Fatigue Life Analysis of Rectangular Plate with Central Hole using Finite Element Method

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Abstract - *Conducting the fatigue life through testing is expensive and time consuming. In present product development scenario, the validated numerical simulations are considered to be one of the reliable source of preliminary fatigue life estimation. Fatigue damage phenomenon can be found by numerical simulations. Present study demonstrates the finite element methodology adopted for accurate prediction of fatigue life and fatigue damage of a medium strength steel plate with hole at the centre. Fatigue life estimation can be found by crack initiation approach. Strain-life criterion is applied and number of cycles to crack initiation has been computed using Morrow's equation. Fatigue life predicted is in close agreement with the experimental results from literature. Maximum 3% of deviation has been observed when compared with experimental results. Finite element methodology can be further extended to evaluate fatigue life for the same structural element under variable amplitude loading. Cumulative fatigue life and damage under variable amplitude loading has been estimated using Miner's rule. Methodology used is generic in nature and can be used for estimation of fatigue life of real time structural components with complex geometries under a constant or variable amplitude loading.*

Key Words: **Fatigue life, Fatigue damage, Strain-life criterion.**

1. INTRODUCTION

This document is template. Finding the fatigue life through testing is expensive and time consuming affair. In product development scenario, validated numerical simulations are considered to be one of the reliable sources of preliminary fatigue life estimation. Numerical simulations may not prove to be a complete replacement to the fatigue testing but they can provide a detailed insight into the fatigue damage phenomenon. Present study demonstrates the finite element methodology adopted for accurate prediction of fatigue life and fatigue damage of a medium strength steel plate with hole at the centre. Crack initiation approaches have been used for fatigue life estimation. Strain-life criterion is applied and Morrows equation is used to compute number of cycles to crack initiation. Fatigue life predicted is in close agreement with the experimental results from literature. Maximum 3% of deviation has been observed when compared with experimental results [1].Finite element methodology demonstrated in this work is further extended to evaluate fatigue life for the same structural element under variable amplitude loading. Cumulative fatigue life and damage under variable amplitude loading has been estimated using Miner's rule. Methodology used is generic in nature and can be used for estimation of fatigue life of real time structural components with complex geometries under a constant or variable amplitude loading [1].

Fatigue testing is a time consuming and expensive activity and most of the time it will be taken up in the last phase of product development. During fatigue testing if component fails to meet the specified intended life it needs to be redesigned and retested resulting in delay in the overall product development time.

Keeping in view the amount of time and money involved in the fatigue testing; fatigue analysis through numerical simulation has been proved to be an effective method for fatigue life and damage prediction [2]. Accurate fatigue life estimation plays a crucial role in ensuring structural integrity of the component throughout its intended operational life.

Present work demonstrates finite element methodology followed for predicting fatigue life of the rectangular plate with hole up to crack initiation and assessment of fatigue damage. Estimation of fatigue life has been done based on Strain-life criterion. Morrow.s equation has been used to calculate the fatigue life under constant amplitude cyclic loading [1].

Fatigue life so estimated has been used to determine fatigue life under variable amplitude loading. Continuum damage law has been applied for predicting cumulative damage under variable amplitude loading.

1.1 Strain life approach for fatigue life estimation

Widely used strain based approach has been adopted for fatigue life estimation. From the experimental data available on fatigue it has been observed that the fatigue behaviour of a material can be accurately characterized by cyclic strain curves, plotted under constant amplitude, completely reversed straining with constant strain rate.

Also it has been observed that the failure initiates at local plastic zones, crack nucleates and grows to a critical size due to plastic straining in localized zones. Hence a local strain based approach with a material model which captures cyclic stress strain behaviour has been selected for the present work. Elastic, plastic and cyclic stress-strain behaviour of the material has been captured using appropriate material model. Cyclic stress strain data available in literature [1] established using Romberg Osgood relationship has been used for cyclic strain computation. Surface finish effect has been accounted by including appropriate surface roughness values in to the fatigue model. Morrow.s model which deals with mean stress effect has been used for accurate fatigue life prediction.

2. FATIGUE ANALYSIS USING FINITE ELEMENT METHOD

Fatigue analysis has been carried out in three phases using

1. Static stress analysis under given cyclic loading.

2. Estimating the fatigue life.

3. Finding the load so that the component can sustain for infinite number of cycles.

Maximum stress value is obtained by carrying out static analysis using commercially available ANSYS software.

For carrying out the static stress analysis elasto-plastic material model has been used in order to capture the stresses for range of loadings.

