# ICMERE2019-PI-059

# NUMERICAL INVESTIGATION ON FATIGUE LIFE ESTIMATION OF ALUMINUM STRUCTURE FOR UNIAXIAL CYCLIC LOADING BY FINITE ELEMENT MODELING

Md. Jarir Hossain[1], Md. Mahbubur Rahman[2] , Fahim Islam Anik[3], MD Ikramul Hasib[4], Abdullah Arafat[5], Dewan Wardy Hasan[6]

[1,2,3,4,6]*Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna9203, Bangladesh*
[2]*Department of Energy Science and Engineering, Khulna University of Engineering & Technology, Khulna9203, Bangladesh*
hossain1505069@stud.kuet.ac.bd; jarirkuet@gmail.com (Md. Jarir Hossain)

***Abstract***- *Fatigue analysis emphasizes on the cyclic behavior of a material and this often leads to crack initiation and propagation. In this research, the stress life method is being used to calculate the minimum fatigue life of different structure in Aluminum 6061 T6 material by Finite Element Modeling, also von mises stress is calculated. Furthermore, a bike crank arm design is used to validate the simulation process of fatigue calculation for uniaxial loading. Where the stress distribution throughout the body of a bike crank arm indicates the scopes of improvement in the design. By applying the theory for minimizing stress, few case studies are done based on different design modifications. In conclusion, one of the case studies, the result is found that minimum fatigue life increases 10.89 times than the one which is being used for validation and the same design is currently used in the industry.*

**Keywords:** Fatigue Life Simulation, Fatigue, Stress Life Analysis, SN Curve, Bike Crank

## 1. INTRODUCTION

When it is subjected to repeated loading, a structure can fail below its monotonic strength, this is known as fatigue. Early in the 19th century, mysterious properties were shown, where fatigue fracture did not show visible plastic deformation. With higher amplitudes of loading, a structure may fail with a lower number of cycle and the same structure also can fail with a higher number of cycle with lower amplitudes of loading. There are three different methods to evaluate fatigue life, these are, stress life method, strain life method and using the Linear Elastic Fracture Mechanics method [1,3]. From the mentioned three methods, the stress life method will be used which is suitable for High Cycle Fatigue and is highly used in industries. (Generally, the point in material curve where slope suddenly falls) [2]. Uniaxial load is the force that acts in a single direction only. In this type of loading, the cross-sectional area faces a tensile stress and strain. On the other hand, in multiaxial loading, force acts in different directions Crank arm transfers the force exerted from one component to another, so there remains a possibility to visualize crack the crank arm. In motorcycles, a crank arm balance the vehicle while in motion. The failure in this component will result in a massive accident. The cracks initiate from cyclic loading or varying loads, which never causes failure with single-cycle [1, 4, and 5]. This process consists of different phases, creation of crack, extension of crack and finally fracture. In this research, minimum fatigue life estimation of motorcycle crank arm will be done, and different geometry will be proposed which will show a better minimum fatigue life. In this research, Aluminum

6061 – T6 material will be used. This material is used in the industrial crank arm [1].

## 2. VERIFICATION

In paper number [1] at the reference, a simulated study on bicycle crank was done by Solidworks. So, the attempt is made to simulate the same uniaxial test using Ansys. The same model in the reference paper is used for verification, there was some missing data for geometry, and those data were assumed. The specimen dimensions are given below.

### 2.1 Material Properties:

The material used for this simulation is Aluminum 6061 – T6. All the materials properties and SN Curve data is being represented into the following four figures:

| | | |
|---|---|---|
| Density | 2768 | kg m^-3 |
| Isotropic Secant Coefficient of Thermal Expansion | | |
| Coefficient of Thermal Expansion | 1.3333E-05 | F^-1 |
| Reference Temperature | 71.6 | F |
| Isotropic Elasticity | | |
| Derive from | Young's Modulus an... | |
| Young's Modulus | 1.0008E+07 | psi |
| Poisson's Ratio | 0.33 | |
| Bulk Modulus | 6.7647E+10 | Pa |
| Shear Modulus | 2.594E+10 | Pa |
| Field Variables | | |
| Temperature | Yes | |
| Shear Angle | No | |
| Degradation Factor | No | |
| Alternating Stress Mean Stress | Tabular | |
| Interpolation | Semi-Log | |

