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DEPARTMENT OF MECHANICAL ENGINEERING

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PROJECT/ LAB : Design and Analysis of Fracture Behavior of Composite Beam

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SECTIONS:

No.	STUDENT OUTCOMES	COURSE LEARNING OUTCOMES	WEIGHT OF SECTION /100	MARKS OBTAINED	REMARKS
S-1	1	1	25		
S-2	1	2	25		
S-3	1	2	25		
S-4	1	3	25		
TOTAL:(Out of 100)					

Instructions:

1. No Late Submissions accepted.
2. Please include the equations, diagrams, plots and figures in the report.
3. Please include the standards and manufacturer's data of the components in the Appendix.
4. All the sources of data, equations, diagrams, plots and figures used from must be cited.
5. Please provide the references and cite each reference in the text.
6. All references must be cited in APA format.
7. The file/folder uploaded should be named as **[MENG424-PROJECT-STUDENT ID-STUDENT NAME]** Files with any other name or format will be disregarded.
8. Please submit the **pdf Soft copy of the report** via the **MOODLE LMS**/ **Microsoft Assignment** along with the **MATLAB codes, Simulink etc**.
9. **Conditional to University Opening:** All the work carried out should be burn on CD/DVD and submitted together with hardcopy of the report. otherwise softcopy via Microsoft Teams Assignment.
10. Do not forget the cover page.

Student Outcomes:

1	**an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics**
2	an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3	an ability to communicate effectively with a range of audiences
4	an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5	an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6	an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7	an ability to acquire and apply new knowledge as needed,

		using appropriate learning strategies.

ABSTRACT

Deflections of linear two-material composite beams with rectangular cross-sections and singular force acting from the free endpoint were investigated in this study. Large displacements in carrier systems that occur under various loads are a well-known topic, and numerous studies have been undertaken on the subject. Materials have a stress amplitude(s) value; at stress amplitude values below this value, fatigue is not possible even if the material is subjected to an infinite number of stress cycles. When a material is continuously subjected to periodic stress, depending on the magnitude of the stress and the time subjected to stress, the material will fracture even if the applied stress is below the maximum tensile strength of the material. This is called fatigue. Each material has a limit of resistance to fatigue until it changes from elastic deformation to plastic deformation. The equations the result is based on are a dimensionless parameter that can be written using the load, beam length, material cross-sections, and elasticity modulus. Studies on this topic are still ongoing today due to the relevance of the subject. The answers achieved by linearization can be adequately approximated in many circumstances encountered in various engineering domains. As a result, displacements may rarely be estimated using analytical methods, necessitating the employment of approximate and numerical approaches. Huge displacements in linear elastic cantilever beams with uniform and non-uniform, singular, and radiated charges have been studied extensively.

Keywords: Composite Beams, Fracture Behavior, Cyclic loads, Fatigue Life, Finite Element Analysis,

Introduction

There are several kinds of beams used in industries; one of them is cantilever beams. Cantilever beams are beams that are fixed by one end and carry the load on the other hand. Cantilever beams are used for construction the of buildings, bridges, towers, and machines (cranes). Tension is in the upper fiber and compression is in the lower fibers in cantilever beams and when the load is applied to the beam, the beam moves downwards. The bending moment of the cantilever beam is maximum on the fixed end and maximum on the free end. Because of that, major reinforcement was applied to the upper fiber on cantilever beams.

In the past years, numerous research have been done about composite materials many of them through numerical and experimental methods. Some of them include Inaba, Karmakar et.al [1] whose research on the analysis of the stiffness of delaminated composite beams using roller clamps concluded that the frequency increases with the ratio of delamination length to the total length. After that, the frequency decreases. Another similar study is, Truong V.H et al [2] which investigated the delamination growth in the curved composite beam at elevated temperatures. This study examined the delamination growth behavior of curved composite laminates at elevated temperatures. Other experiments investigated the fracture behavior of composite beams by analyzing the buckling of composite beams (Atlihan [3], Chen, Wang [4], C.W. Yap, G.B. Chai [5]). These experiments showcase the bending and behavior of beams under compressive loads. Yang, Bo et.al [6] study on the behavior of composite beam-column joints, is an informative article as it investigates failure modes and ductility of composite beams and shows that strengthened web cleat connections have a high load-carrying capacity.

The numerical model was designed based on axial compression ratio, concrete slab thickness, width-thickness ratio, column size, and beam depth. Nie, Jianguo et.al [12] study loading capacity for prestressed continuous steel-concrete composite beams and the prediction of the load characteristics based on crack, yield and ultimate load. Liang, and Wang [13] studied the debonding behavior of the piezoelectric materials. Their focus is put on crack initiation and growth of the piezoelectric adhesive interface. ANSYS is used for studying cracks of piezoelectric beams.

Bolted connection in composite materials has become popular over the years. Bolt fastening is one of the most commonly used methods to connect wood to wood and/or wood to steel. There is experimental research on this topic such as Wang X.D. et al [14] research on the experimental investigation into high strength bolted shear connections for simple on-site assembly of composite beams, Wang Wei [15]'s paper which explores the mechanical behavior of the advanced bolted shear connections embedded in steel and concrete composite beams.

Wang, Z., Wei, Y., Li, N. et al [16] published a study presenting a new type of bamboo–concrete composite beam with perforated steel plate connections. Wei Y et al [17] performed another experimental investigation of bamboo-concrete composite beams with threaded reinforcement connections. Though these experimental researches seem similar, a different connection was used and different results were acquired through similar tests.

Lokman Gemi et al [18] conducted research on the flexure performance of pultruded GFRP composite beams with damage analyses to determine the mechanical properties of the P-GFRP composite beams used in many engineering fields. The tests were conducted until fractural behavior occurred under large deflection. Lokman Gemi et al [19] also Researched the behavior of the pultruded GFRP composite beams infilled with hybrid fiber reinforced concrete under four-point loading. The specimens with hybrid bars exhibited the best performance in terms of energy dissipation capacity and maximum load capacity when reinforced concrete is used in the pultruded profile. Al-Fasih M. Y, Kueh, A. B. H, W, Ibrahim M [20] H investigated the effects of pre-existing static or impact damage on the flexural behavior of SHC beams under four-point loading and developed a load failure prediction equation that can determine whether a skin crack is the critical failure mode for a given beam geometry and initial crack length. Shariati M et al [21] and Zhang Yujie et al [22] in different experiments with different connectors carried out push-out tests to explore the shear behavior. Wei Hu et al [23] investigates the fracture mechanisms and the post-impact tensile behaviors of 2D-C/SiC beams and concluded that with the increase in impact velocity, the residual strength decreases. Lu, B., Zhai, C., Li, S. et al [24] investigated the flexural behavior of SC beams subjected to cyclic loading.