2.1 Estimating the fatigue life

This is the second phase in the fatigue analysis.

Strain based approach has been used for fatigue life estimation. Morrow.s criterion which deals with the mean stress effect has been applied for accurate fatigue life estimation. Strain range results obtained from first phase using Romberg-Osgood equation has been used to estimate cycles to crack initiation.

3. PROBLEM DEFINITION:

Fatigue analysis of a steel plate with hole at the centre

Fatigue life assessment is carried out for medium strength steel 100 mm long x 25.6 mm wide x 7.68 mm thick plate with a hole of diameter 12.8 mm at the centre. The plate geometry under consideration is shown in Fig.1

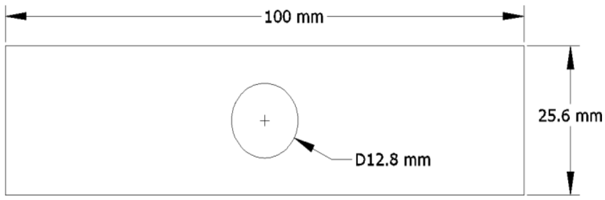

Fig-1: Geometrical details of specimen

Mechanical properties of medium strength steel used during analysis have been tabulated in Table 1.

Plate having a central hole of diameter 12.8 mm is subjected to uni-axial completely reversed cyclic loading i.e. stress ratio(R) = -1.

Table 1: Material properties for Medium strength steel

Static Properties

Modulus of Elasticity (MPa)	206900
Poisson's ratio ...	0.32
Yield Stress (MPa) ...	648.3
Ultimate Stress (MPa) ...	786.2

3.1 Finite element modeling

The specimen with hole at the centre is modeled using three dimensional deformable solid elements.

Model has been meshed with 8-node linear brick elements available in ANSYS software. The mesh size and mesh pattern has been finalized based on the convergence studies carried out before proceeding for the full analysis.

Series of analysis have been carried out for various uni-axial constant amplitude cyclic loadings compiled at Table 2[1].

Loads have been applied along length direction of the plate FE Model and Mesh details of the specimen are as shown in Fig.2

Table 2: Load data

Sl. No	Load (kN)
1	62.25
2	56.29
3	53.89
4	47.39
5	40.18
6	40.14
7	31.14
8	25.27
9	22.02
10	20.92

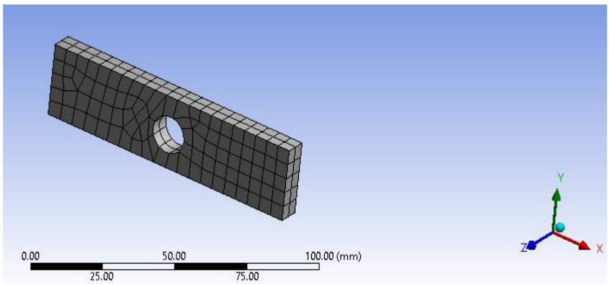

Fig-2:FE Model of the specimen

4. RESULTS

The following figures will give the results of vonmises stress and fatigue life for various loading conditions.

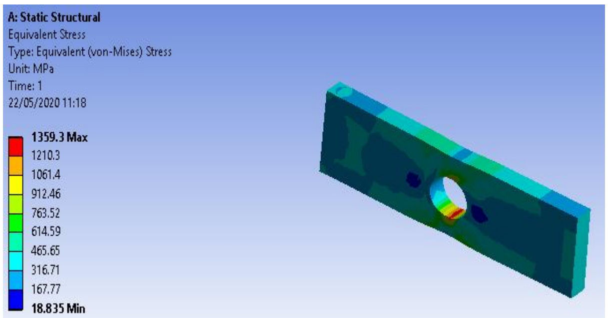

Fig-3: Vonmises stress of 1359.3KN/mm2 for a load of 62.25KN

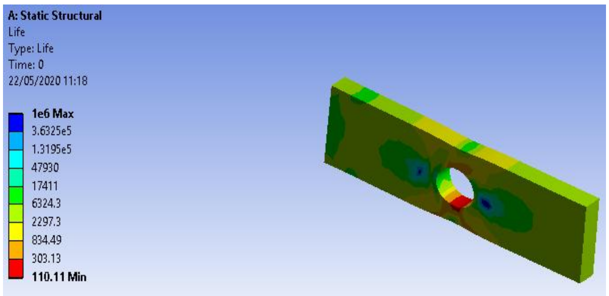

Fig-4: Fatigue life of 110.11 for a load of 62.25KN.

