DESIGN AND FABRICATION OF THREE COMPONENTS INTERNAL STRAIN GAUGE BALANCE

A PROJECT REPORT

Submitted by

D. GURU SANKAR	U17AE026
N. NIKHIL	U17AE035
A. NAGA SAIKIRANMAI	U17AE044
A. NAVYA	U17AE057

Submitted to the

FACULTY OF MECHANICAL ENGINEERING

In partial fulfillment of the requirements

for the award of the degree of

BACHELOR OF TECHNOLOGY

in

AERONAUTICAL ENGINEERING

DEPARTMENT OF AERONAUTICAL ENGINEERING

BHARATH INSTITUTE OF SCIENCE AND TECHNOLOGY

BHARATH INSTITUTE OF HIGHER EDUCATION AND RESEARCH

(Declared as Deemed – to – be University under section 3 of UGC Act, 1956)

CHENNAI – 600 073

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BONAFIDE CERTIFICATE

This is to certify that the project report titled, "**DESIGN AND FABRICATION OF THREE COMPONENTS INTERNAL STRAIN GAUGE**", is being submitted by

D.GURU SANKAR	U17AE026
N. NIKHIL	U17AE035
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To the Department of **Aeronautical Engineering, Bharath Institute of Science and Technology, Bharath Institute of Higher Education and Research** in the partial fulfillment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY (AERONAUTICAL ENGINEERING)**. This is a Bonafide record of the work carried out by him under my guidance and supervision in the academic year 2020 – 2021. Further certified that, to the best of my knowledge, the work reported herein does not form part of any other degree or diploma, on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

PROJECT GUIDE
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BHARATH INSTITUTE OF SCIENCE AND TECHNOLOGY

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CERTIFICATE OF EVALUATION

S. No.	Student Name	Register No.	Title of the Project	Name of the Supervisor with Designation
1	D.GURU SANKAR	U17AE026	DESIGN AND FABRICATION OF THREE COMPONENTS INTERNAL STRAIN GAUGE BALANCE	Dr. C SURESH KUMAR Associate Professor and Mr. M. RAMAKRISHNA Assistant professor
2	N. NIKHIL	U17AE035		
3	A. NAGA SAIKIRANMAI	U17AE044		
4	A. NAVYA	U17AE057		

The report of the project work submitted by the above students in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Aeronautical Engineering of Bharath Institute of Higher Education and Research has been evaluated and confirmed to be their genuine work.

Submitted for Viva Voce held on 19/05/2021

INTERNAL EXAMINER EXTERNAL EXAMINER

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First of all, we express my sincere thanks to the almighty, for bestowing his blessings throughout this project work. We express our gratitude to our parents for their care, support, prayers and love.

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ABSTRACT

For many engineering systems the designing of components is based upon applications of theoretical model. The accuracy of the model is verified through testing. Each material has its own characteristics. So, it is important to avoid sudden structural deformations in the materials so that they may prevent structure from full filling the purpose. To obtain an internal strain and stress state to evaluate the reliability of the structure. The way of the validating a mathematical model is used to estimate strain gauge measurement to compute strain at the surface of the structure. An effort is made to develop a new three component force-moment balance which is capable of measuring lift, drag and pitching moment of a model mounted in a wind tunnel. The forces acting on the beam causes strain on its surface which are measured by strain gauge. The strain which is yielded through axial direction is very small which is not practically possible to measure axial force using strain gauge directly. The model which is mounted in the wind tunnel the readings are extracted through DAQ (Data acquisition system) in the form of forces. The forces are then converted to lift, drag and pitching moment. A brief error analysis is performed to justify discrepancies between various forms of measurements and theoretical values. By using this three-component internal strain gauge balance we can measure any aerodynamic model and can obtain aerodynamic parameters.

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LIST OF SYMBOLS AND ABBREVIATIONS

G. F - Gauge factor

ΔR - change in resistance

ε - strain

R_1 - Resistance

L - Length

A - cross sectional area

D - Diameter

E - Young's modulus

I_c - Moment of inertia for circular section

r - Radius

I_{sq} - Moment of inertia for square section

d - depth

I_{sc} - Moment of inertia for screw

δ - Deflection

W - Weight

CHAPTER 1

INTRODUCTION

1.1 STRAIN GAUGES

Strain gauge are the sensors based on electrical resistance which generates a variation in its electrical resistance when subjected to an external force/deformation in its length. It is used to measure strain on an object.

1.2 TYPES OF STRAIN GAUGES

- Linear strain gauges
- Membrane rosette strain gauges
- Double linear strain gauges
- Full bridge strain gauges
- Shear strain gauges
- Half bridge strain gauges
- Column strain gauges
- Unbounded metal strain gauges
- Diffused metal strain gauges

➢ **BASED ON WORKING**

- Mechanical
- Electrical
- Piezoelectric

➢ **BASED ON MOUNTING**

- Bounded strain gauge
- Unbounded strain gauge

1.3 STRAIN GAUGE DESIGN CONSIDERATION

- Gauge's length
- Number of gauges in gauge pattern
- Arrangement of gauges in gauge pattern
- Grid resistance

- Strain sensitive alloy
- Carrier material
- Gauge width
- Solder tab type
- Configure ration of solder tab
- Availability

Based on these considerations we use metal foil strain gauge

METAL FOIL STRAIN GAUGE

A foil strain gauge is a sensor for measuring relative changes in the length of a material (strain) due to applied forces. The formation is registered as compression or tension and is greatly influenced by the elastic properties of the tested material.

The metal foil of 0.02 mm thick is produced using the printed circuit technique. This metal foil is produced on one side of the plastic backing. Leads are soldered to the metal foil for electricity connecting the strain gauge to measuring instrument. With the help of an adhesive material, the strain gauge is pasted on the structure under study. Now the structure is subjected to a force (tensile or compressive).

1.3.1 WHY STRAIN GAUGE USED IN MEASURING FORCE

- They are highly precise and don't get influenced due to temperature changes. However, if they do get affected by temperature changes, a thermistor is available for temperature corrections.
- They are ideal for long distance communication as the output is an electrical signal.
- Strain Gauges require easy maintenance and have a long operating life.
- The production of strain gauges is easy because of the simple operating principle and a small number of components.
- The strain gauges are suitable for long-term installation. However, they require certain precautions while installing.
- All the strain gauges produced by Encardio-Rite are hermetically sealed and made up of stainless steel thus, waterproof.

- They are fully encapsulated for protection against handling and installation damage.
- The remote digital readout for strain gauges is also possible.

1.4 WORKING PRINCIPLE

A strain gauge works on the principle of electrical conductance and its dependence on the conductor's geometry. Whenever a conductor is stretched within the limits of its elasticity, it doesn't break but, gets narrower and longer. Similarly, when it is compressed, it gets shorter and broader, ultimately changing its resistance. We know, resistance is directly dependent on the length and the cross-sectional area of the conductor given by:

$$R = L/A$$

1.5 MEASURING STRAIN USING STRAIN GAUGE

Strain gauges work on the principle of the conductor's resistance which gives you the value of Gauge Factor by the formula:

$$GF = [\Delta R / (RG * \varepsilon)]$$

Now, in practice, the change in the strain of an object is a very small quantity which can only be measured using a Wheatstone Bridge. The Wheatstone Bridge circuit is given below. A Wheatstone Bridge is a network of four resistors with an excitation voltage, vex that is applied across the bridge. The Wheatstone Bridge is the electrical equivalent of two parallel voltage divider circuits with R1 and R2 as one of them and R3 and R4as the other one.

The output of the Wheatstone circuit is given by:

$$Vo = [(R3/R3+R4) — (R2/R1+2)] * Vex$$

Whenever R1/ R2 = R4/ R3, the output voltage Vo is zero and the bridge is said to be balanced. Any change in the values of R1, R2, R3, and R4 will, therefore, change the output voltage. If you replace the R4 resistor with a strain gauge, even a minor change in its resistance will change the output voltage Vex which is a function of strain. The equivalent strain output and voltage output always have a relation of 2:1.

CHAPTER 2

REVIEW OF LITERATURE

Frederik F et al. (2008) - This study presents the measurement of forces on aircraft engine components or scale down models with the help of three component internal strain gauge balance where the balance is placed inside the model with the help of a string. This paper also presents how the strain gauges works and the principle of the strain gauges. With an internal balance, the forces are measured in a co-ordinate system attached to the model. The results must be corrected to produce the required forces and moments. When using a string with model, there may be a chance of change in the structure. Additional tests are required to estimate the final forces and moments.

Hou JW et al. (2017) - In his thesis stated that simulated results of a wind tunnel tested models of aerodynamic objects. The author describes about the measurement of forces and moments by the loads acting on the model. Distinguished two balances internal and external balance. For internal the balance is Mounted inside the test rig and external means that the model is tested outside the wind tunnel, here mentioned about internal balance. While testing the flow properties there are certain parameters that going to affect to get the accurate results those could be according to wind tunnel model, the quality of flow, the supported system interference causes some sort of error and there could be a change in model as a deformative one, imposing of constraints from wall of wind tunnel when the results could be expected from rigid body scaled models have to consider all the things as mentioned above. In this literature concluded that the calibration data and transformation matrix as presumed and can test this for any aerodynamic model, by Finite element analysis that the stress and deformation are in linear pattern.

James F et al. (2003)- Range and accuracy are the main things to respond by this experiment along with that management to the time response. Another way to determine the aerodynamic model forces by a scan valve system or pressure scanner where the loads is measured by pressures by attaching pressure sensors to it. This kind of test requires extremely complex and expensive kind of test channels. The model surface which is used should made with some holes with measurement points for attaching tubes to it and measure the loads by pressure sensor to get accurate results. The real behaviour of model is modified by the flow over the model due to the holes that are accumulated to the scaled models.

Lee C.S et al. (2005)- Moment balances are single pieced balance designs with gauges cantilever beam that measure strain from single or double bending. These balances can measure the following:

- one force (axial)
- five moments (two pitching, two yawing and one rolling)

➢ Force balances can measure six forces

- one axial force
- Two normal forces
- Two side force and One moment

Ladson T et al. (2001)- The strain gauge balance can be considered as a cantilever beam when mounted in a wind tunnel. The fixed end is mounted to the string of the wind tunnel while the free end is loaded with the aerodynamic beam. The beam deformation is the result of two components, internal shear force and bending moment. The largest contributor to deformation in an elastic beam is due to bending, when the ratio of beam length to beam depth (L/D) is very large, i.e., greater than 10:1. The deformation effects due to shear will be neglectable. If the beam length to beam depth (L/D) is less than 10:1, then the Timoshenko Beam Theory (TBT) provides a more accurate results of deformation.

Milan T et al. (2020) - Described about wind tunnel balance for three components, it is one of the efficient ways to measure the air loads and moment in an accurate and rapid way for an aerodynamic model. Glance about a three individual weighing beams X, Y and Z which demonstrates drag, side drag and lift, weighing beams respectively. Used translation mechanism to measure independently and even directly, wind balance translation mechanism with floating pipes is used. And also tested with rotation mechanism to get the accuracy of results. Without stopping the wind by applying loads can extract the data of lift, drag, pitching moment. The author clearly states about the multiple methods and usage of three components internal strain gauge balance.

Thierry A et al. (2019) - Briefed about the external balance, internal balance and rotary balances. Stated how to measure the three-component internal strain gauge Balance and glanced about data acquisition system which is used to extract the details in required formulae which eases our work of formulating in essential forms. And explained about wind tunnel balances requirements and various kinds of experiments and calibrated according to the test for three components balances. Concluded that by using DAQ to extract the results from strain gauges is more efficient way of calibrating the forces and moments for the internal strain gauge balance.

CHAPTER 3

CONCEPTUAL DESIGN

3.1 CONCEPTUAL DESIGN

A strain gauge balance for aerodynamic model testing comprising an elongated horizontally mounted cantilever beam having a base, an opposite model supporting tip, and an intermediate instrument portion.

The forces acting on the spring element cause strains on its surface, which are measured by strain-gauges. Strain-gauges are connected in a Wheatstone bridge where the change in strain will result in corresponding change in strain-gauge resistance thus producing a certain amount of voltage difference from the bridge.