The SC beams subjected to cyclic loading experienced brittle fractures. This article also helps to show the design method for flexural behavior of SC structure and how the interfacial shear distribution of shear connectors affects the design. Some researches deal with adding reinforcement to the strengthen layers to significantly enhance the flexural capacity of the beam. Kaan, Torun I.B [25] investigated the flexural behaviors of highly reinforced composite beams with UHPFRC layer in the compressive side with an aim to obtain beams with high flexural capacity and ductility, thanks to the compressive strength and deformation capacity of UHPFRC. Öztürk Oğuzhan et al [26] investigated the performance of cyclic self-sensing behavior of reinforced composite beams produced with carbon fiber and carbon black in a hybridized form. Engineering properties and self-sensing assessments were simultaneously performed.

Experimental findings revealed that developed composite beams provided a reversible piezoresistive behavior under plastic regime although it was partially possible under the elastic regime. Wang Haitao et al [27] published a paper on dynamic performance of composite beam-column connections subjected to impact loadings where he concluded that the slab effect and connection type had a profound influence on the formation of catenary action of beam-column connections under the dynamic progressive collapse scenario. Liu et al [28] research on Structural behavior of isolated composite beam-slab system subject to elevated temperature showed that the slab with larger aspect ratio had tensile membrane action in earlier stage, greater the cross-sectional tensile forces and lower fire resistance because the failure mechanism changed from two-directional tensile membrane action to one-way catenary action.

In this paper, fracture analysis of composite cantilever beam is investigated. The material properties are investigated based on alternating stress, total deformation, fatigue life, fatigue damage, and Factor of Safety.

1.1 Finite Elemet Method

The Finite Element Method or Method (SEM, Finite Element Method, FEM) is a numerical technique used in engineering calculations to perform various analyzes of a substance with any physical quantity.

According to this method, there is a problem that needs to be solved, and in this problem, there is a structure that needs to be analyzed under certain conditions, and this structure is divided into a certain number of small pieces called finite elements, and it is aimed to test the mathematical 'behavior' of each piece in the subsequent analysis. For this, mostly formulas derived using partial differential equations are used.

1.2 Theory

Studying or analyzing a phenomenon with SEM is often called finite element analysis (FEA). This is achieved by discretization of a given space in space dimensions applied by creating a mesh of the object (numerical space for the solution with a finite number of points). The finite element method formulation of a boundary value problem eventually results in a system of algebraic equations. The method approximates the unknown function over the domain. The simple equations that model these finite elements are then combined into a larger system of equations that models the entire problem. SEM then uses variational methods from the calculus of variations to approximate a solution by minimizing an associated error function.

1.3 Applications of FEA

A process as above is followed from the most realistic state of a model until it becomes analyzable. Finite element analysis (SEA, Finite Element Analysis, FEA) allows detailed visualization of where structures are bent or twisted and shows the distribution of stresses and displacements. SEM software offers a wide variety of simulation options to control the complexity of both modeling and analysis of a system. Similarly, the desired level of accuracy and associated computation time requirements can be managed simultaneously to cater to most engineering applications. SEM ensures that all designs are built, refined, and optimized before the design is produced. The mesh is an integral part of the model and should be carefully controlled to give the best results. In general, the higher the number of elements in a mesh, the more accurate the solution to the discretized problem. However, there is one value where the results converge and further mesh improvement does not improve accuracy.

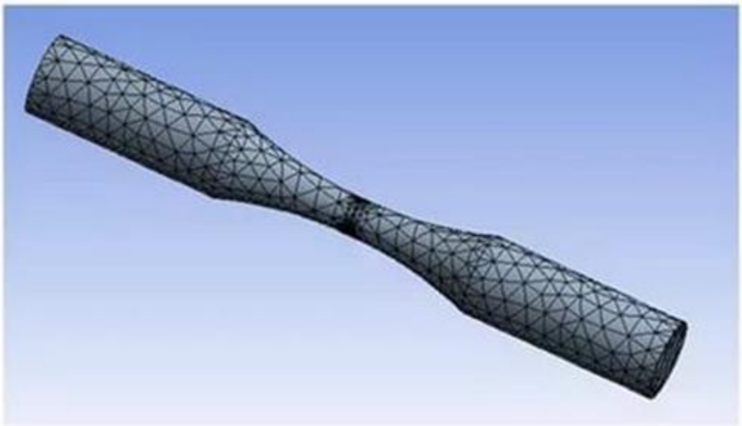


Figure 1. Specimen of mesh

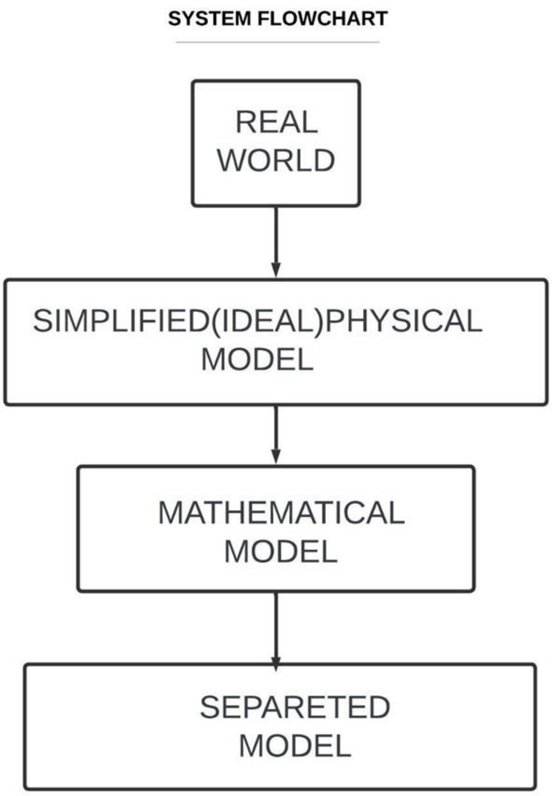


Figure 2. Flow chart system of FEM

2 Methodology

If there is a problem to be solved, and within that problem is a structure that needs to be analyzed under certain conditions, the Finite Element Analysis is applied. The structure is divided into a certain number of small parts referred to as finite elements, with the goal of the subsequent analysis to test the mathematical 'behavior' of each part.

A Cantilever beam is subjected to a load from one side and the fatigue behavior of is analyzed using Ansys workbench software.