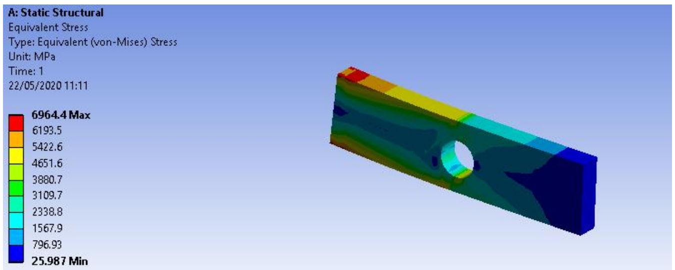

Fig-5: Vonmises stress of 6964.4KN/mm2 for a load of 56.29KN

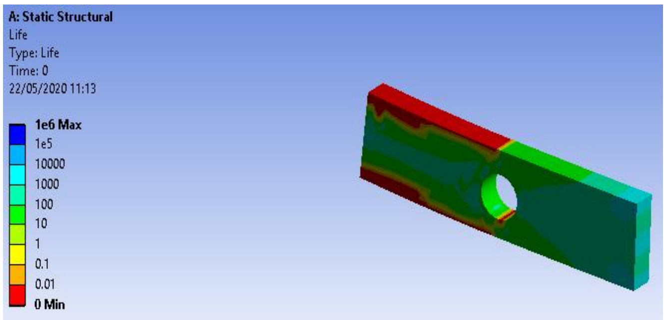

Fig-6: Fatigue life of 0 for a load of 56.29KN.

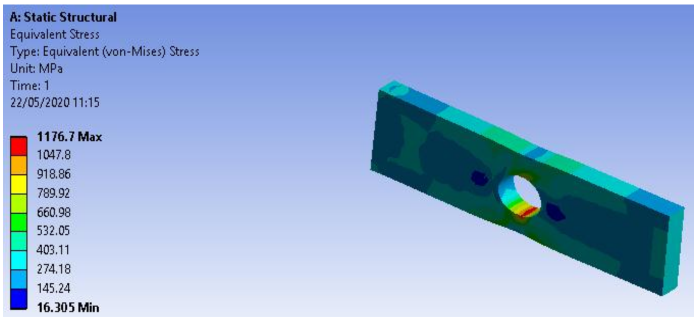

Fig-7: Vonmises stress of 1176.7KN/mm2 for a load of 53.89KN.

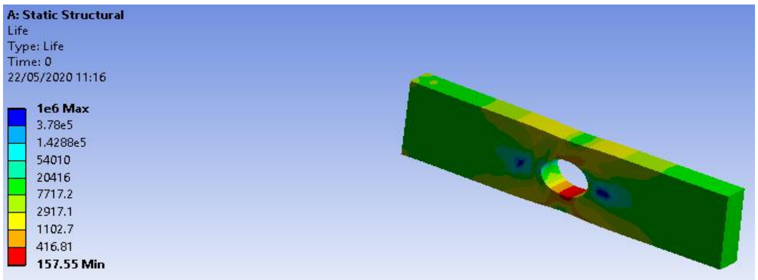

Fig-8: Fatigue life of 157.55 for a load of 53.89KN.

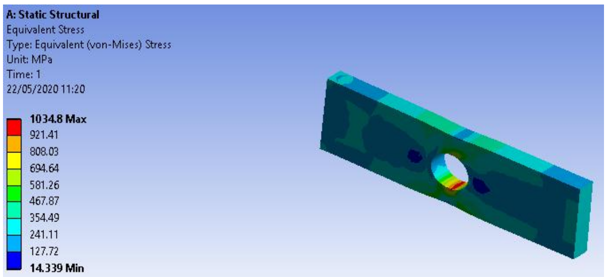

Fig-9: Vonmises stress of 1034.8KN/mm2 for a load of 47.39KN

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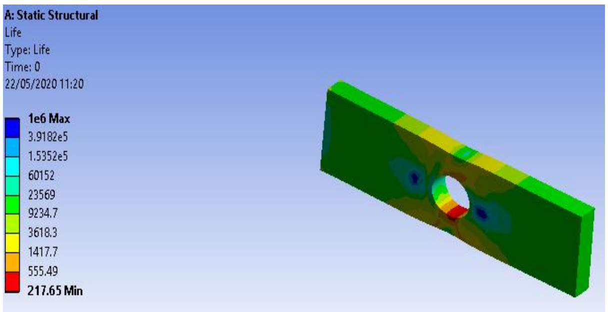

Fig-10: Fatigue life of 217.65 for a load of 47.39KN.