3.2 FLOW CHART

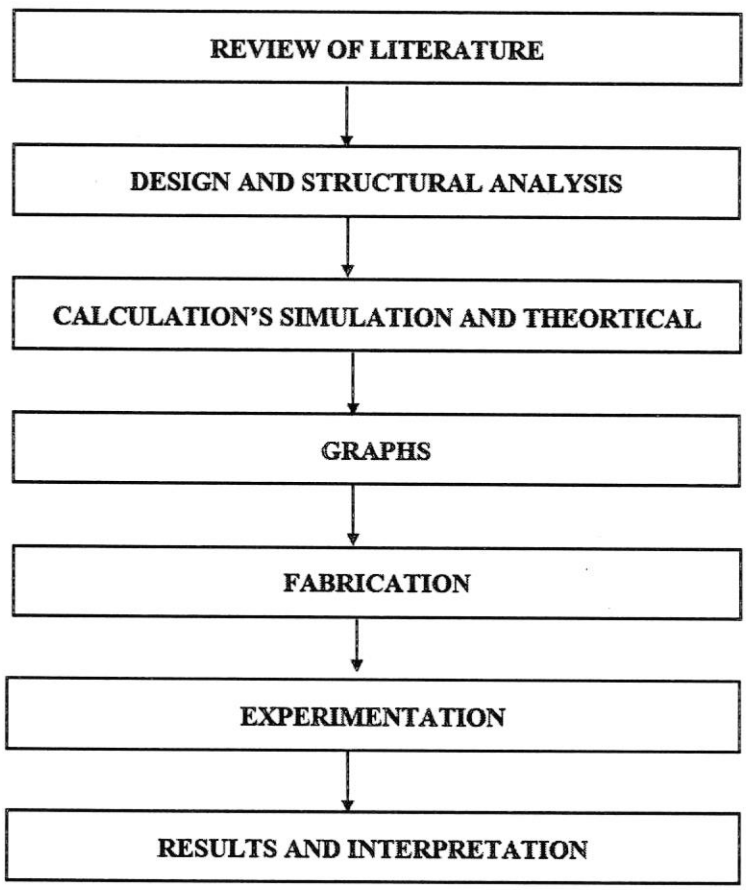


Figure 3.1: Flow process of the project work

3.3 OBJECTIVE PART

The main objective of this project is to design a 3-component internal strain gauge, by using this model we can calculate the lift drag and one of the moments.

3.4 OBSERVATIONS

- The role of student as an engineer is to design the components based on theoretical model and the accuracy of the model is verified by testing the model. And our design consideration is selected cantilever beam with a circular cross section of Día 1.5cm and length 30cm and there will be two square sections with 8mm side.
- By mounting the beam in wind tunnel, fixing it to the model and set air pressure, allow the flow in the wind tunnel then we can measure the aerodynamic forces such as lift, drag and pitching moment through the strain Gauge is attached to the beam's square portion.
- Incentive of circular cross section of a beam is to extract the pitching moment value. The screws on the beam, to mount on models. The strain gauges are attached on the square or rectangular cross sections rather than circular section due to circumvent the more errors and extract nearly exact results and also to avoid more percent of strain gauges.
- The wires will be connected to the beam directly passed to DAQ. To extract the results and to avoid maximum errors in calculation. Beam is designed to withhold maximum sensitivity of 100 grams and it can be capable of extracting the required forces for any Aerodynamic model.

3.5 DESIGN

- Selected cantilever beam with a circular cross section of Día **1.5cm** and length **30cm** and there will be two square sections with **8mm** side. By mounting the beam in wind tunnel, fixing it to the model and set air pressure, allow the flow then we can measure the aerodynamic forces such as lift, drag and pitching moment through the strain Gauge attached to the beam's square portion.

- Incentive of circular cross section of a beam is to extract the pitching moment value. The screws on the beam, to mount on models. The strain gauges are attached on the square or rectangular cross sections rather than circular section due to circumvent the more errors and extract nearly exact results and also to avoid more percent of strain gauges.
- The wires will be connected to the beam directly passed to DAQ. To extract the results and to avoid maximum errors in calculations.
- Beam is designed to withhold minimum load of 100 grams and it can be capable of extracting the required forces for any Aerodynamic model.

CHAPTER 4

BEAM DESIGN

The balance is sketched in CATIA software with the below mentioned dimensions.

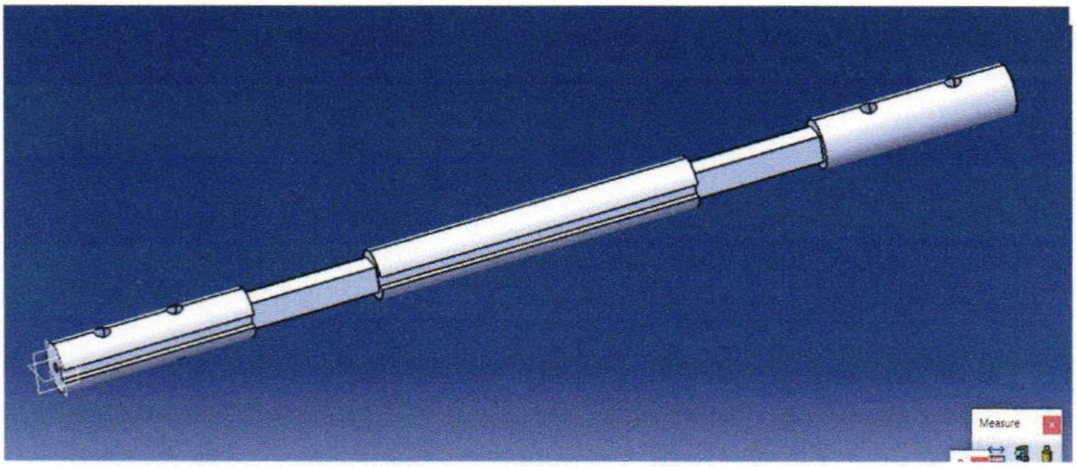


Figure 4.1: Design of Balance in Catia

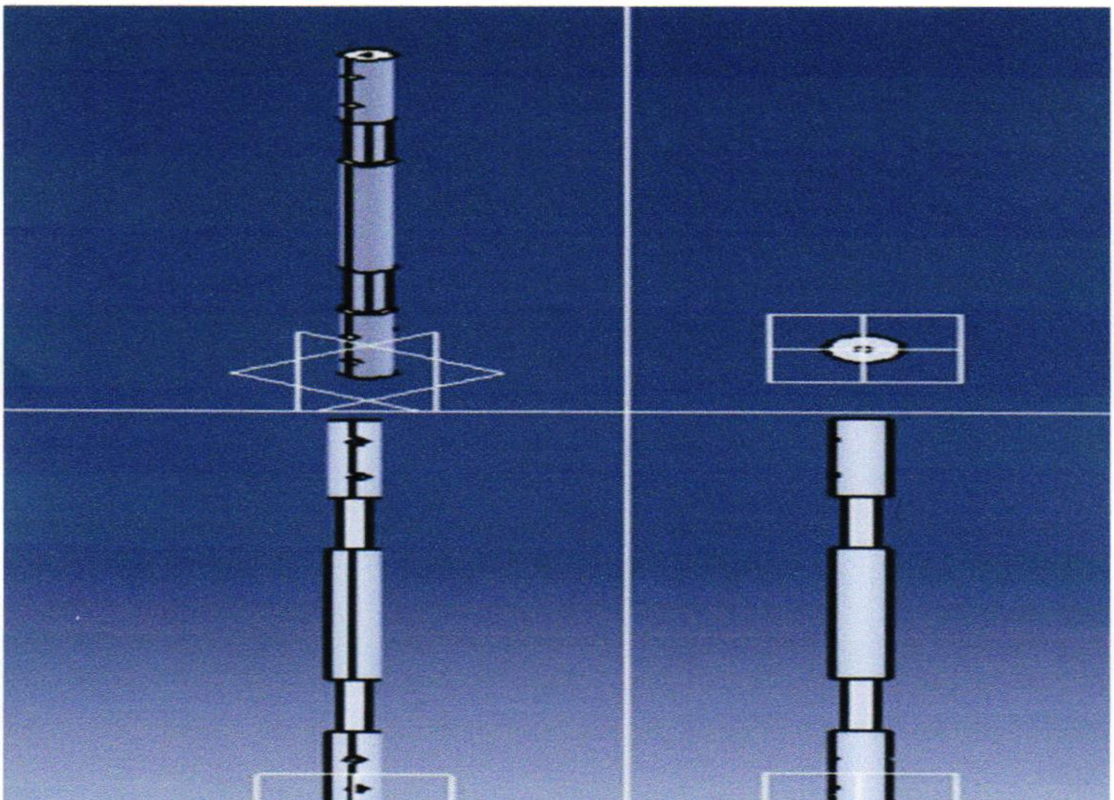


Figure 4.2: 3-View Diagram of the Balance

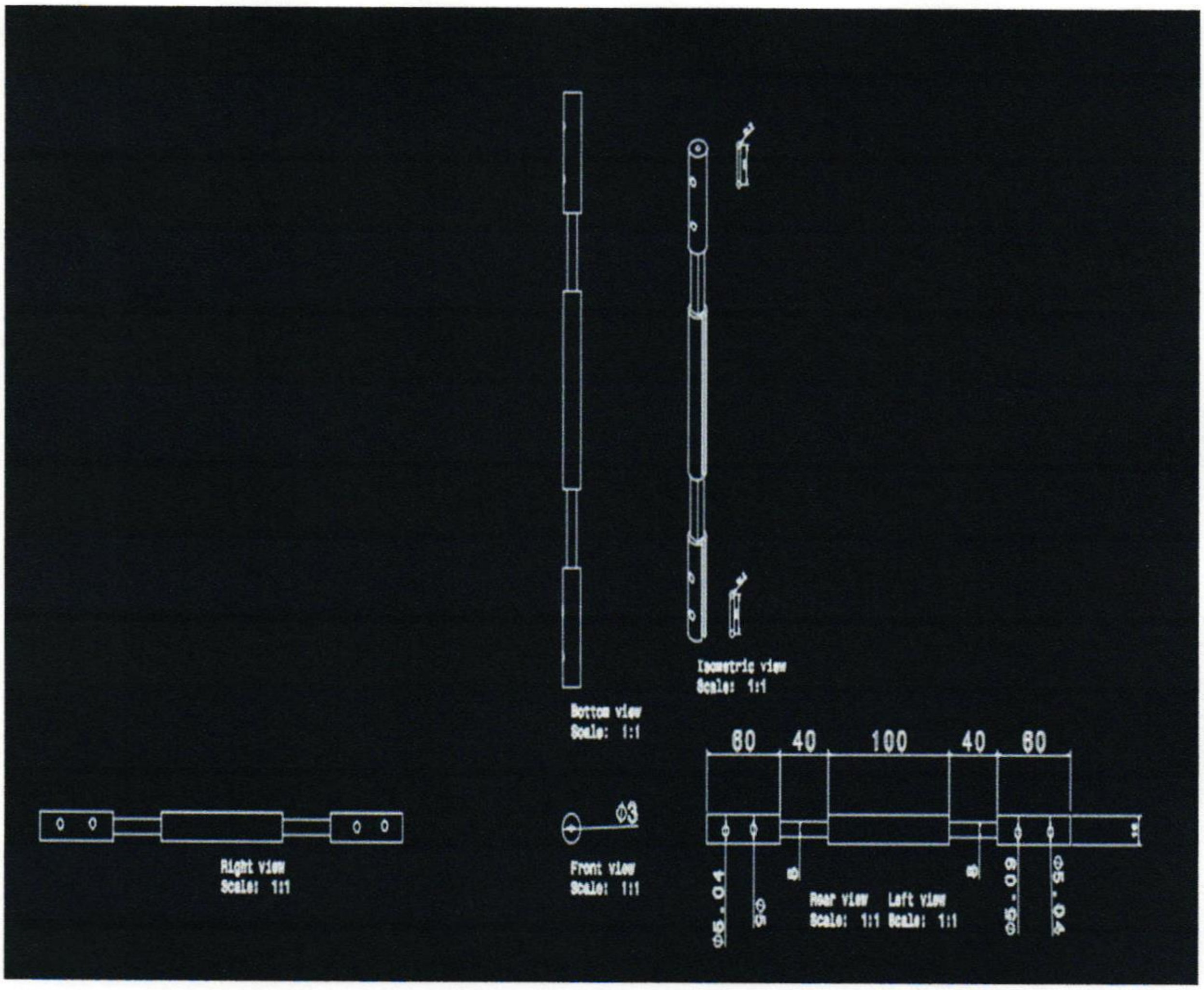


Figure 4.3: Designed balance with dimensions

CHAPTER 5

STRUCTURAL ANALYSIS

The structural analysis is done in two ways

1. **Uni axial loading**
   - With loading under longitudinal load
   - With loading under axial load
   - With loading under moment
2. **Combined loading**
   - With loading under axial direction and longitudinal loading
   - With loading under moment and axial load
   - With loading under moment and longitudinal load

UNI DIRECTIONAL LOADING OF BEAM

5.1 Loading under longitudinal load

5.1.1 Simulation results

When a balance is subjected to longitudinal loading(lift), the results are analysed Some of the simulation results were shown