2.1 Model of the beam

The dimensions of the single layer are 30mm X 300mm X 2200mm. The model was drawn in SOLIDWORKS and then imported into ANSYS.

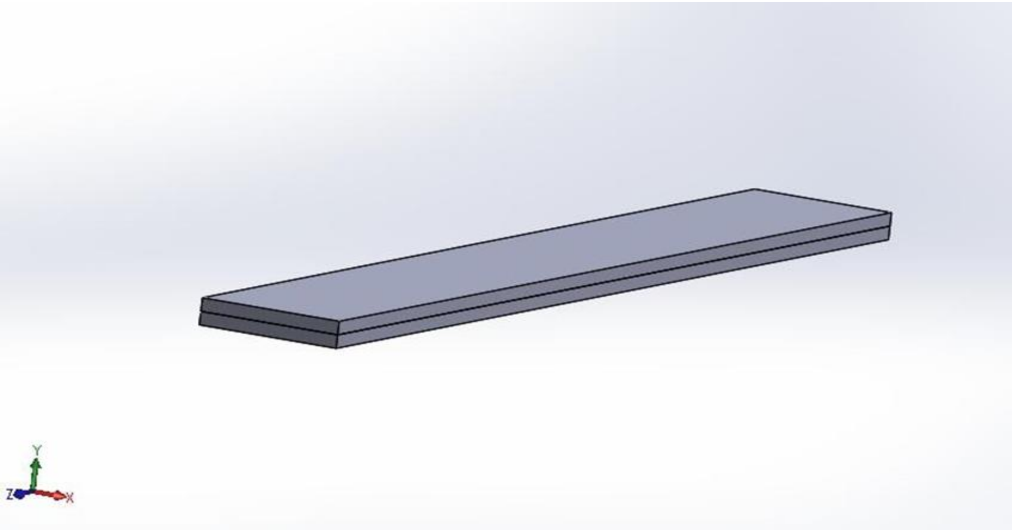


Figure 3. Model of the beam

Top layer of the beam material is structural steel. Bottom layer of the beam material is aluminum alloy.

Density	7.85e-06	kg/mm³

Structural		
Isotropic Elasticity		
Derive from	Young's Modulus and Poisson's Ratio	
Young's Modulus	2e+05	MPa
Poisson's Ratio	0.3	
Bulk Modulus	1.6667e+05	MPa
Shear Modulus	76923	MPa
Isotropic Secant Coefficient of Thermal Expansion	1.2e-05	1/°C
Compressive Ultimate Strength	0	MPa
Compressive Yield Strength	250	MPa

Figure 4. Structural steel properties

Density	2.77e-06	kg/mm³

Structural		
Isotropic Elasticity		
Derive from	Young's Modulus and Poisson's Ratio	
Young's Modulus	71000	MPa
Poisson's Ratio	0.33	
Bulk Modulus	69608	MPa
Shear Modulus	26692	MPa
Isotropic Secant Coefficient of Thermal Expansion	2.3e-05	1/°C
Compressive Ultimate Strength	0	MPa
Compressive Yield Strength	280	MPa

Figure 5. Aluminum alloy properties

Cycles	Alternating Stress [M Pa]
10	3999
20	2827
50	1896
100	1413
200	1069
2000	441
10000	262
20000	214
1e+05	138
2e+05	114
1e+06	86.2

Figure 6. Applied cycles and alternating stress values for structural steel

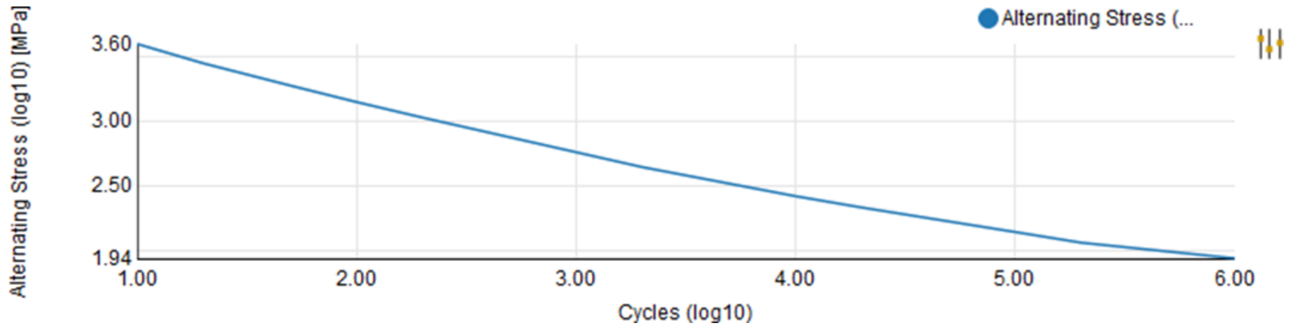


Figure 7. S-N Curve of structural steel

Cycles	Alternating Stress [M Pa]
1700	275.8
5000	241.3
34000	206.8
1.4e+05	172.4
8e+05	137.9
2.4e+06	117.2
5.5e+07	89.63
1e+08	82.74

Figure 8. Applied cycles and alternating stress values for aluminum alloy

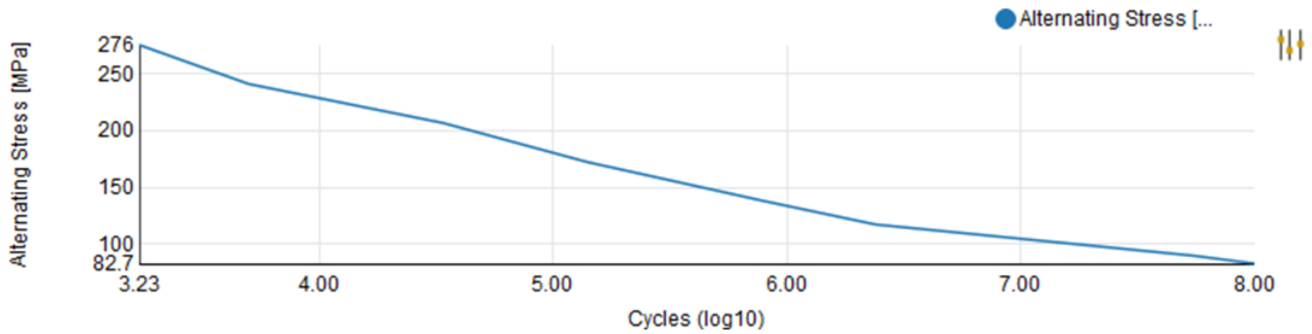


Figure 9. S-N curve of aluminum alloy

S-N curve defines the number of loads cycles to failure of material. This curve is important for us because it is used by program to calculate the damage in a fatigue analysis for each material.