**(a)**

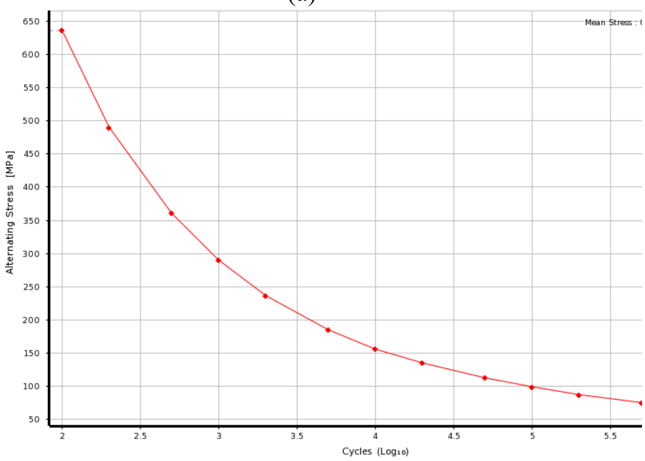
| | | | | |
|---|---|---|---|---|
| 16 | ⊟ Alternating Stress Mean Stress | Tabular | |
| 17 | Interpolation | Semi-Log | |
| 18 | Scale | 1 | |
| 19 | Offset | 0 | MPa |
| 20 | ⊟ Strain-Life Parameters | | |
| 21 | Display Curve Type | Strain-Life | |
| 22 | Strength Coefficient | 534 | MPa |
| 23 | Strength Exponent | -0.082 | |
| 24 | Ductility Coefficient | 4.49 | |
| 25 | Ductility Exponent | -1.1 | |
| 26 | Cyclic Strength Coefficient | 369 | MPa |
| 27 | Cyclic Strain Hardening Exponent | 0.039 | |
| 28 | Tensile Yield Strength | 44962 | psi |
| 29 | Compressive Yield Strength | 0 | psi |
| 30 | Tensile Ultimate Strength | 300 | MPa |
| 31 | Compressive Ultimate Strength | 0 | Pa |

**(b)**

**Fig. 1:** Material properties used for simulation

| | B | C |
|---|---|---|
| 1 | Cycles | Alternating Stress (MPa) |
| 2 | 100 | 636.36 |
| 3 | 200 | 490.07 |
| 4 | 500 | 360.85 |
| 5 | 1000 | 290.14 |
| 6 | 2000 | 236.5 |
| 7 | 5000 | 185.3 |
| 8 | 10000 | 156.04 |
| 9 | 20000 | 135.32 |
| 10 | 50000 | 112.89 |
| 11 | 1E+05 | 99.477 |
| 12 | 2E+05 | 87.53 |
| 13 | 5E+05 | 75.583 |
| 14 | 1E+06 | 69 |
| * | | |

(a)




(b)

**Fig. 2** (a) SN Curve Data for Al 6061 T6 (b) SN Curve for the same material

### 2.2 Meshing & Boundary Conditions:

The mesh element size was 0.307107 inches this number is given in the paper, and 8895 elements were found from the geometry.

Boundary conditions were also maintained as the reference paper. 5 points were taken as fixed support and 1556.8 N bearing loads were used in the negative z-direction.

### 2.3 Verification Results

Maximum Equivalent von misses stress obtained is 138.69MPa.