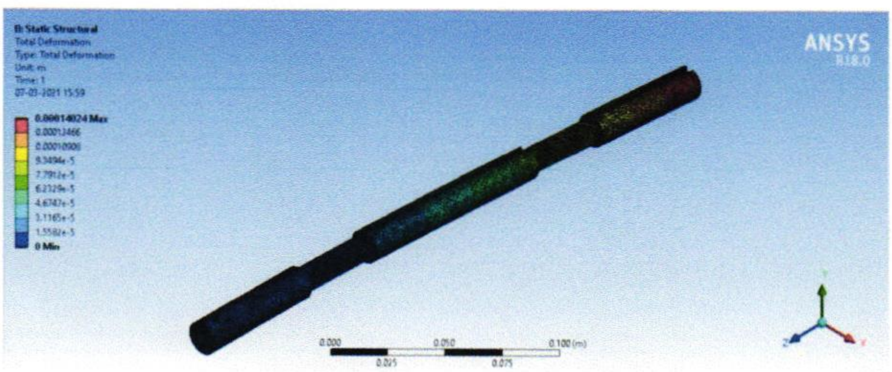


Figure 5.1.1: Aluminum beam subjected to 0.1 N at free end - least case

Figure 5.1.2: Aluminum beam subjected to 1 N at free end – intermediate case

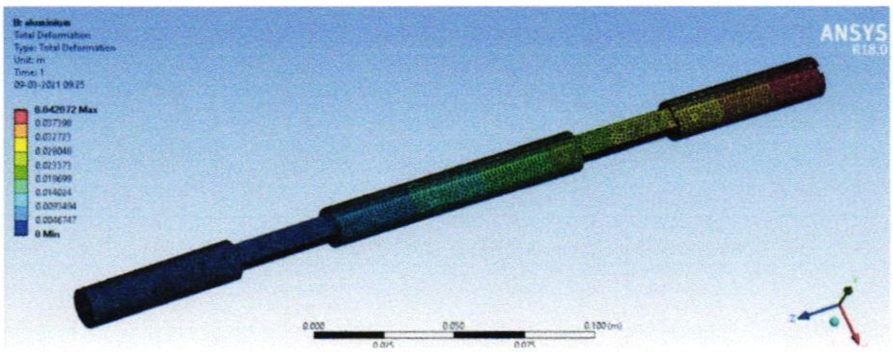


Figure 5.1.3: Aluminum beam subjected to 3 N at free end – extreme case

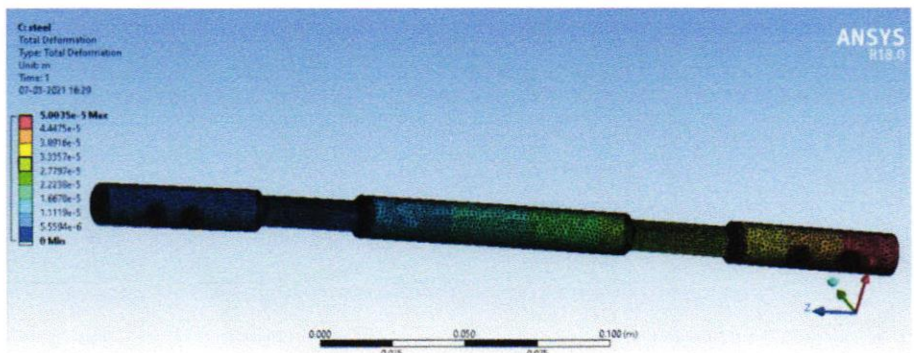


Figure 5.1.4: Steel beam subjected to 0.1 N at free end – least case

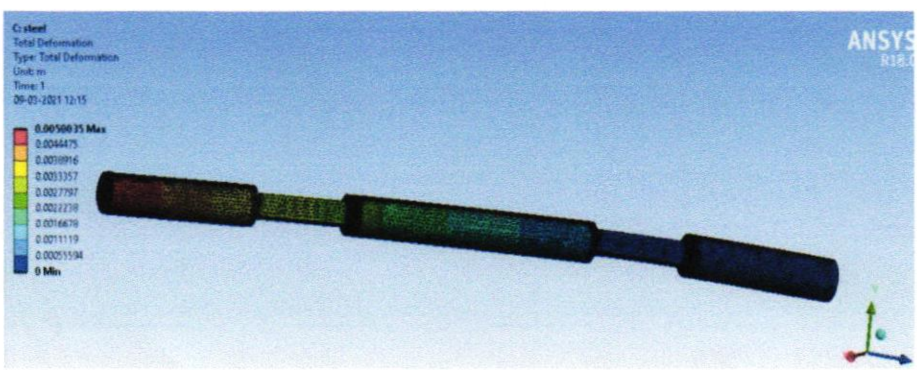


Figure 5.1.5: Steel beam subjected to 1 N at free end – intermediate case

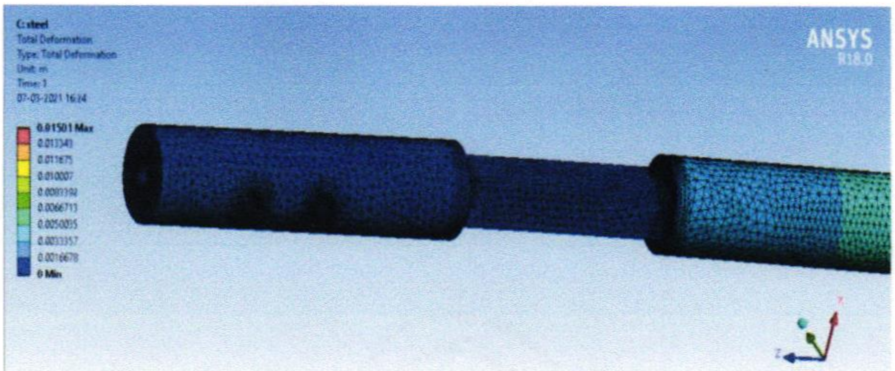


Figure 5.1.6: Steel beam subjected to 3 N at free end – extreme case

Simulation is done in Ansys for given loading conditions with different loads and the results are shown in the table 1.

Table 1: simulation results for longitudinal loading

Load (N)	Aluminium deflection (m)	Steel Deflection (m)
1	0.0001	0.00005
5	0.0007	0.0002
10	0.0014	0.0005
15	0.0021	0.0007
20	0.0028	0.001
25	0.0035	0.0012
30	0.0042	0.0015
35	0.0049	0.0017
40	0.0056	0.0020
45	0.0063	0.0022
50	0.0070	0.0025
55	0.0077	0.0027
60	0.0084	0.003
65	0.0091	0.0032
70	0.0098	0.0035
75	0.0105	0.0037
80	0.0112	0.004
85	0.0119	0.0042
90	0.0126	0.0045

95	0.0133	0.0047
100	0.0140	0.005
105	0.0147	0.0052
110	0.0154	0.0055
115	0.0161	0.0057
120	0.0168	0.006
125	0.0175	0.0062
130	0.01823	0.0065
135	0.0189	0.0067
140	0.0196	0.007
145	0.0203	0.0072
150	0.0210	0.0075
200	0.0280	0.01
250	0.0350	0.0125
300	0.042	0.0150

5.1.2 Theoretical calculation

To compare the simulation results, theoretical results are also been analysed with the below given formula

$D = 15mm = 1.5*10^{-2}m.$

$L = 30*10^{-2}m.$

$E = 71.7*10^{9}$ Pa

First consider circular section of whole beam as one

To find moment of Inertia of circular section

$$I_c = \frac{\pi r^4}{4} = \frac{\pi(0.75*10^{-2})^4}{4}$$

$I_c = 0.2485*10^{-8}$ m^4

Next consider the square section which is 0.8cm*0.8cm

To find moment of Inertia for square section

$$I_{sq} = \frac{bd^3}{12} + \frac{db^3}{12}$$

$$= \frac{0.8^4}{12} + \frac{0.8^4}{12}$$

$I_{sq} = 0.0682*10^{-8}\ m^4$

There are two square sections in the beam with same dimensions.

$I_{sq} = 2*0.0682*10^{-8} = 0.1365*10^{-8}\ m^4$

Next considering two screws and calculate its moment of inertia

$$I_{sc} = \frac{0.3*0.4^3}{12} + \frac{0.4*0.3^3}{12} = 0.0025*10^{-8}\ m^4$$

$I_{sc} = 2*0.0025*10^{-8} = 0.005*10^{-8}\ m^4$

$\mathbf{I = I_c - I_{sq} - I_{sc}}$

$I = (0.2485*10^{-8}) - (0.0682*10^{-8}) - (0.0682*10^{-8})$

$I = 0.10697*10^{-8}\ m^4$

For, w = 10kg or 100N

$$\boldsymbol{\delta} = \frac{\mathbf{wl^3}}{\mathbf{3EI}}$$

$\boldsymbol{\delta} = 11.73$ mm

Similarly, the theoretical calculations are made for every load starting from 100gms to 30kg with an interval of 100 gms for aluminium and steel and are shown in table 2.

Table 2: Theoretical results for balance when subjected to longitudinal loading

Load (N)	Aluminum Deflection (m)	Steel Deflection(m)
1	0.0001	4.12E-05
5	0.0006	0.0002
10	0.0012	0.0004
15	0.0018	0.0006
20	0.002	0.0008
25	0.003	0.001
30	0.0036	0.0012
35	0.0042	0.0014
40	0.0048	0.0016
45	0.0054	0.0018
50	0.0060	0.0020
55	0.0066	0.0022
60	0.0072	0.0024
65	0.0078	0.0026
70	0.0084	0.0028
75	0.0090	0.003
80	0.0096	0.0032
85	0.0102	0.0035
90	0.0108	0.0037
95	0.0114	0.0039
100	0.0120	0.0041
105	0.0126	0.0043
110	0.0132	0.0045
115	0.0138	0.0047
120	0.0144	0.0049
125	0.0150	0.0051
130	0.0156	0.0053

135	0.0162	0.0055
140	0.0168	0.0057
145	0.0175	0.0059
150	0.0181	0.0061
200	0.0241	0.0082
250	0.0301	0.0103
300	0.0362	0.0123

Simulation and the theoretical results are graphically shown in figure 1 with the given loading conditions and with different loads.

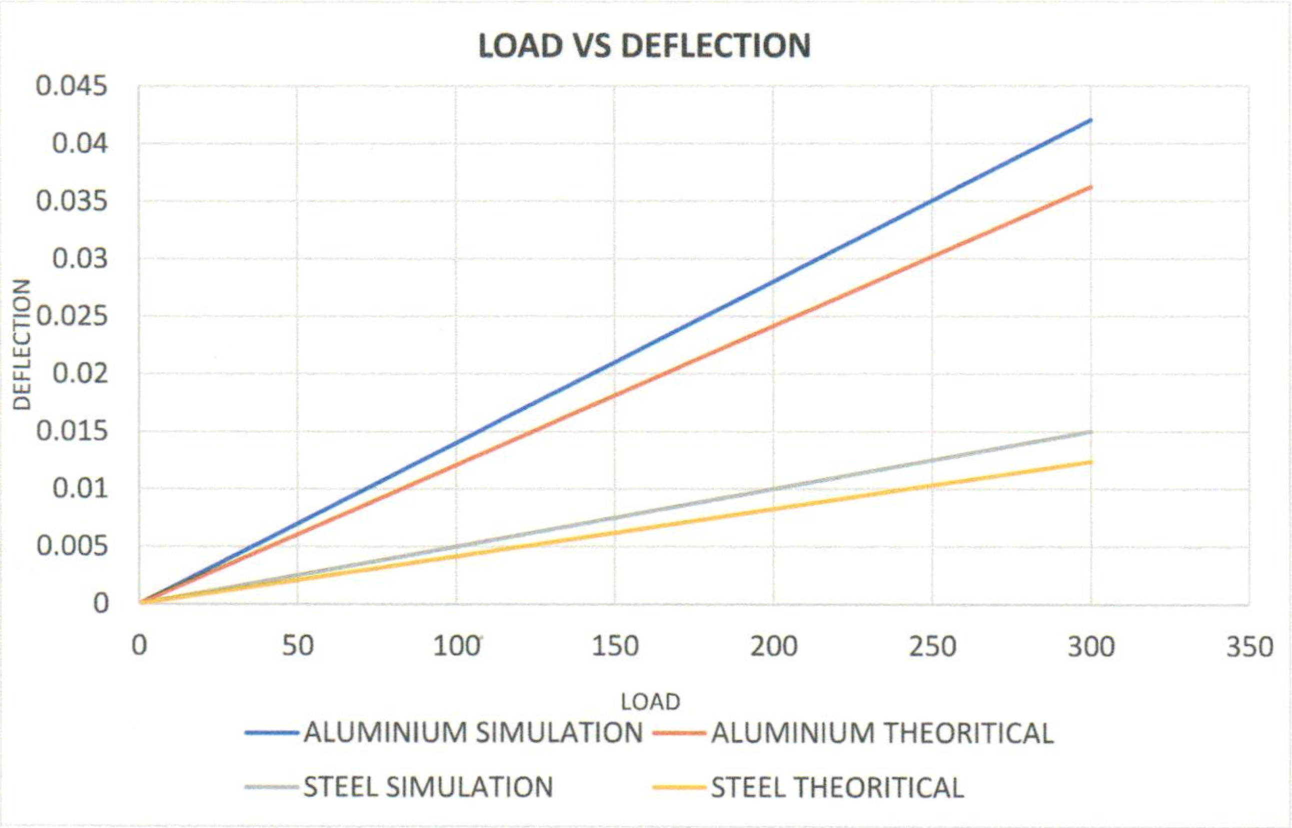
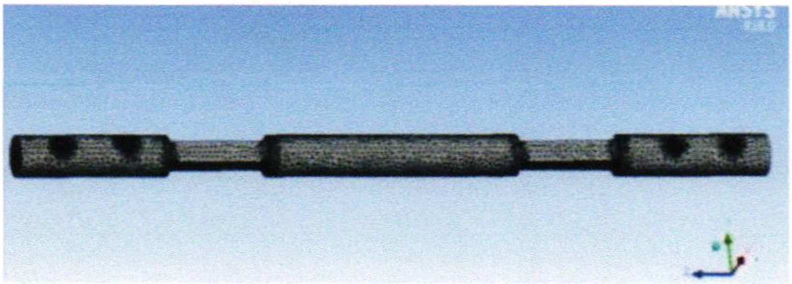


Figure :5.1.7 Graphical representation of theoretical and simulation results

5.2 Mesh Analysis

Tetrahedral mesh refinement is chosen, so as to get the accurate results



Tetrahedral mesh refinement of the beam with 2,33,328 nodes and 1,56,000 elements

Mesh independence test

We had conducted a mesh independence test to know whether the simulation depend on type of mesh we use. For better accuracy we mesh should be independent.