2.2 Analysis

Some steps must be performed before fatigue analyze to the beam. These are:

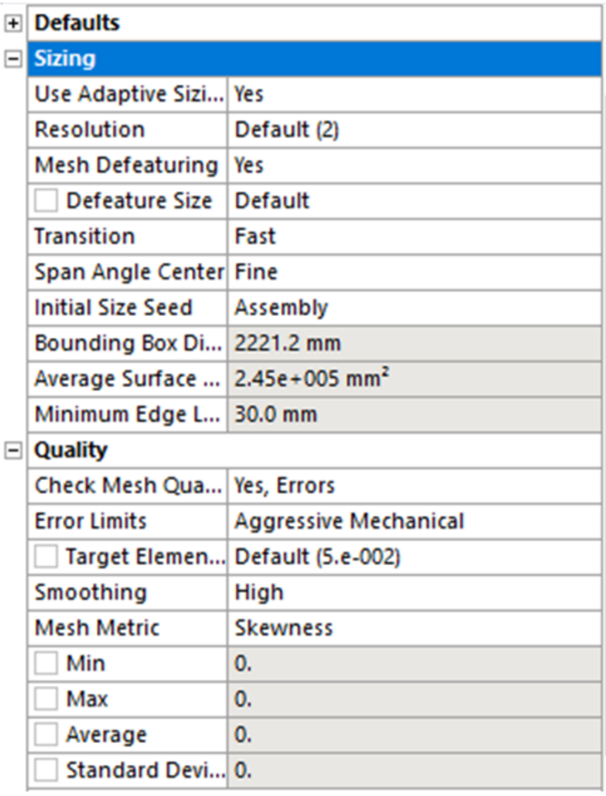
I. Mesh

II. Static Structural

III. Solution

2.2.1 Mesh

In the mesh settings, span angle center has been changed to FINE. Smoothing has been changed into HIGH and mesh metric setting adjusted into Skewness. Element size stayed at default. Figure below shows the changed mesh setting:



Defaults	
Sizing	
Use Adaptive Sizi...	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Fine
Initial Size Seed	Assembly
Bounding Box Di...	2221.2 mm
Average Surface ...	2.45e+005 mm²
Minimum Edge L...	30.0 mm
Quality	
Check Mesh Qua...	Yes, Errors
Error Limits	Aggressive Mechanical
Target Elemen...	Default (5.e-002)
Smoothing	High
Mesh Metric	Skewness
Min	0.
Max	0.
Average	0.
Standard Devi...	0.

Figure 10. Changed mesh settings (Retrieved from

After changing the mesh settings, inserted a new mesh method which is Tetrahedrons. Then mesh has been generated.

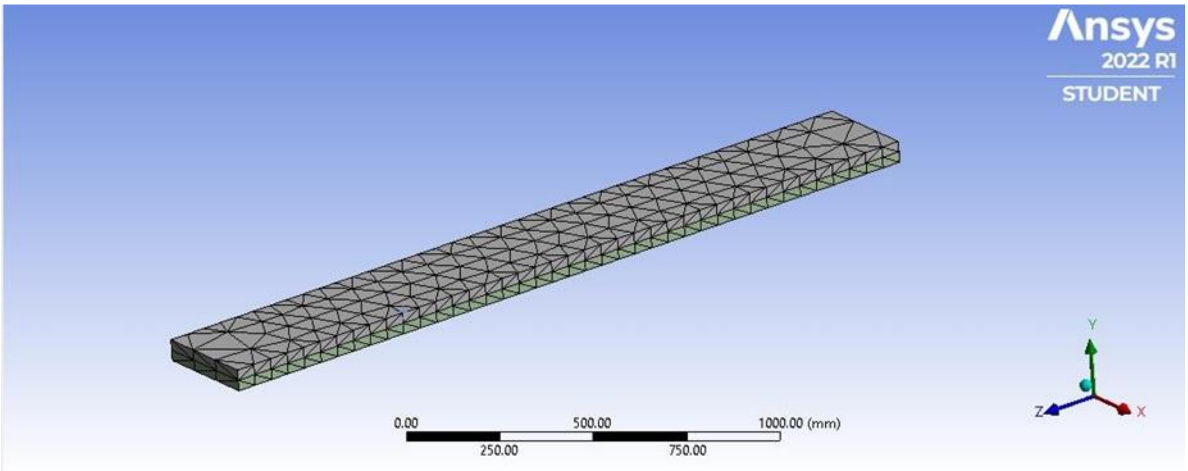


Figure 11. After generating mesh

2.2.2 Static Structural

One side of the beam has been fixed. Then the beam has been subjected to force of -10000N at Y component from the other end of the beam.