Minimum life found from this geometry is 17865 cycles and fully reversed loading

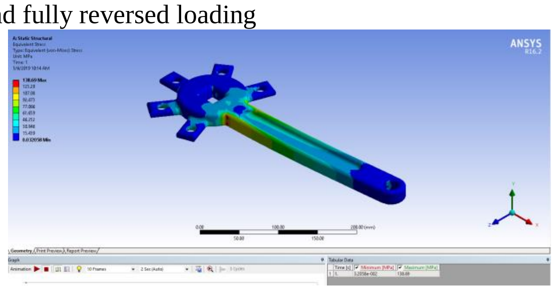



**Fig. 3:** Bike Crank Arm (Stress Analysis)

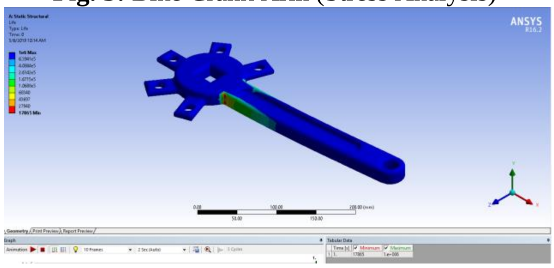



**Fig. 4:** Bike Crank Arm (Fatigue Life Estimation)

### 2.4 Validation

| Parameters | Solidworks | Ansys |
|---|---|---|
| Maximum Stress(MPa) | 106.61 | 138.69 |
| Minimum Life Cycle(Number of Cycles) | 69158 | 17865 |

There was some difference obtained from two results. The possible reasons for this difference are given below:

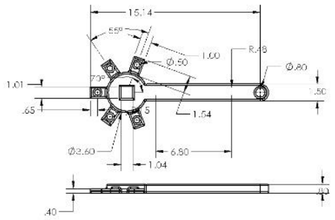
1. One dimension at the geometry is being assumed because of the lack of data.
2. Two different Finite Element Modelers are being used. That is why two different element numbers are being found for the same element size.

Because of these above-mentioned reasons, two different results were being obtained. Though the result found is accurate. Because similar data can be obtained from the same SN Curve.

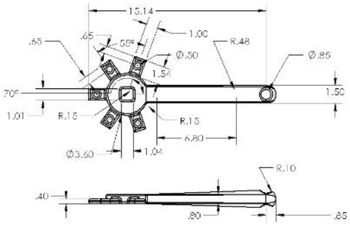
So we can validate the software for Uni-Axial Cyclic loading fatigue analysis

## 3. CASE STUDY

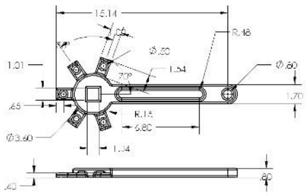
**3.1 Introduction:** The model used for validation purposes is an industry-standard bicycle crankcase. Here, some different geometry is proposed where better fatigue life can be obtained. Different modeled geometry is discussed in the following sections,



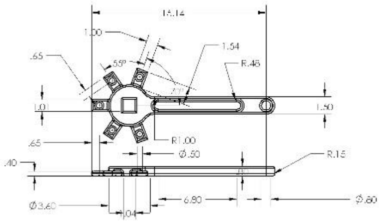
(a)



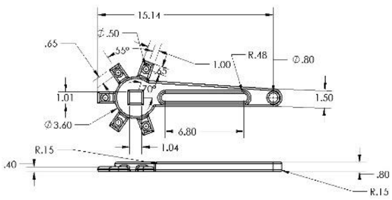
(b)



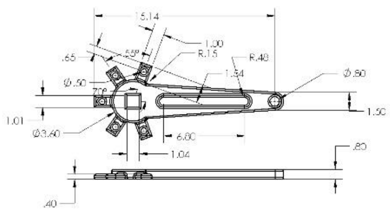
(c)



(d)



(e)



(f)

**Fig. 5:** Geometry Dimension (a) CS1 (b) CS2 (c) CS3 (d) CS4 (e) CS5 (f) CS6

CS-1. The step in the crankcase is being removed.

CS-2. The crankcase cross-section is changed to a circular cross-section.

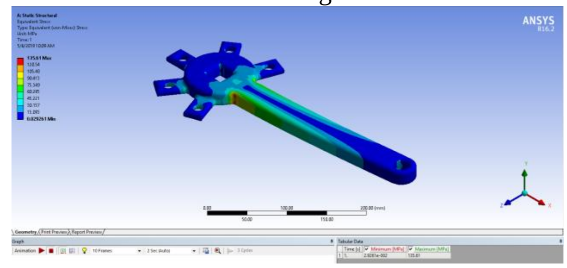
CS-3. The width of the part where load is applied is being increased to 1.70 inches.

CS-4. The curve angle is being reduced.