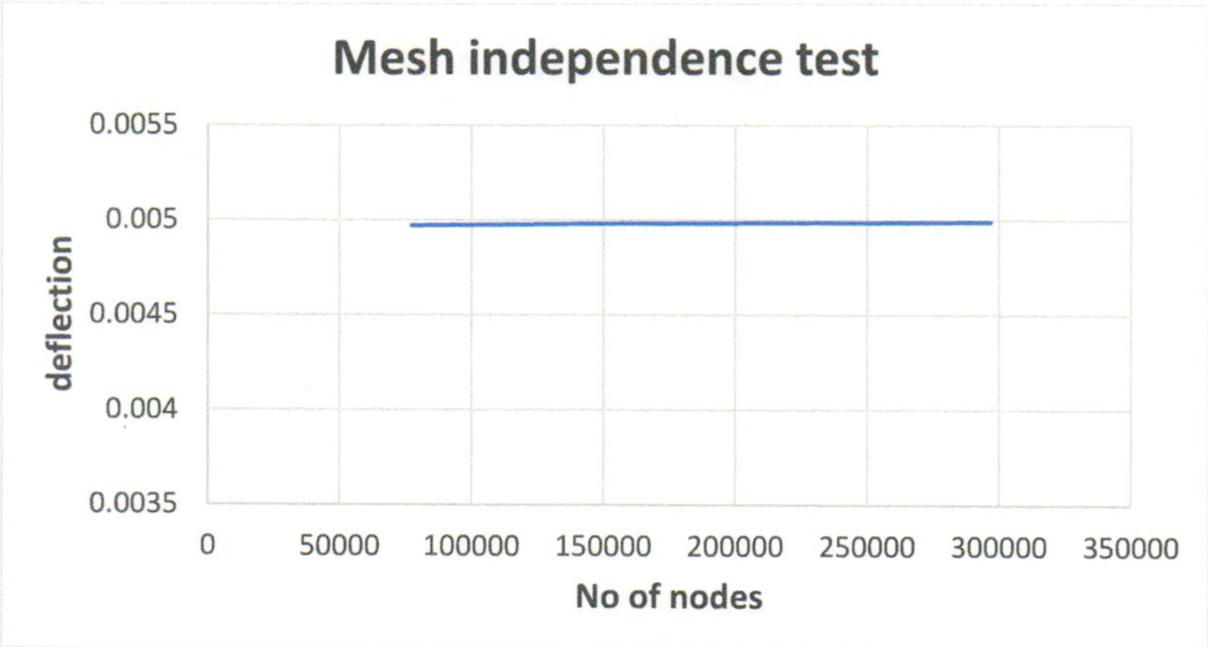


Figure 5.2: Mesh independence test

5.3 Torsional analysis

When the balance is subjected to torque (pitching moment), the results are been analyzed.

5.3.1 Simulation Results

Simulation is done in Ansys for given loading conditions with different loads and ssome of the simulation results are analyzed

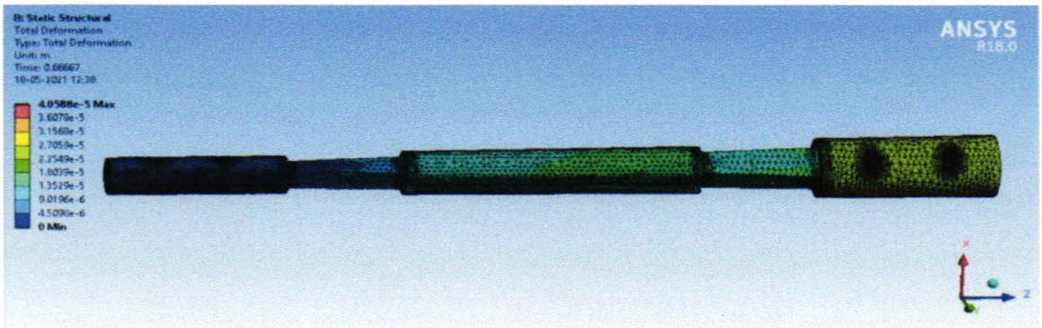


Figure 5.3.1: Steel beam subjected to torque of 2 Nm in anticlockwise direction

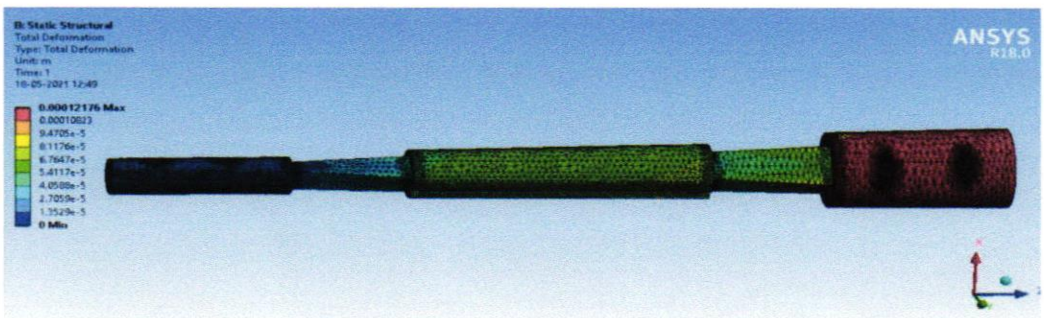


Figure 5.3.2: Steel beam subjected to torque of 6 Nm in anticlockwise direction

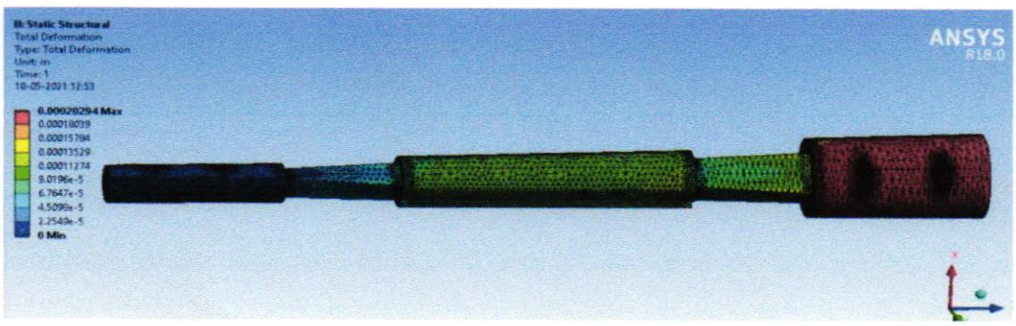


Figure 5.3.3: Steel beam subjected to torque of 10 Nm in anticlockwise direction

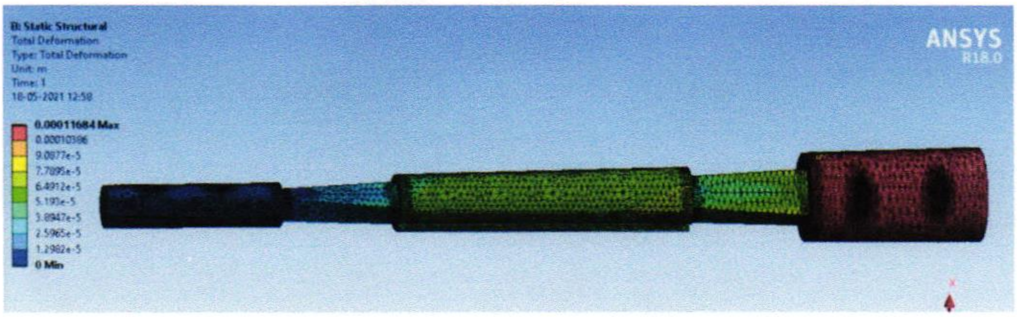


Figure 5.3.4: Aluminum beam subjected to torque of 2 Nm in anticlockwise direction

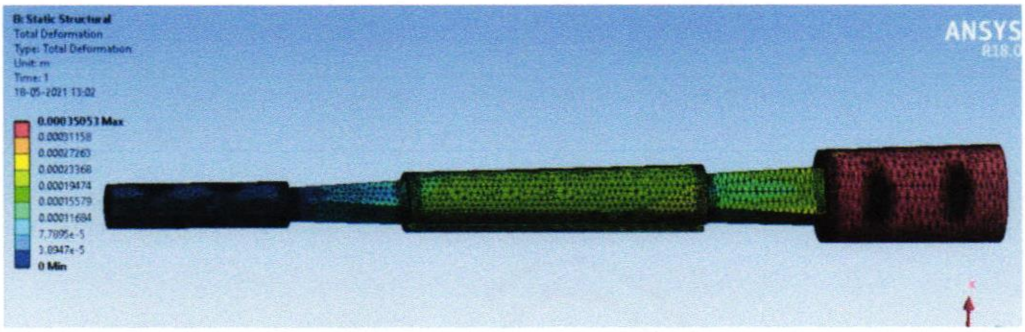


Figure 5.3.5: Aluminum beam subjected to torque of 6 Nm in anticlockwise direction

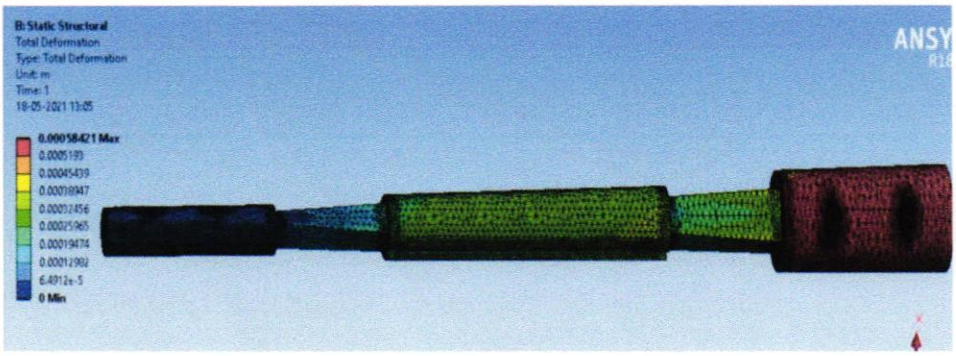


Figure 5.3.6: Aluminum beam subjected to torque of 10 Nm in anticlockwise direction

5.3.2 Theoretical calculation

The results were calculated theoretically using the below formula,

Angle of twist = (TL)/(GJ)

WHERE; T = torsion

L = length of beam

G = rigidity modulus

(For aluminum = 26.9 Gpa and for steel 77.2Gpa)

J = Polar moment of inertia (3.14*(d^4))/32

On subsisting these values

We get the angle of twist for different values of torque for aluminum and steel balance.

Table 3: Tabulation of theoretical results when balance is subjected to torque

Torsion (Nm)	Angle of twist (aluminum) (rad)	Angle of twist (STEEL) (rad)
2	0.257	0.179
4	0.514	0.358
6	0.772	0.538
8	1.029	0.717
10	1.286	0.896

Combined loading

5.4 Loading under axial load and longitudinal load

Combined loading comes into effect when two or more forces acting on the model. Balance is loaded under combination of axial load (drag) and longitudinal load (lift)

5.4.1 Simulation results

Balance is analyzed under the combination of longitudinal load and axial load and some of the simulation results are shown.