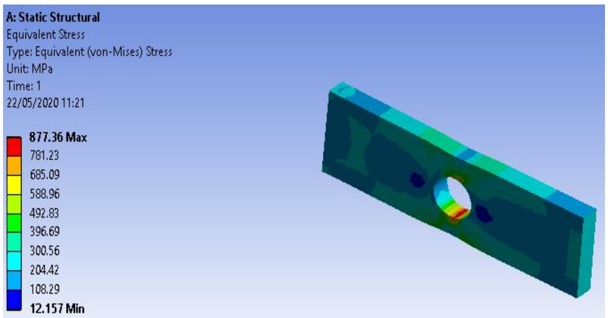

Fig-11: Vonmises stress of 877.36KN/mm2 for 40.18KN load

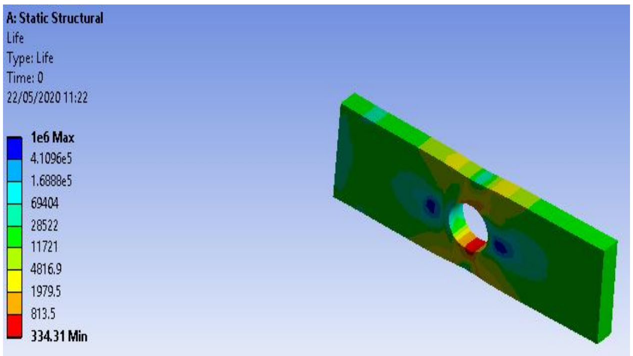

Fig-12: Fatigue life of 334.31 for 40.18KN load.

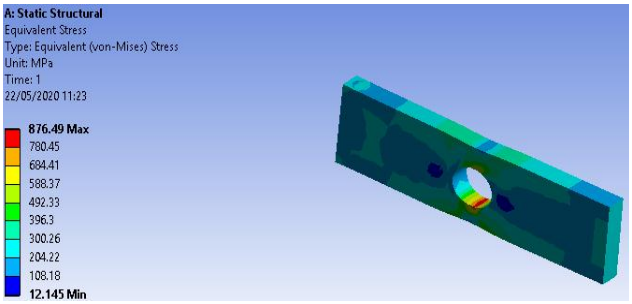

Fig-13: Vonmises stress of 876.49KN/mm2 for 40.14KN load

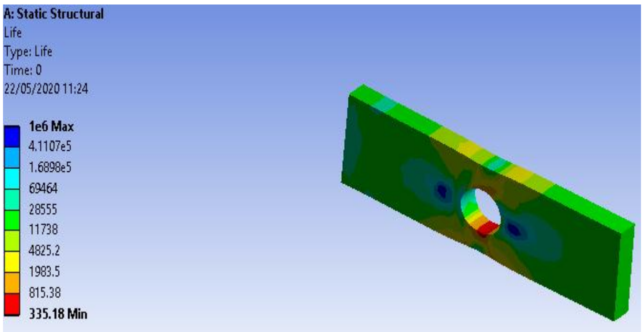

Fig-14: Fatigue life of 335.18 for 40.14KN load

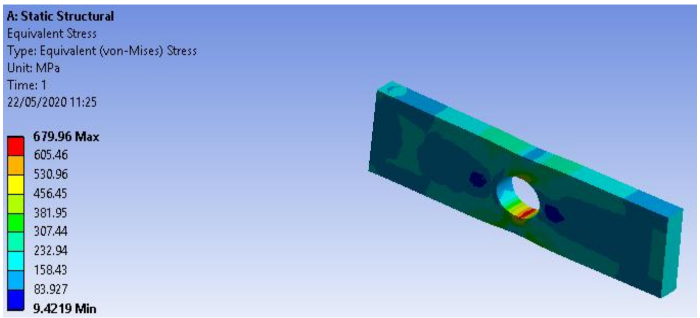

Fig-15: Vonmises stress of 679.96KN/mm2 for 31.14KN load

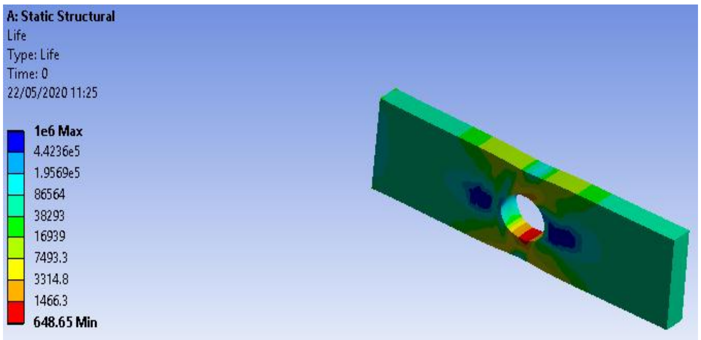

Fig-16: Fatigue life of 648.65 for 31.14KN load.