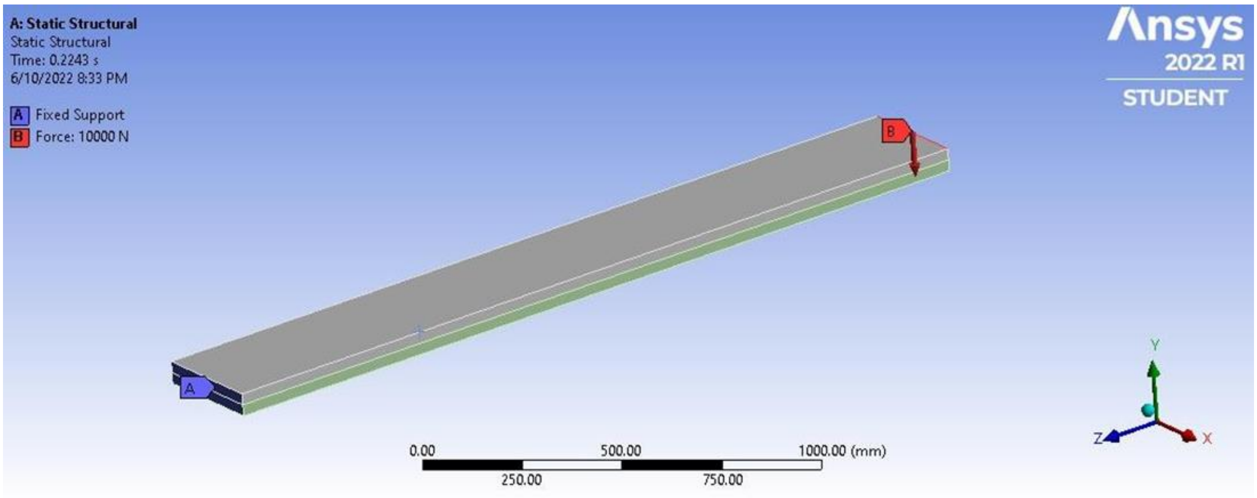


Figure 12. Static structure of the beam

2.2.3 Solution

2.2.3.1 Total Deformation

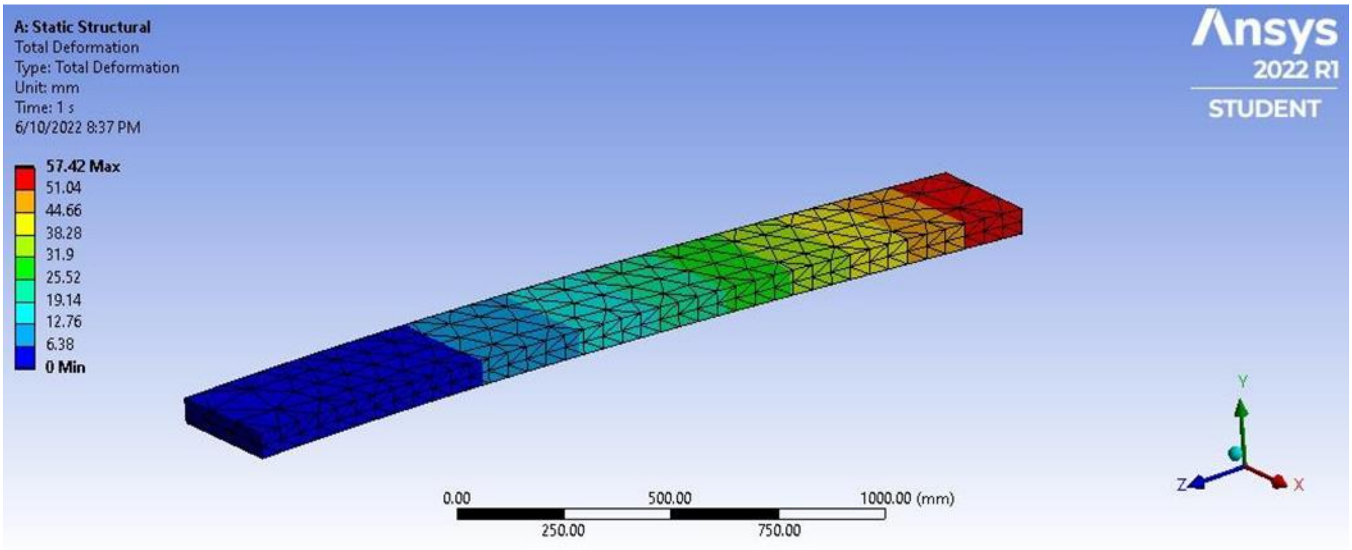


Figure 13. Total deformation of the beam

The maximum deformation is 57.42 mm and average deformation is 21.318 mm.

2.2.3.2 Equivalent Stress

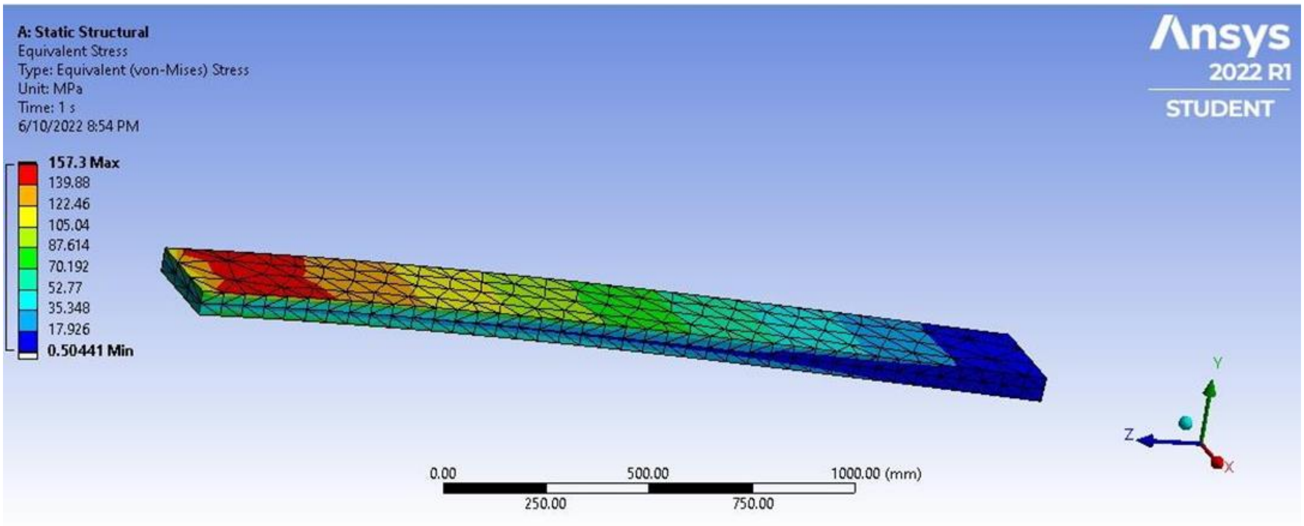


Figure 14. Equivalent stress for top layer (Structural steel)

For structural steel, the maximum equivalent stress is at the support end is equal to 157.3 MPa. Minimum equivalent is equal to 0.50441 MPa. At the support end the distortion energy density reached to a critical value for that material.