Figure 5.4.1: Steel Loaded under axial load of 5 N and longitudinal load of 5 N

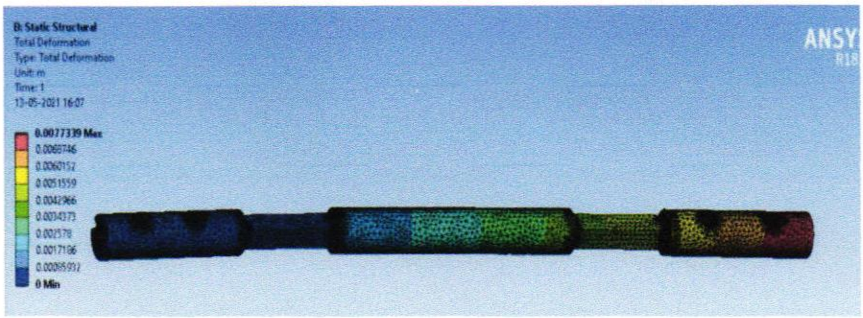


Figure 5.4.2: Steel Loaded under axial load of 5 N and longitudinal load of 150 N

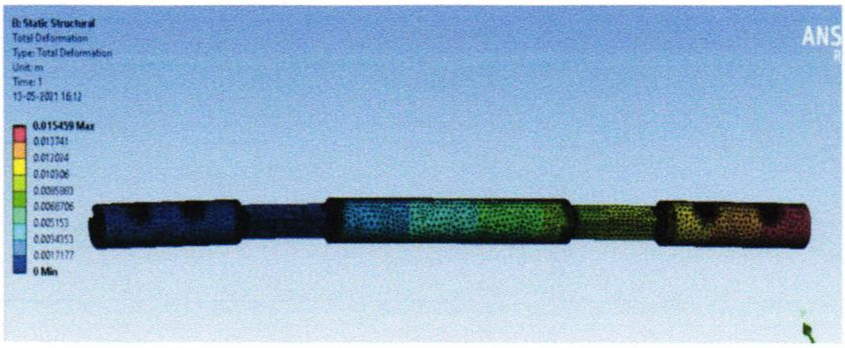


Figure 5.4.3: Steel Loaded under axial load of 5 N and longitudinal load of 300 N

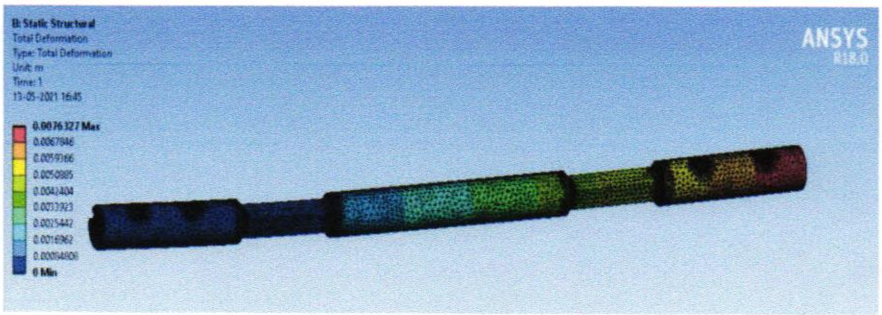


Figure 5.4.4: Steel Loaded under axial load of 150 N and longitudinal load of 5 N

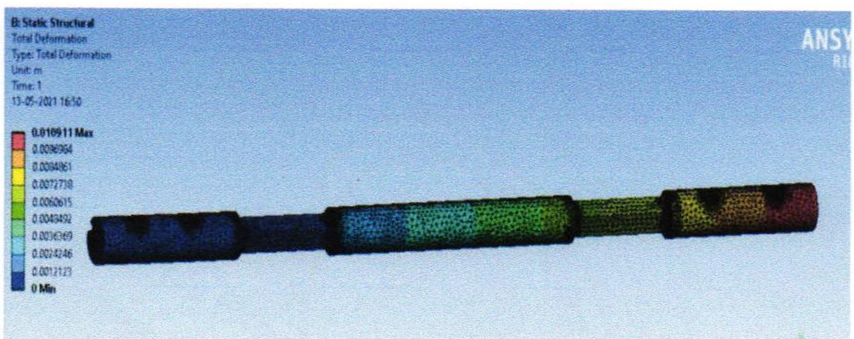


Figure 5.4.5: Steel Loaded under axial load of 150 N and longitudinal load of 150 N

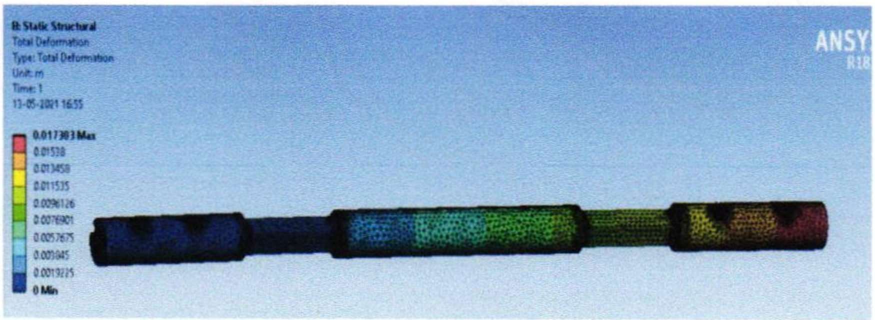


Figure 5.4.6: Steel Loaded under axial load of 150 N and longitudinal load of 300 N

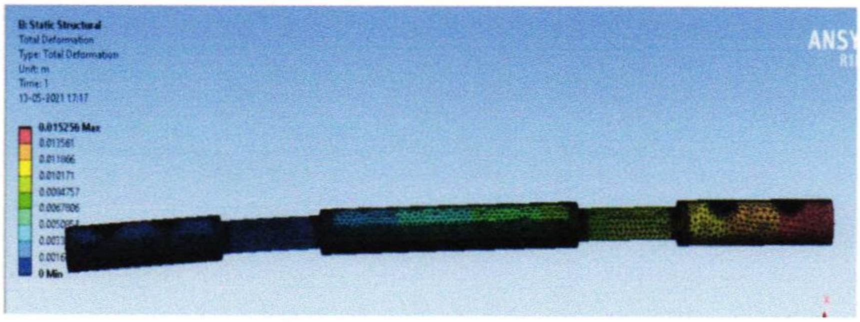


Figure 5.4.7: Steel Loaded under axial load of 300 N and longitudinal load of 5 N

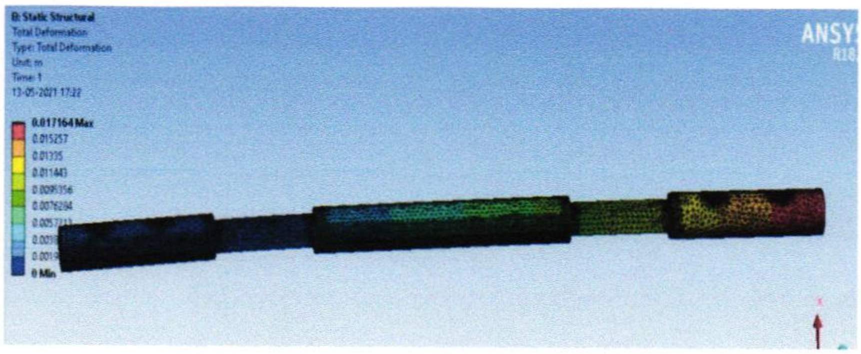


Figure 5.4.8: Steel Loaded under axial load of 300 N and longitudinal load of 150 N

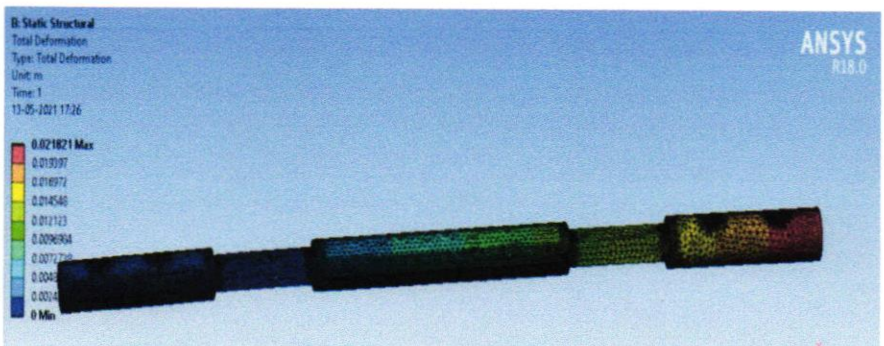


Figure 5.4.9: Steel Loaded under axial load of 300 N and longitudinal load of 300 N

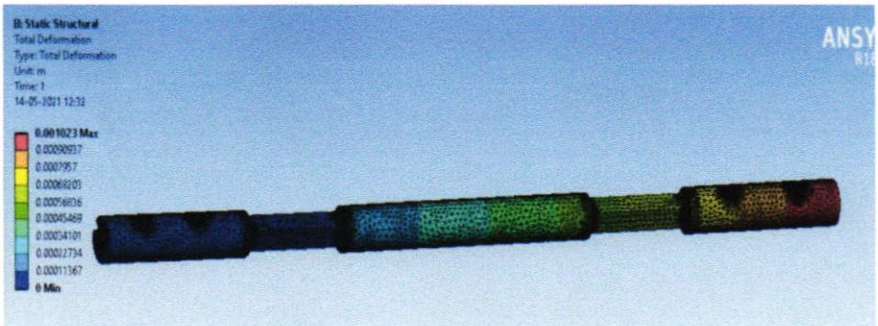


Figure 5.4.10: Aluminum beam Loaded under axial load of 5 N and longitudinal load of 5 N

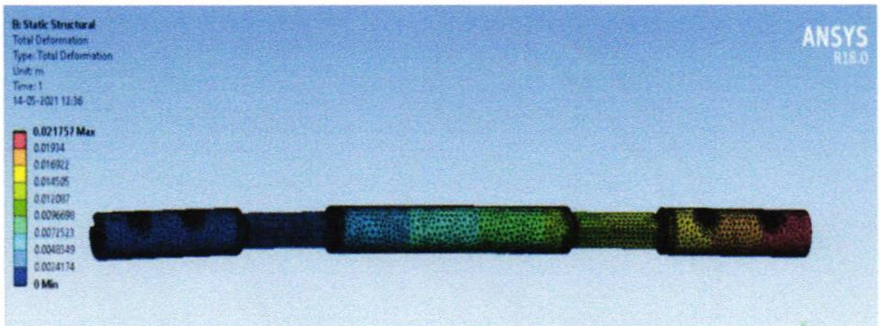


Figure 5.4.11: Aluminum beam Loaded under axial load of 5 N and longitudinal load of 150 N

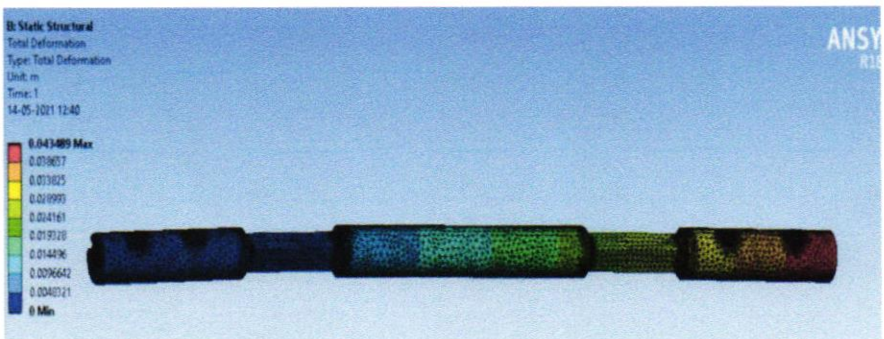


Figure 5.4.12: Aluminium beam Loaded under axial load of 5 N and longitudinal load of 300 N

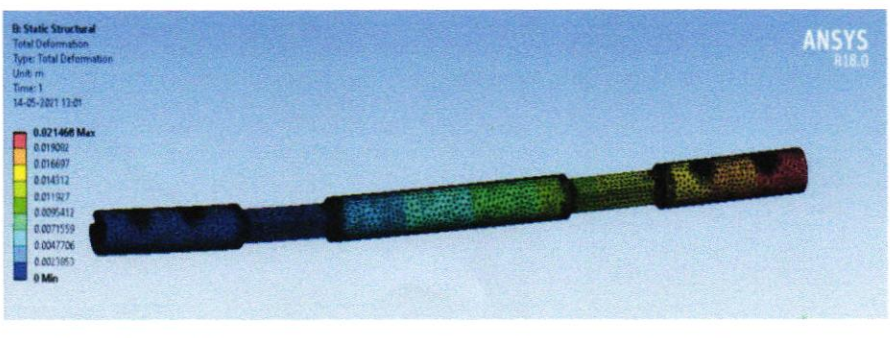


Figure 5.4.13: Aluminum beam Loaded under axial load of 150 N and longitudinal load of 5 N