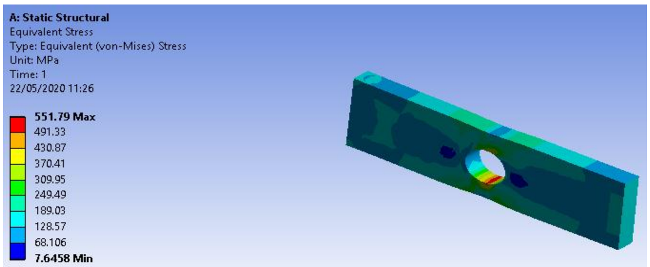

Fig-17: Vonmises stress of 551.79KN/mm2 for 25.27KN load

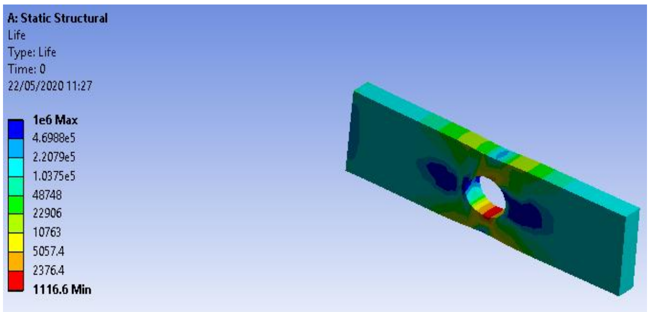

Fig-18: Fatigue life of 1116.6 for 25.27KN load

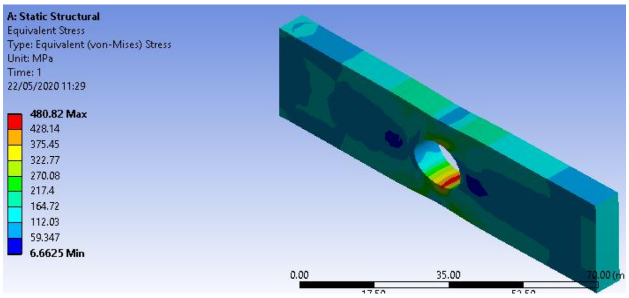

Fig-19: Vonmises stress of 480.82KN/mm2 for 22.02KN

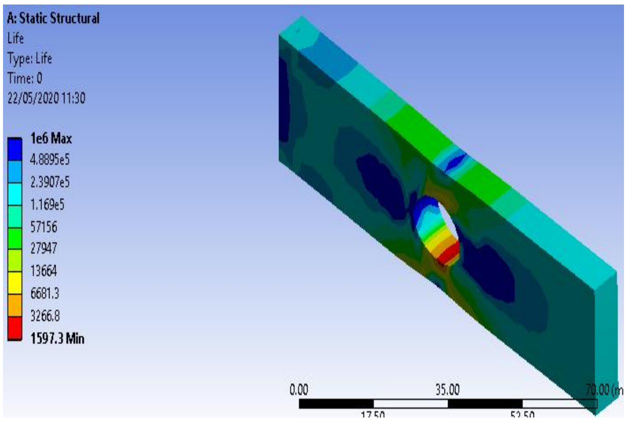

Fig-20: Fatigue life of 1597.3 for 22.02KN

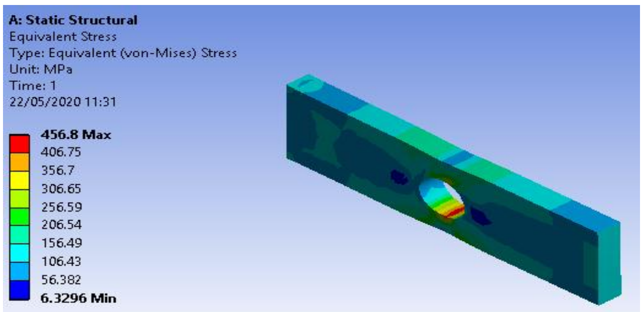

Fig-21: Vonmises stress of 456.8KN/mm2 for 20.92KN

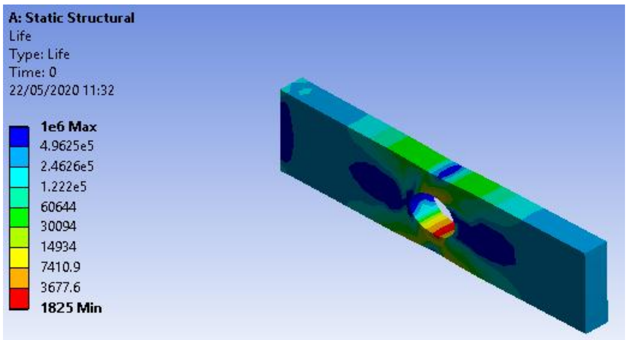

Fig-22: Fatigue life of 1825 for 20.92KN

Table 3: Load -Life-Stress data

LOAD (KN)	LIFE	VONMISES (KN/mm2)
62.25	110.11	1359.3
56.29	0	6964
53.89	157.55	1176.7
47.39	217.65	1034.8
40.18	334.31	877.36
40.14	335.18	876.49
31.14	648.65	679.96
25.27	1116.6	551.79
22.02	1597.3	480.82
20.92	1825	456.8

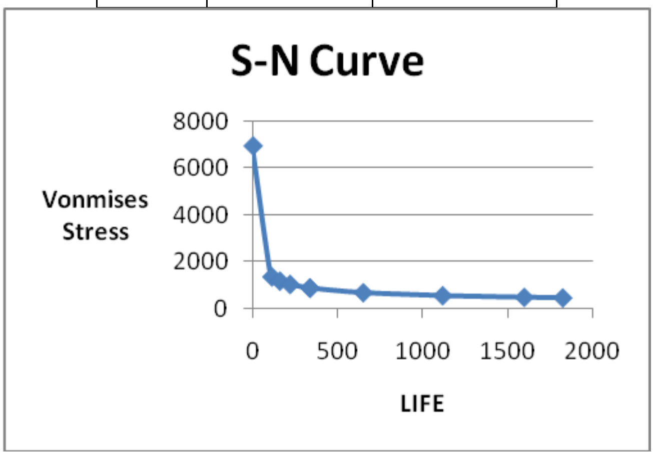

Fig-23: S-N curve for the different loads

As the stress decreases the fatigue life of the given specimen increases.