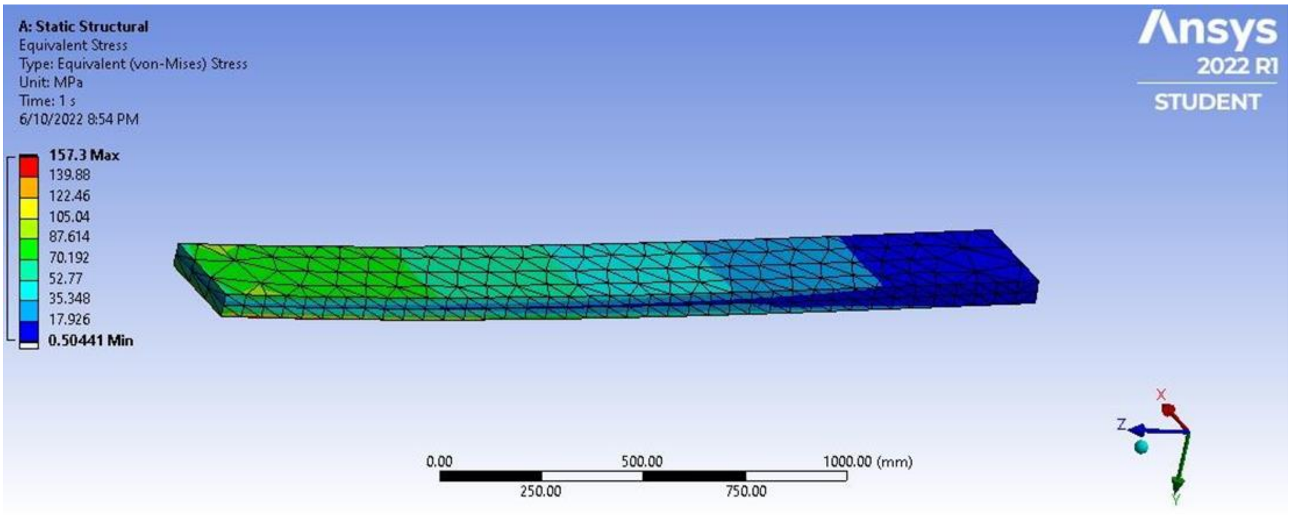


Figure 15. Equivalent stress for bottom layer (Aluminium alloy)

For aluminum alloy, the maximum equivalent stress is at the support end and is averagely equal to 78.903 MPa. Minimum equivalent stress is equal to 0.50441 MPa.

2.2.3.3 Fatigue Analysis

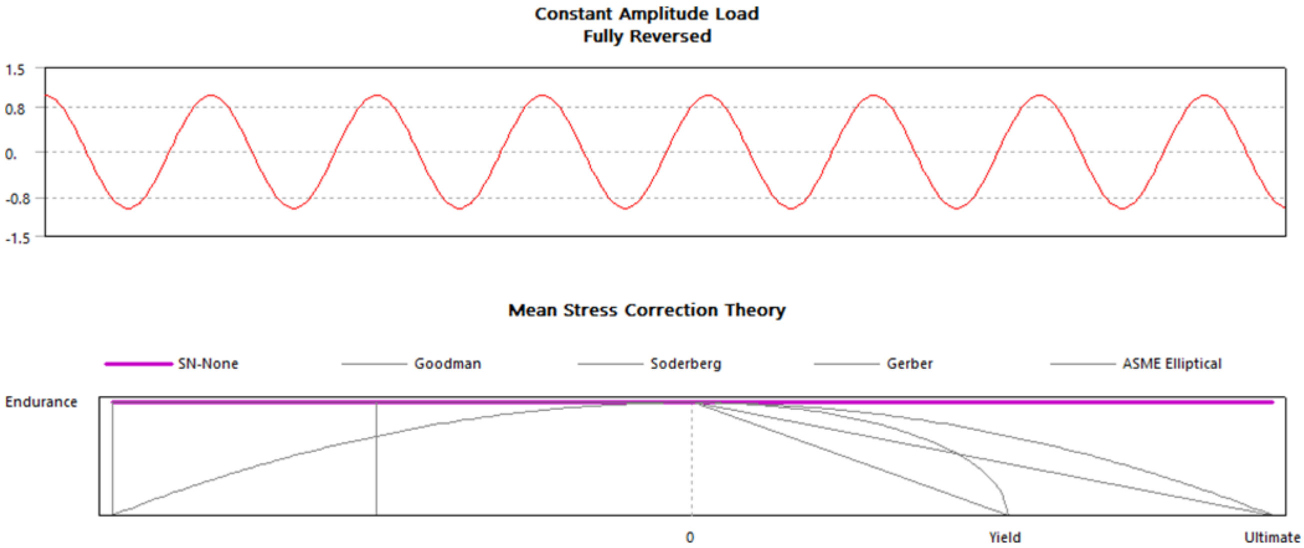


Figure 16. Fatigue analysis tool solution

2.2.3.4 Fatigue Life

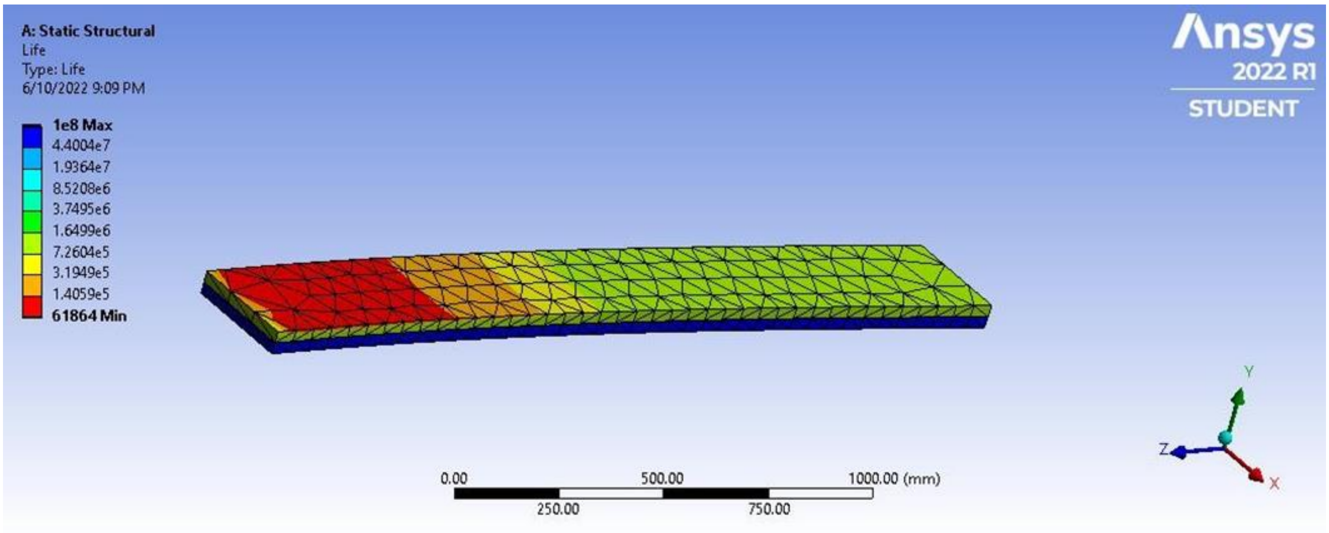


Figure 17. Fatigue-life of structural steel

According to the result, the support end of the structural steel cannot last longer than the number of 61864 cycles. The other end of the beam has more life than the support end. The free end has can carry a greater number of cycles, an average of 726040. Cyclic stresses, residual stresses and material properties are the main things that affect the fatigue life.