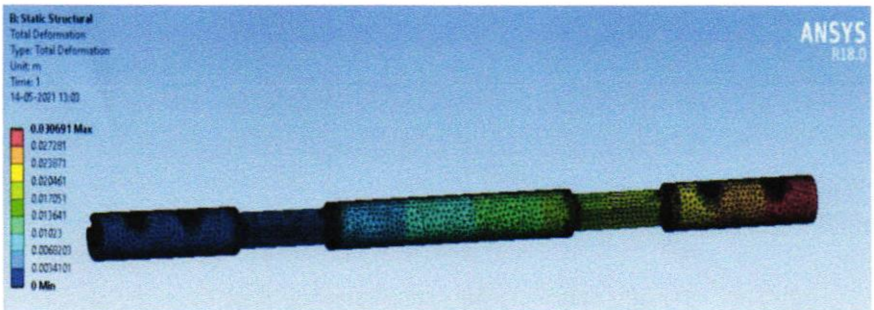


Figure 5.4.14: Aluminum beam Loaded under axial load of 150 N and longitudinal load of 150 N

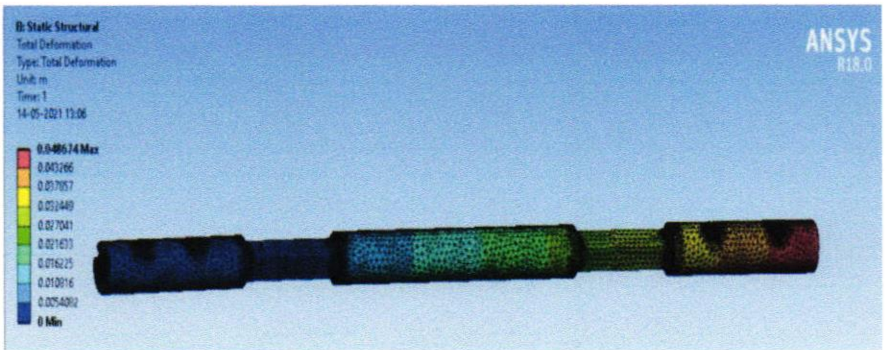


Figure 5.4.15: Aluminum beam Loaded under axial load of 150 N and longitudinal load of 300 N

Figure 5.4.16: Aluminium beam Loaded under axial load of 300 N and longitudinal load of 5 N

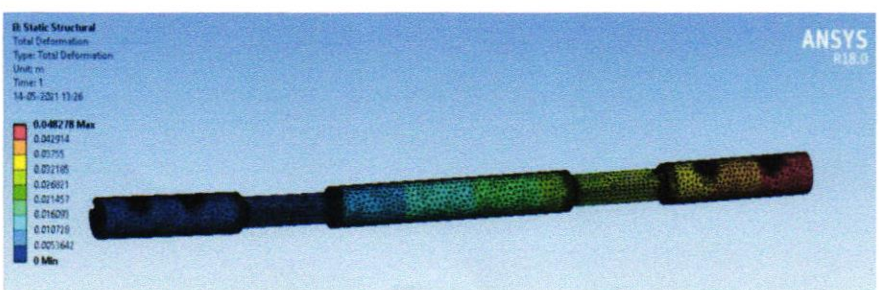


Figure 5.4.17: Aluminum beam Loaded under axial load of 300 N and longitudinal load of 150 N

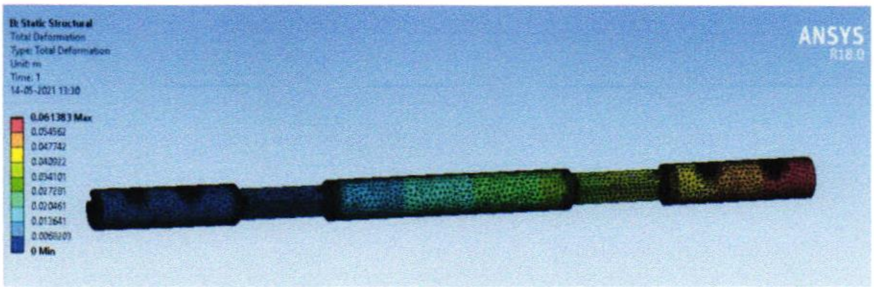


Figure 5.4.18: Aluminum beam Loaded under axial load of 300 N and longitudinal load of 300 N

Simulation is done according to the given loading conditions and the results are captured in table 4

Table 4: Tabulation of simulation results when balance is subjected to axial and longitudinal load

Loading in axial direction (N)	Loading in longitudinal direction (N)	Aluminium deflection (m)	Steel deflection (m)
5	5	0.001	0.0003
5	50	0.007	0.0025
5	100	0.014	0.0051
5	150	0.021	0.0077
5	200	0.029	0.01
5	250	0.036	0.012
5	300	0.043	0.0154
50	5	0.072	0.0025
50	50	0.01	0.0036
50	100	0.016	0.0057
50	150	0.023	0.0081
50	200	0.03	0.01
50	250	0.037	0.013
50	300	0.044	0.0156
100	5	0.014	0.005
100	50	0.016	0.0057

100	100	0.02	0.0072
100	150	0.026	0.0092
100	200	0.032	0.011
100	250	0.039	0.013
100	300	0.045	0.0163
150	5	0.021	0.0076
150	50	0.023	0.008
150	100	0.026	0.0092
150	150	0.0306	0.01
150	200	0.0362	0.012
150	250	0.042	0.015
150	300	0.0486	0.0176
200	5	0.0286	0.0101
200	50	0.0295	0.0105
200	100	0.0321	0.0114
200	150	0.036	0.0128
200	200	0.04	0.0145
200	250	0.046	0.0164
200	300	0.052	0.0185
250	5	0.035	0.0127
250	50	0.036	0.0129
250	100	0.038	0.0137
250	150	0.042	0.0149
250	200	0.046	0.0164
250	250	0.051	0.0181
250	300	0.056	0.02
300	5	0.042	0.0152
300	50	0.0435	0.0154
300	100	0.045	0.0161
300	150	0.048	0.0171

300	200	0.052	0.0184
300	250	0.0564	0.02
300	300	0.0613	0.0218

The results for the simulation and theoretical results are observed and the results are shown in graphical form.

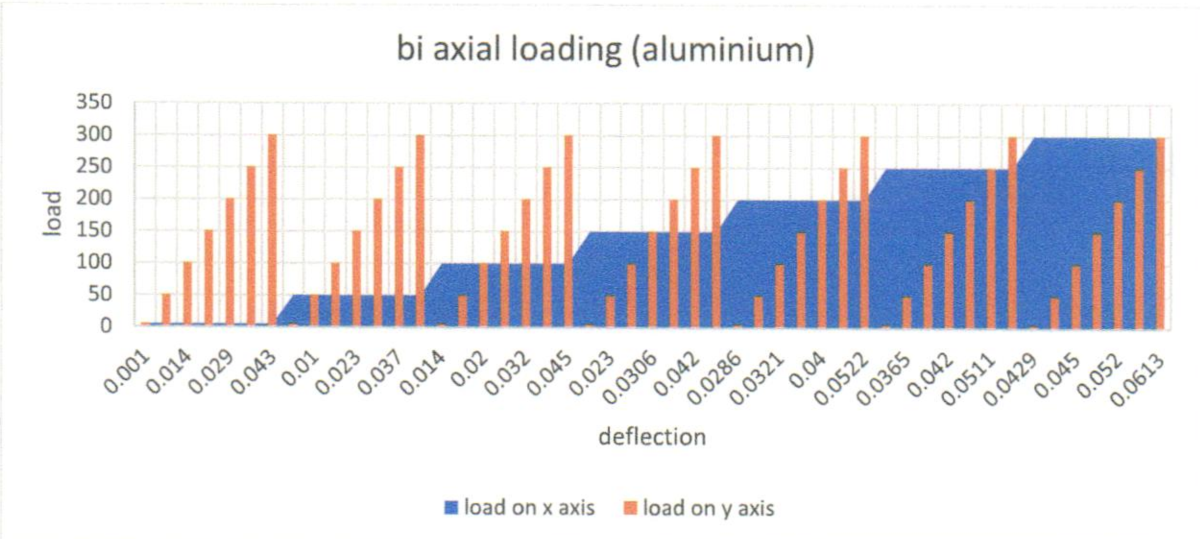


Figure 5.4.19: Graphical representation of results when aluminum balance is subjected to axial loading and longitudinal loading

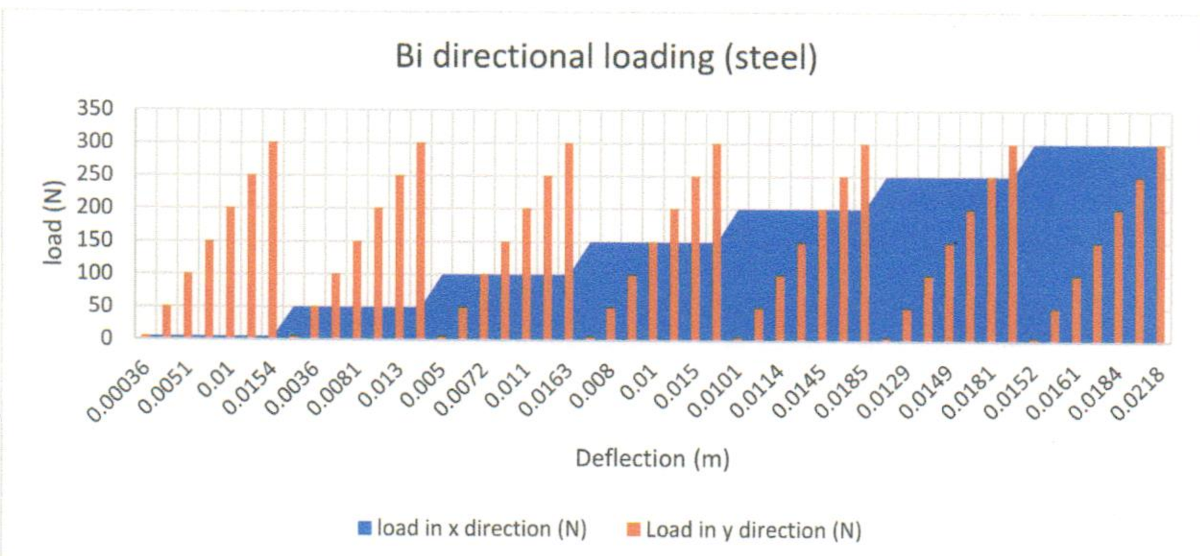


Figure 5.4.20: Graphical representation of results when steel balance is subjected to axial loading and longitudinal loading

5.4.2 Theoretical calculation

Consider a cantilever beam subjected to axial load of 5 N and longitudinal load of 5 N.

For deflection of a cantilever beam subjected to both axial and longitudinal load

$\delta = (W/P)\ (L*(TanU/U) - L)$

$U = L(sqrt(p/EI)$

Where p = axial load

W = longitudinal load

L = length of beam

By the above-mentioned formula, we calculated the deflection of beam with varying longitudinal load and axial load for aluminium and steel and the results are tabulated in table 5.

Table 5: Tabulation of theoretical results when balance is subjected to axial and longitudinal load

Axial load (N)	Longitudinal Load (N)	Deflection Aluminium (m)	Deflection Steel (m)
5	5	0.0006	0.0002
5	50	0.006	0.002
5	100	0.0120	0.004
5	150	0.0181	0.006
5	200	0.0241	0.0082
5	250	0.0302	0.0103
5	300	0.0362	0.0123
50	5	0.0006	0.0002
50	50	0.006	0.0020
50	100	0.012	0.0041
50	150	0.018	0.0062
50	200	0.024	0.0083
50	250	0.030	0.010

50	300	0.037	0.012
100	5	0.0006	0.0002
100	50	0.0063	0.002
100	100	0.0126	0.004
100	150	0.0190	0.006
100	200	0.025	0.008
100	250	0.0317	0.010
100	300	0.038	0.012
150	5	0.0006	0.0002
150	50	0.0065	0.002
150	100	0.0130	0.004
150	150	0.0195	0.006
150	200	0.0260	0.008
150	250	0.0325	0.01
150	300	0.0390	0.012
200	5	0.0006	0.0002
200	50	0.0066	0.002
200	100	0.0133	0.004
200	150	0.02	0.006
200	200	0.026	0.0085
200	250	0.0334	0.010
200	300	0.0400	0.0127
250	5	0.0006	0.0002
250	50	0.0068	0.002
250	100	0.0137	0.004
250	150	0.0206	0.006
250	200	0.0274	0.008
250	250	0.0343	0.010
250	300	0.0411	0.012
300	5	0.0007	0.0002

300	50	0.007	0.002
300	100	0.014	0.004
300	150	0.0211	0.006
300	200	0.0282	0.008
300	250	0.0359	0.010
300	300	0.0423	0.013

Theoretical results are tabulated for the given loading conditions and shown graphically to compare the deformation with aluminum and steel