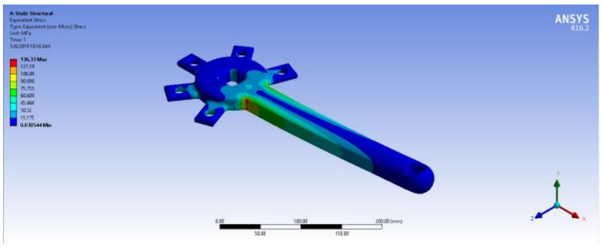
CS-5. Material volume is increased on one side of the step where minimum fatigue life was found.

CS-6 Material volume is increased on both sides of the step where minimum fatigue life was found.

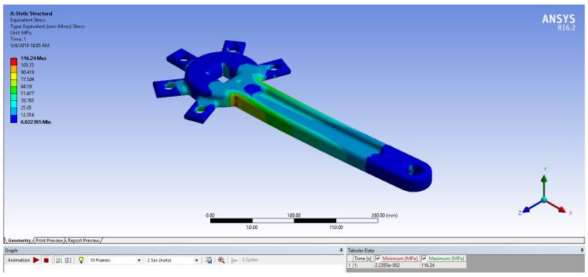
**3.2 Stress Results:** Stress distribution results obtained from the case studies is given below



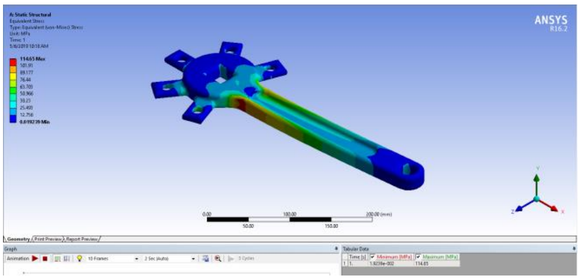
(a)



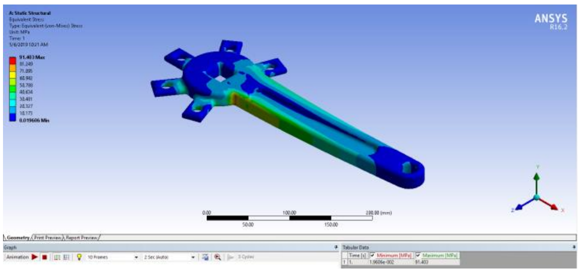
(b)



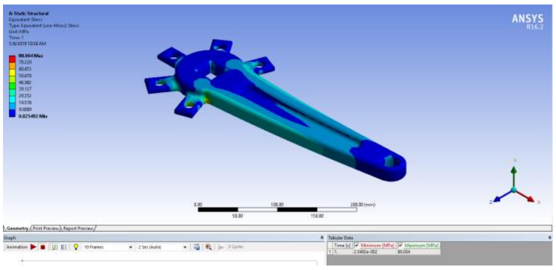
(c)



(d)



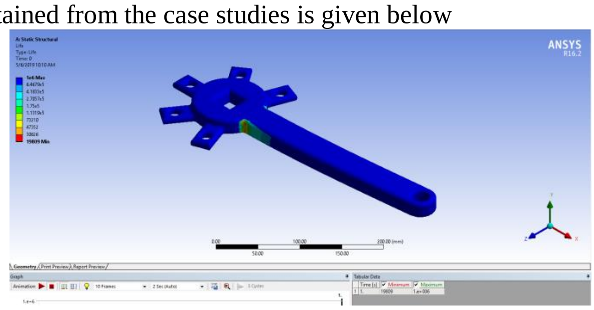

(e)



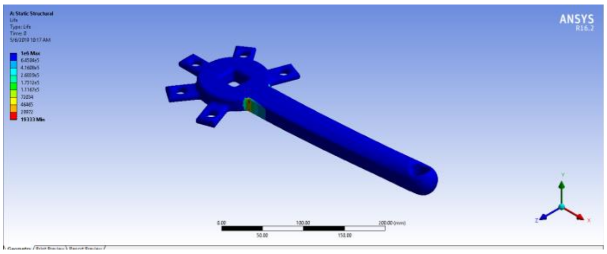

(f)