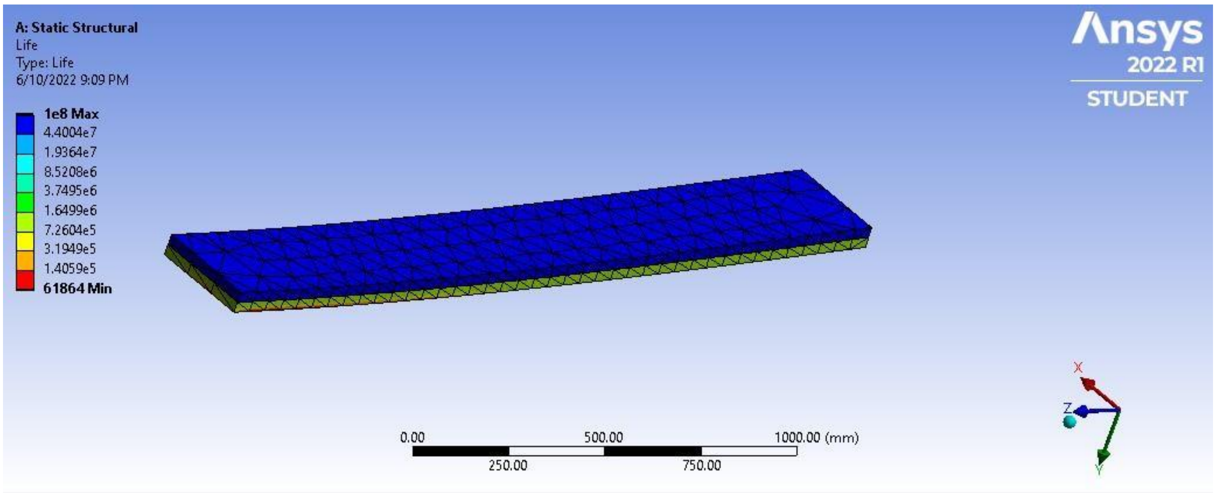


Figure 18. Fatigue-life of aluminium alloy

Aluminum alloy has no critical number of cycles. The whole part has an average number of cycles of 4.4004e+7.

2.2.3.5 Fatigue Damage

Fatigue damage figures are the same as Figures 14 and 15. For top layer support end the maximum fatigue damage value is equal to 16165 and minimum is around 266.7. For aluminum alloy, whole part has a damage value of 10.

2.2.3.6 Safety Factor

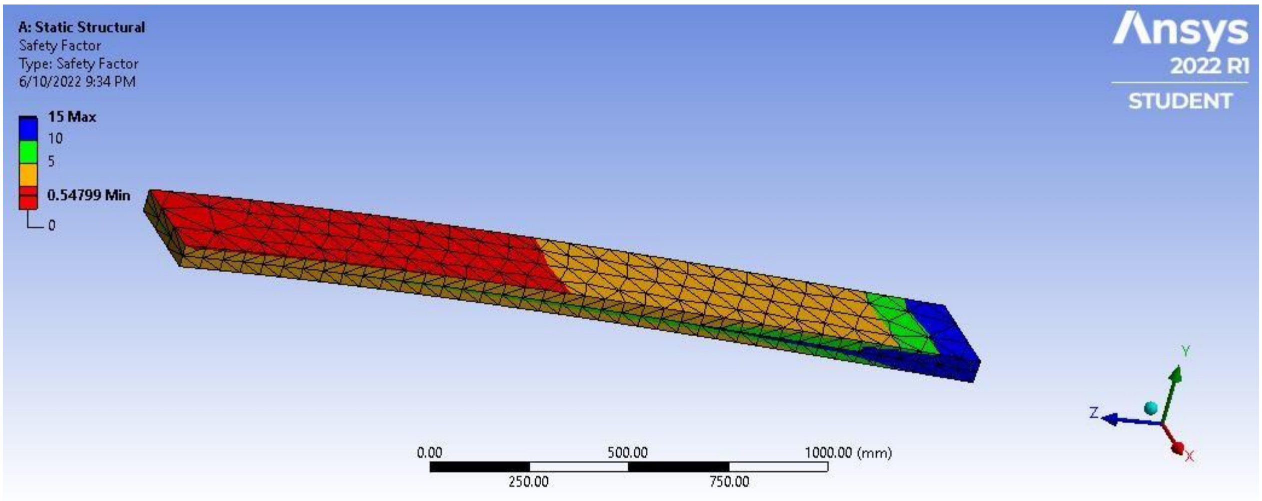


Figure 19. Safety factor values of structural steel

From the result we can compute that at the support end the minimum safety factor for structural steel is 0.54799. If the factor of safety value is less than 0.54799, the structure will fail. The maximum factor of safety value is 15.To see how safety factor leads the structure to fail, we can change the safety factor value to 0.54799 and see the result.

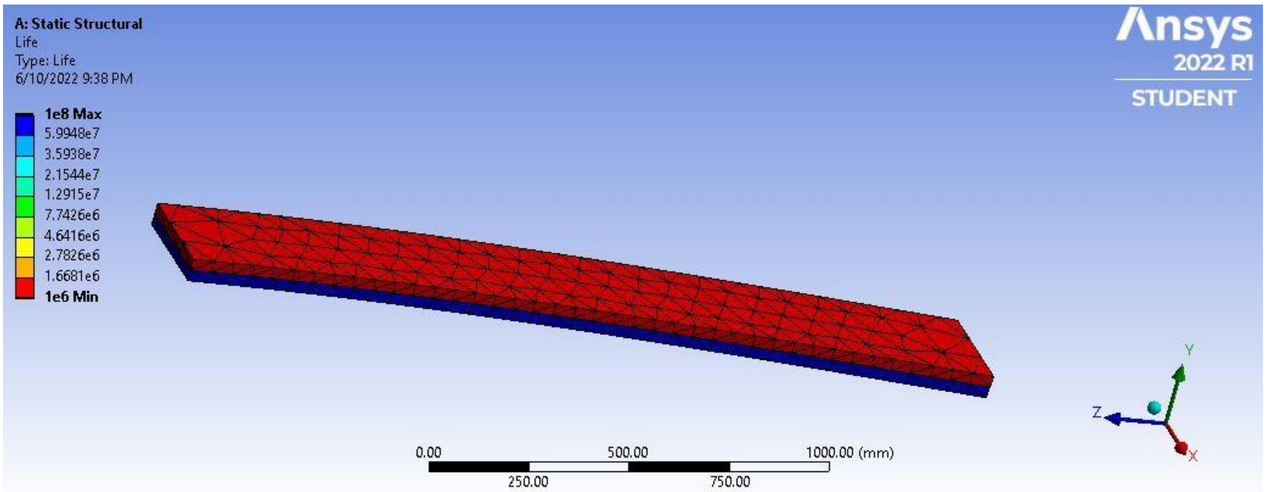


Figure 20. Life of the structure after changing the scale factor from 1 to 0.54799