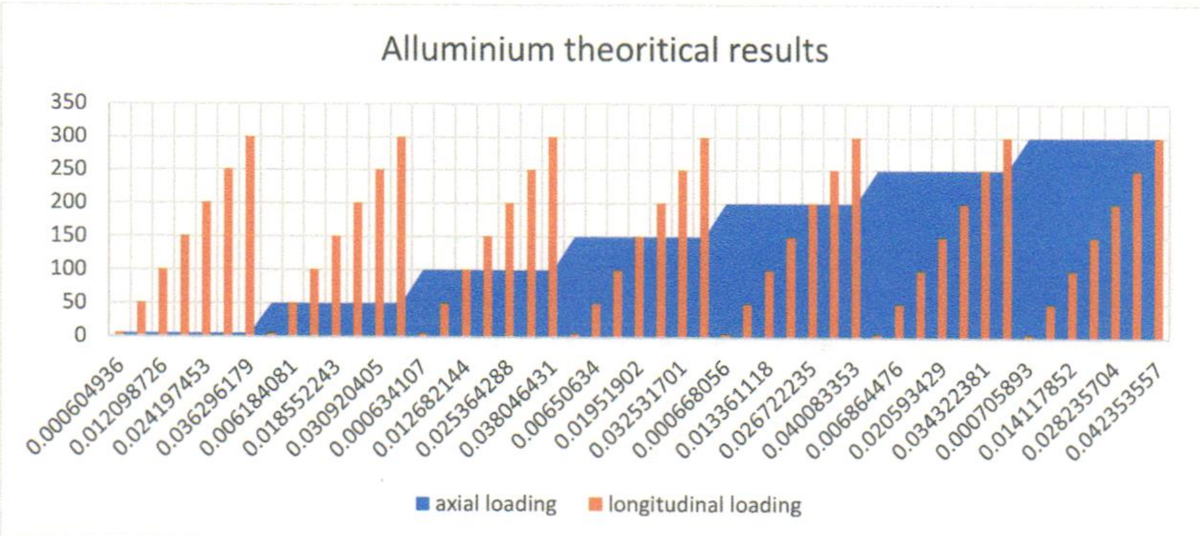


Figure 5.4.21: Graphical representation of theoretical results when aluminum beam is subjected to axial and longitudinal load

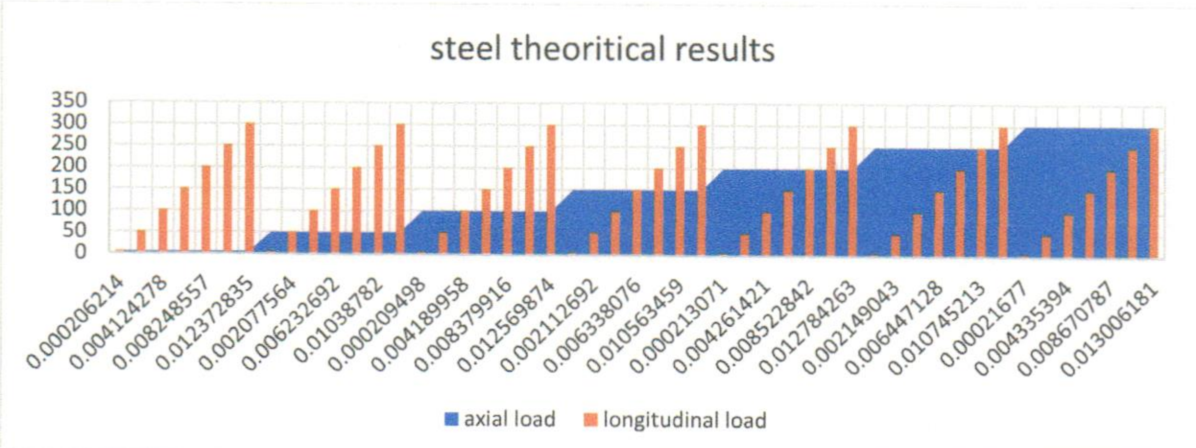


Figure 5.4.22: Graphical representation of theoretical results when steel beam is subjected to axial and longitudinal load

5.5 Loading with moment and longitudinal load

Balance is analyzed under the combination of longitudinal load and torque

5.5.1 Simulation results

The simulation results are been analyzed under the combination of longitudinal load and moment and the results are shown below pictorially.

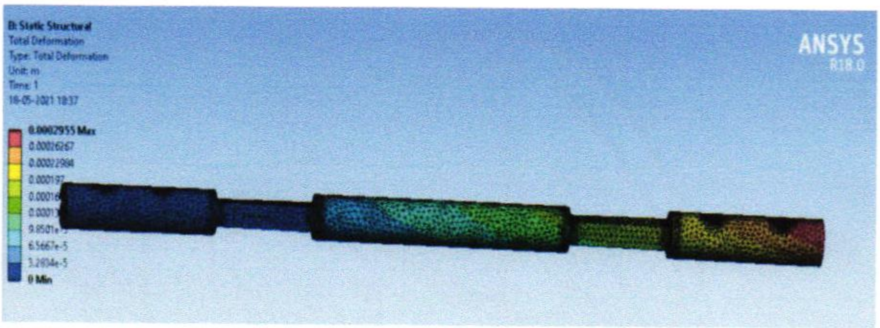


Figure 5.5.1: Steel beam subjected to moment 2 Nm and longitudinal load of 5 N

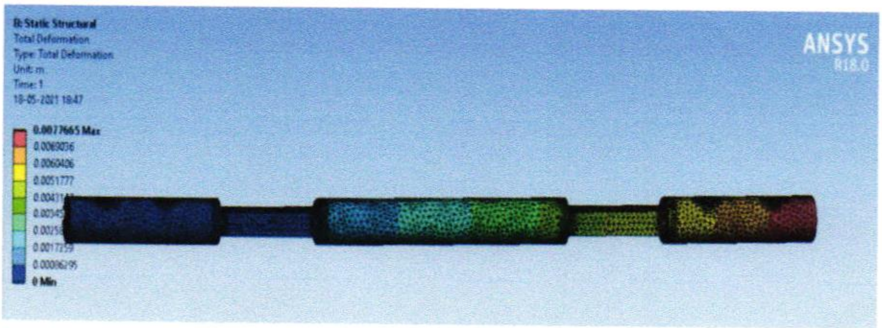


Figure 5.5.2: Steel beam subjected to moment 2 Nm and longitudinal load of 150 N

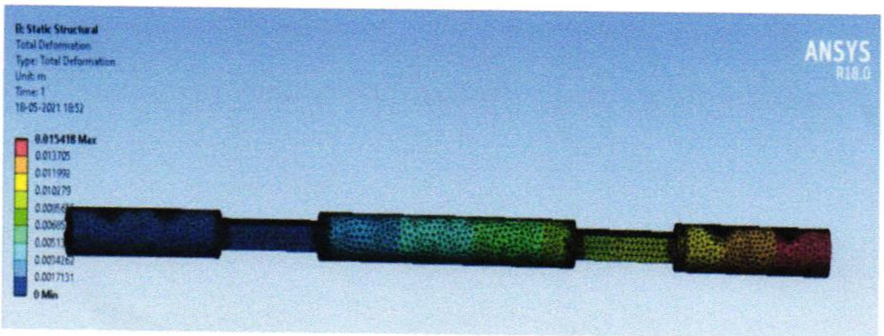


Figure 5.5.3: Steel beam subjected to moment 2 Nm and longitudinal load of 300 N

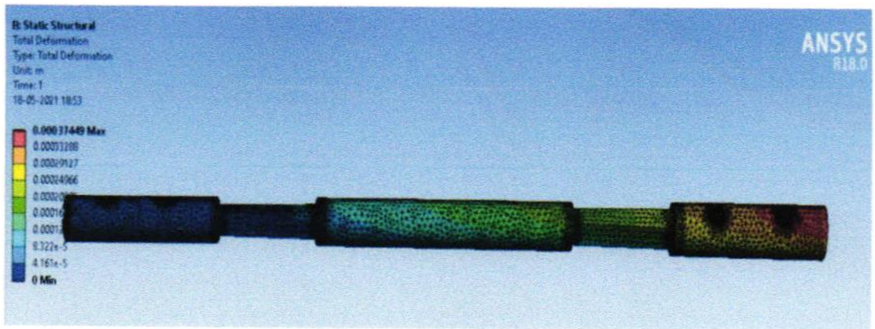


Figure 5.5.4: Steel beam subjected to moment 6 Nm and longitudinal load of 5 N

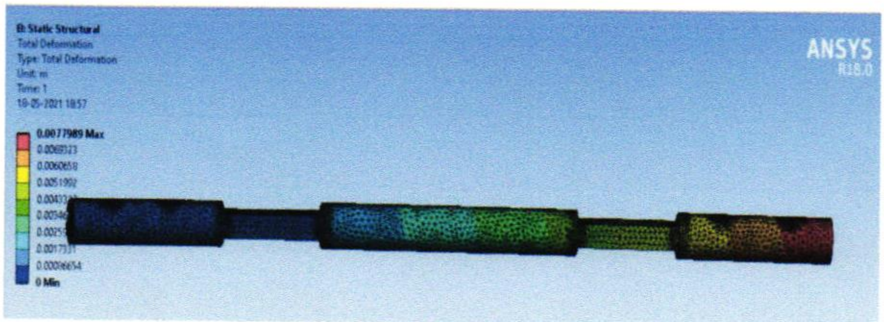


Figure 5.5.5: Steel beam subjected to moment 6 Nm and longitudinal load of 150 N

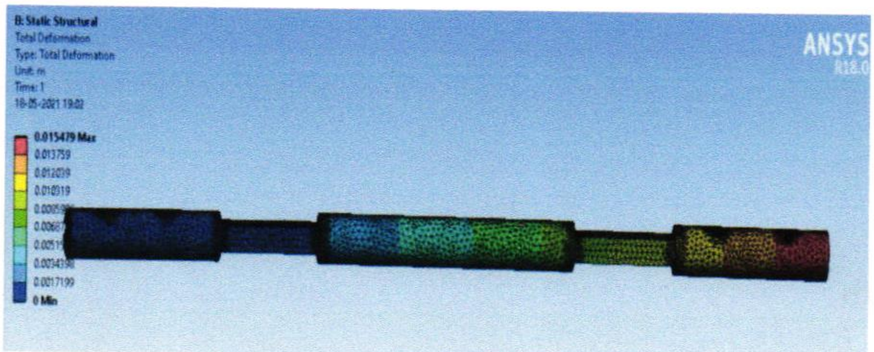


Figure 5.5.6: Steel beam subjected to moment 6 Nm and longitudinal load of 300 N

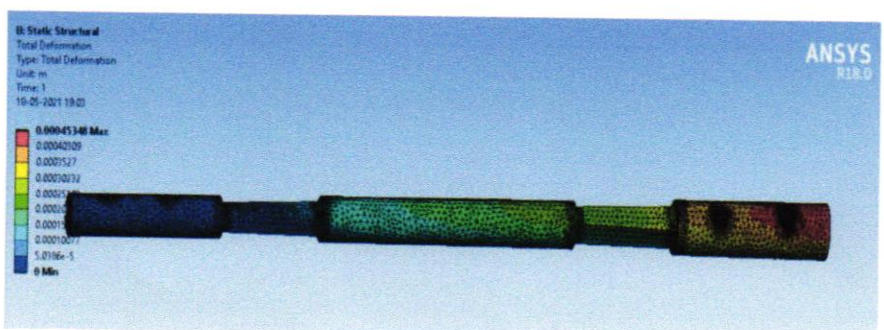


Figure 5.5.7: Steel beam subjected to moment 10 Nm and longitudinal load of 5 N

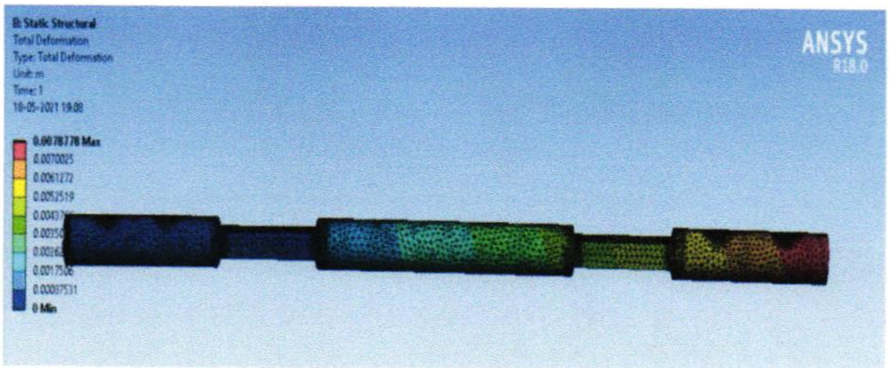


Figure 5.5.8: Steel beam subjected to moment 10 Nm and longitudinal load of 150 N