**Fig. 6:** Static Analysis Result for different case studies (a) CS1 (b) CS2 (c) CS3 (d) CS4 (e) CS5 (f) CS6

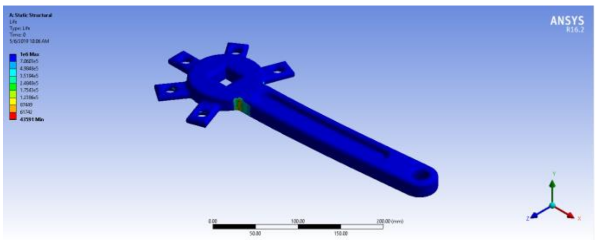
**3.3 Fatigue Life Results:** Fatigue life results obtained from the case studies is given below



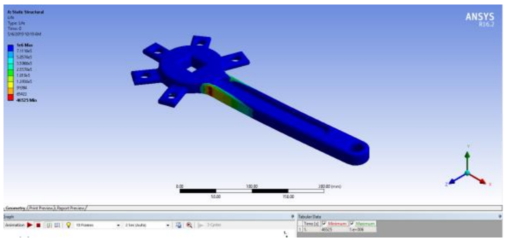

(a)



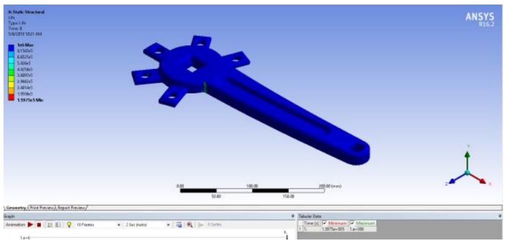

(b)



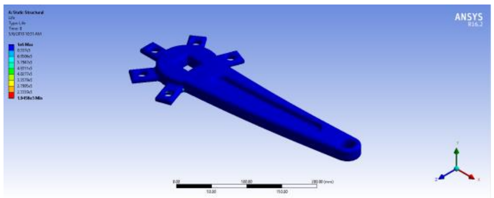

(C)




(d)




(e)




(f)

**Fig.7:** Fatigue Life Estimation for different case studies (a) CS1 (b) CS2 (c) CS3 (d) CS4 (e) CS5 (f) CS6

## 4. Result

### 4.1 Result Overview

| Observation Number | Maximum Stress( MPA) | Minimum Fatigue Life |
|---|---|---|
| Geometry obtained from reference | 138.69 | 17865 |
| CS-1 | 135.61 | 19809 |
| CS-2 | 136.33 | 19333 |
| CS-3 | 116.24 | 43591 |
| CS-4 | 114.65 | 46525 |
| CS-5 | 91.40 | 159750 |
| CS-6 | 88.00 | 194580 |

### 4.2 Result Discussion

Here it is found that every design discussed and simulated in this case study shows better results in minimum fatigue life. If all the design geometries are combined with one single geometry, it could show better results.

## 5. Conclusion

A verification of software has been made through Ansys. The result was satisfactory. The model is being used in the industry now. So several changes have been made to the neck area and fatigue life estimation simulation has been performed. Where satisfactory results have been found. In six different case studies, decreased maximum equivalent stress and minimum fatigue life has been found. The maximum result was 10.89 times from the geometry which is used in industry. Now the proposal is to combine all these case studies for a unique geometry to get a better result. As well as, better results can be found by replacing materials that have a higher slope in the SN curve.

## REFERENCES


[1] Madivalar, C. N., Shay, T., & Kolekar, S. (n.d.). FATIGUE FAILURE ANALYSIS OF BIKE CRANK ARM USING SOLIDWORKS SIMULATION. Retrieved 2018

[2] Fatemi, A. (n.d.). Chapter-4 - Fatigue Tests and Stress-Life (S-N) APPROACH.

[3] Mishra, S. K., Dutta, K., & Ray, K. K. (2018). Fatigue life estimation in presence of ratcheting phenomenon for AISI 304LN stainless steel tested under uniaxial cyclic loading.

[4] Bressar, S., Ogowa, F., & Itoh, T. (2019). Cyclic plastic behavior of additively manufactured Ti-6Al-4V under uniaxial and multiaxial non-proportional loading.

[5] Liu, T., Zhang, J., & Fei, B. (2019). Crack initiation and propagation of 30CrMnSiA steel under uniaxial and multiaxial cyclic loading.