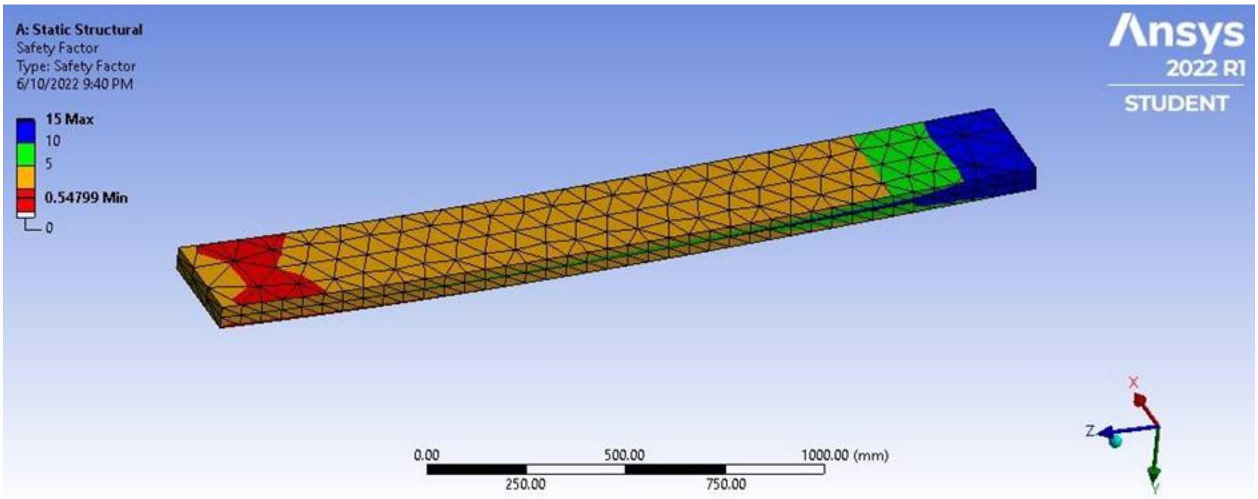


Figure 21. Safety factor of aluminium alloy

The minimum safety factor for the aluminum alloy at support end is the same as structural steel.

2.2.3.7 Biaxiality Indication

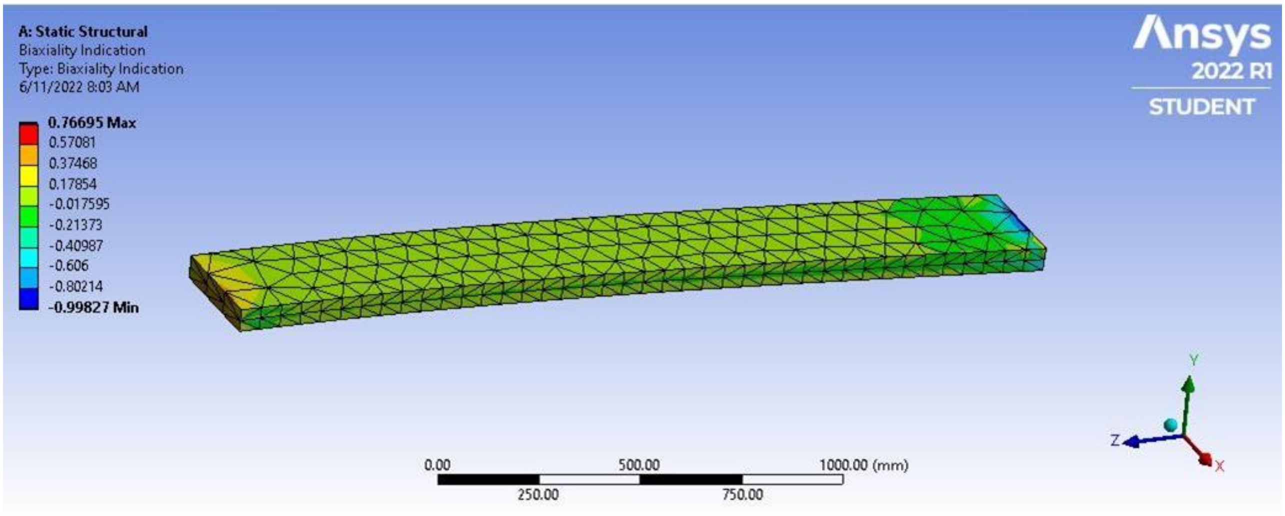


Figure 22. Biaxiality Indication of structural steel and aluminium alloy

The above figure shows the biaxiality indication values for both materials. Maximum biaxiality indication value is 0.76695 at support end. Minimum value is -0.99827 at the free end of the beam. There is uniaxial stress distribution in regions close to the 0 value. A value of 1 corresponds to a pure biaxial state. And -1 is state of pure shear. The majority of this model is under uniaxial stress.

Conclusion

This paper presented the design and analysis of the behavior of composite beams, the beam was a structural steel and aluminum alloy material and through finite Element analysis methodology, the beam was analyzed as it was subjected to a load and conclusions were made. An analysis was conducted through creating meshes on a beam and static structural method where a force was applied to the beam which resulted into total deformation. A greater force than the yield strength of the beam led to the total deformation of the beam. Through calculating the equivalent stress of the different metals of the beam, it was found out that the maximum equivalent stress for structural steel was higher than the aluminum alloy but both possessed the same minimum equivalent stress. If the maximum equivalent strength exceeds the ultimate tensile strength of the material, the material will fracture. Fatigue life of both metals was investigated and through the result it can be seen that the free end for the structural steel can support more cyclic stresses than the supporting end. After the supporting and free end reaches their limit, the structure will fail or fracture. The aluminum alloy on the other side proved to not have any critical number of cycles. The safety factor was also calculated, and through the results we identified the minimum ratio of ultimate stress to working stress (safety factor), which could lead to structural failure. Through comparison, the minimum safety factor for both the aluminum alloy and structural steel where the same but the aluminum alloy could withstand more stress than structural steel. With this we can see that as long as the factor of safety is between.

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