔN

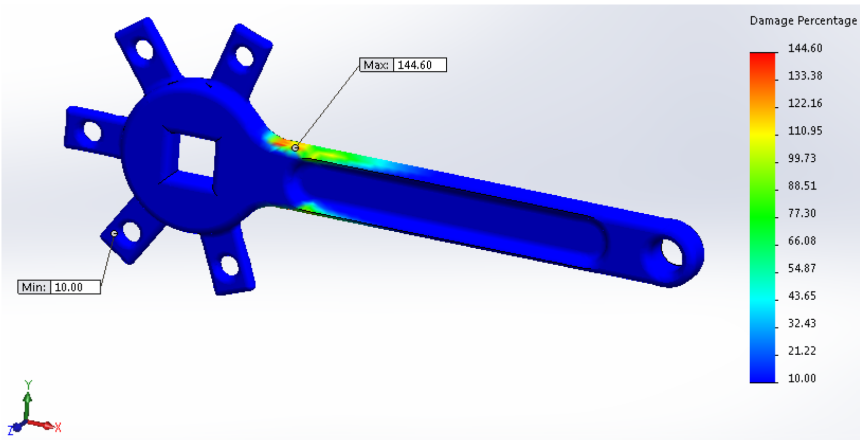


Figure 16: Plot of damage percentage of component and failure affected area

The damage percentage of a component is the representation of life in percentage, which is number of cycles consumed. Damage = N/(N - ΔN). One percent value signifies that the applied fatigue events observe 100 percent of life of the model at that point.

4. CONCLUSION

The designed component is failing under fatigue analysis at 69,159 cycles and does not meet the requirement of 100,000 cycles of fatigue life. From figure 15 the location of the failure is at the neck area which is critical to fatigue loads and cracks at that region. In order to avoid failure, solutions can be that the neck curve radius be increased or the step in the middle of crank arm can be removed or even different material with better properties can be chosen for the same design. Solutions to this failure are many, depending upon the cost and resource availability one has to decide the solution according to the convenience.

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