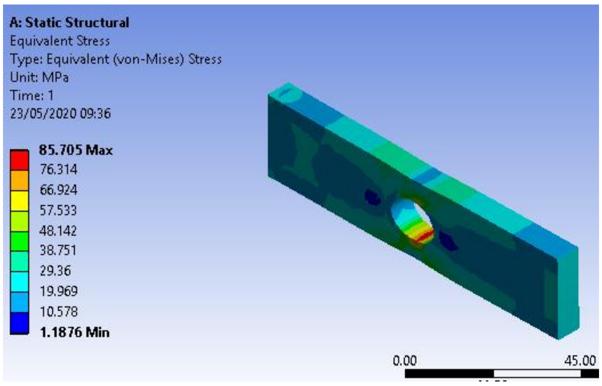

Fig-24: Vonmises stress of 85.705KN/mm2 for load of 3.925N

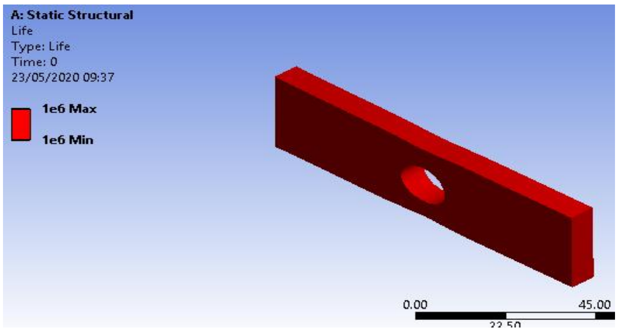

Fig-25: Infinite Fatigue life for load of 3.925N

4. CONCLUSION

The finite element formulation is used to study effect of different loads on the stress and life of the given specimen. The results obtained from finite element software are presented and discussed above. The conclusions that can be made from the present study are summarized as follows:

It has been observed that as the stress decreases the life of the given specimen increases and at a load of 56.29KN the life reduces to zero cycles.

In one more iteration ie at 3.925N load the component sustains for infinite life and hence 3.925N can be considered as safe load for infinite life (ie106 cycles).Hence for any component with any fatigue load the load for infinite life of the component can be found.

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