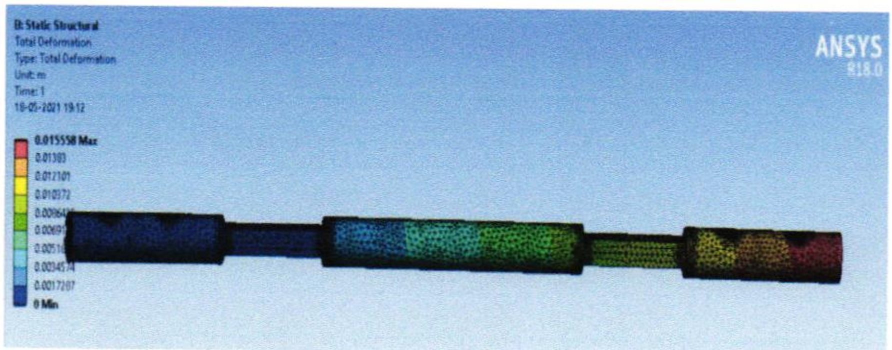


Figure 5.5.9: Steel beam subjected to moment 10 Nm and longitudinal load of 300 N

Figure 5.5.10: Aluminum beam subjected to moment 2 Nm and longitudinal load of 5 N

Figure 5.5.11: Aluminum beam subjected to moment 2 Nm and longitudinal load of 150 N

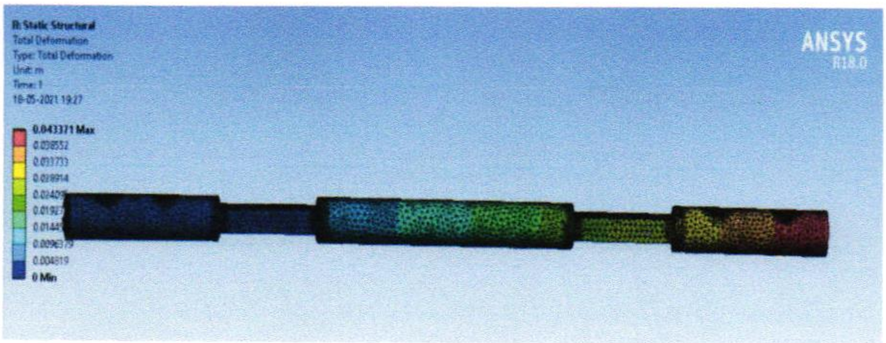


Figure 5.5.12: Aluminum beam subjected to moment 2 Nm and longitudinal load of 300 N

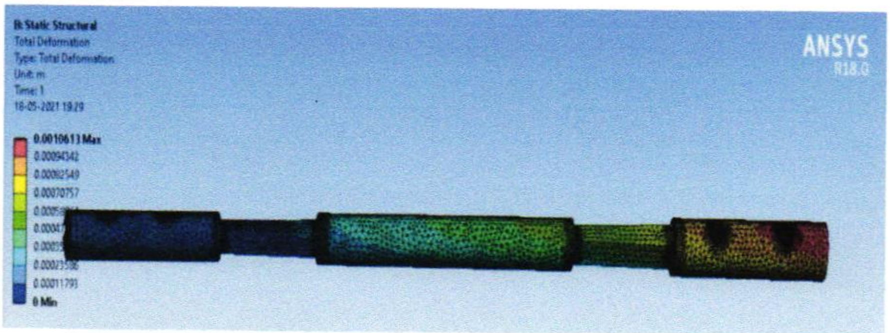


Figure 5.5.13: Aluminum beam subjected to moment 6 Nm and longitudinal load of 5 N

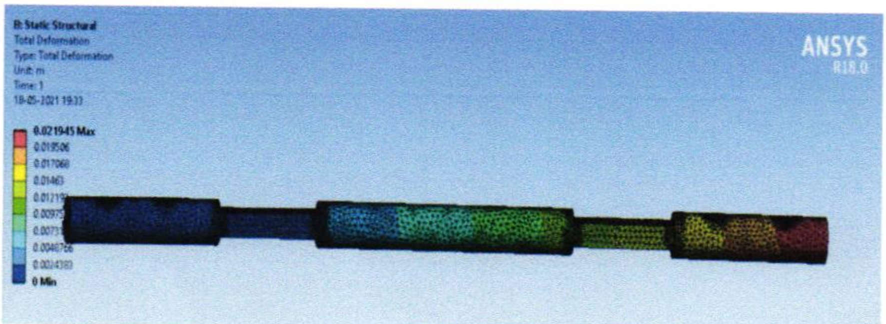


Figure 5.5.14: Aluminum beam subjected to moment 6 Nm and longitudinal load of 150 N

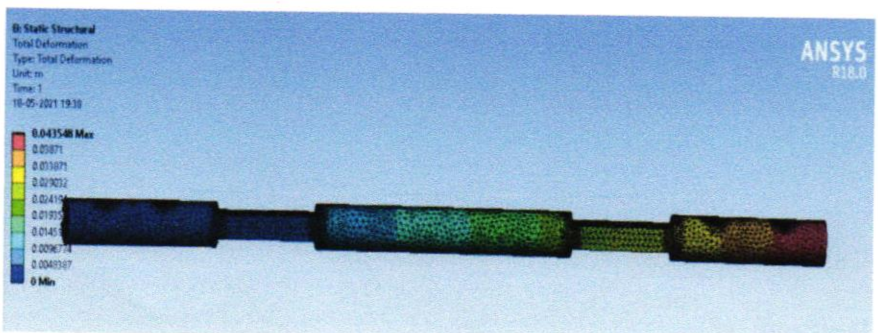


Figure 5.5.15: Aluminum beam subjected to moment 6 Nm and longitudinal load of 300 N

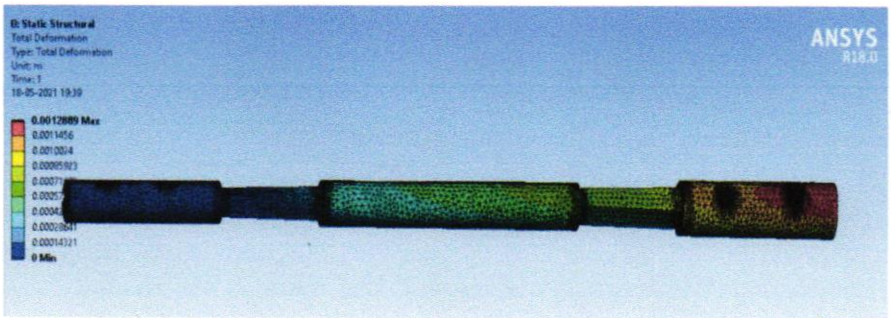


Figure 5.5.16: Aluminum beam subjected to moment 10 Nm and longitudinal load of 5 N

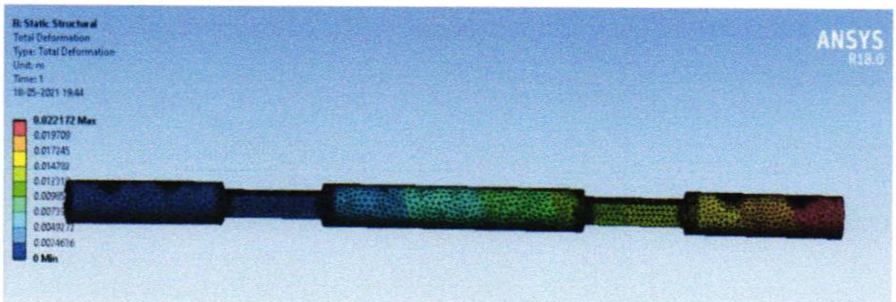


Figure 5.5.17: Aluminum beam subjected to moment 10 Nm and longitudinal load of 150 N

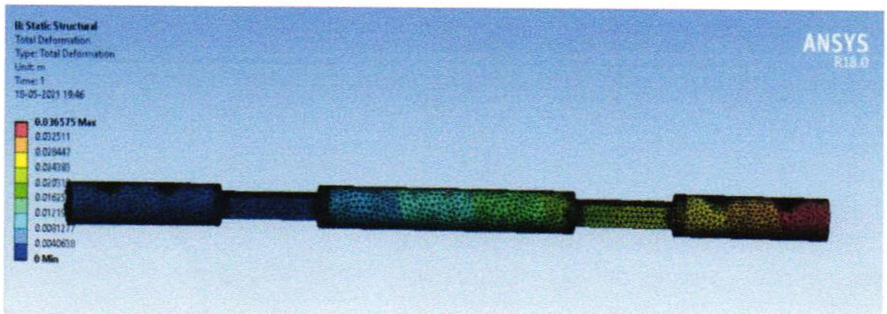


Figure 5.5.18: Aluminum beam subjected to moment 10 Nm and longitudinal load of 300 N

Stress Analysis

Stress is a major concern while considering the combined loading. So, the stress analysis had been done for the given loading conditions with two different materials.

Figure 5.5.19: Steel beam subjected to torque of 2 Nm and axial load of 5 N

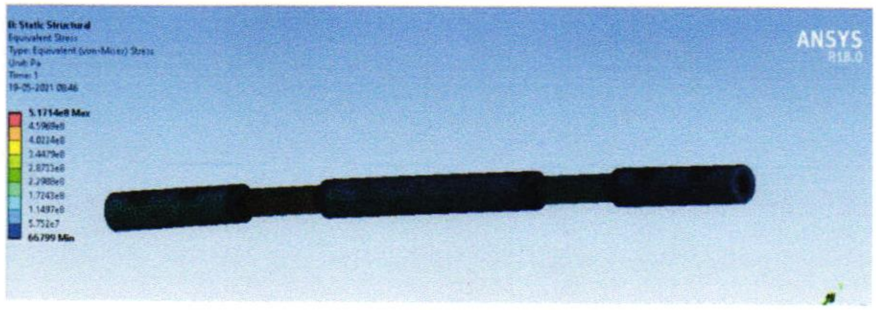


Figure 5.5.20: Steel beam subjected to torque of 6 Nm and axial load of 150 N

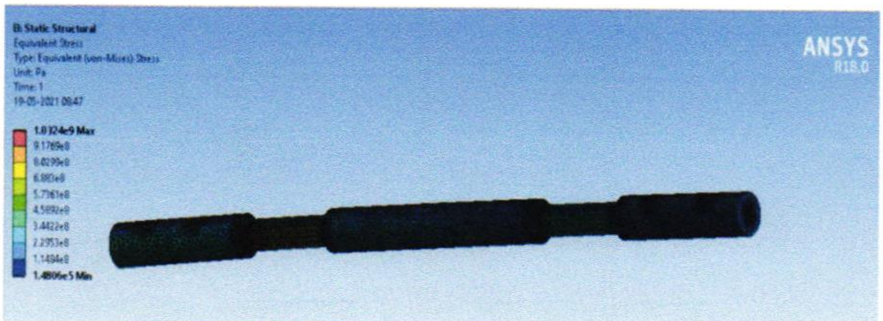


Figure 5.5.21: Steel beam subjected to torque of 10 Nm and axial load of 300 N

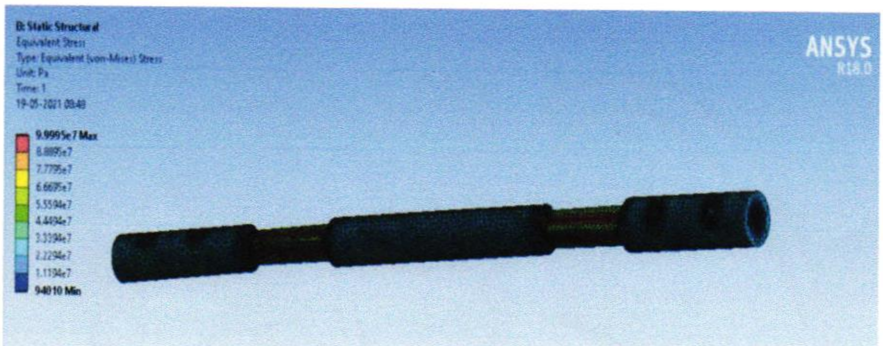


Figure 5.5.22: Steel beam subjected to torque of 6 Nm and axial load of 5 N

Figure 5.5.23: Steel beam subjected to torque of 6 Nm and axial load of 150 N

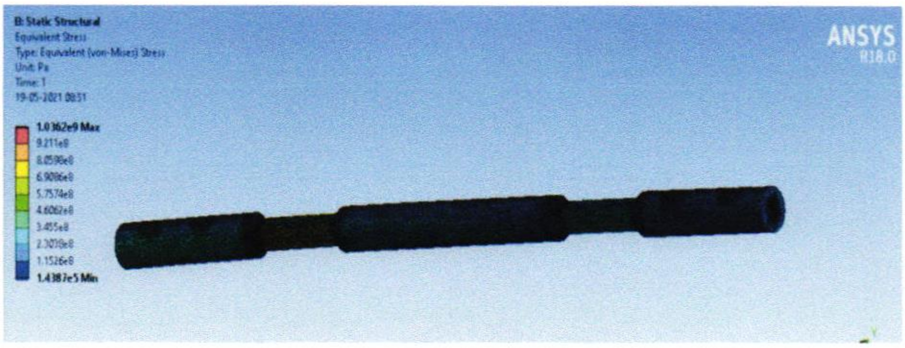


Figure 5.5.24: Steel beam subjected to torque of 6 Nm and axial load of 300 N

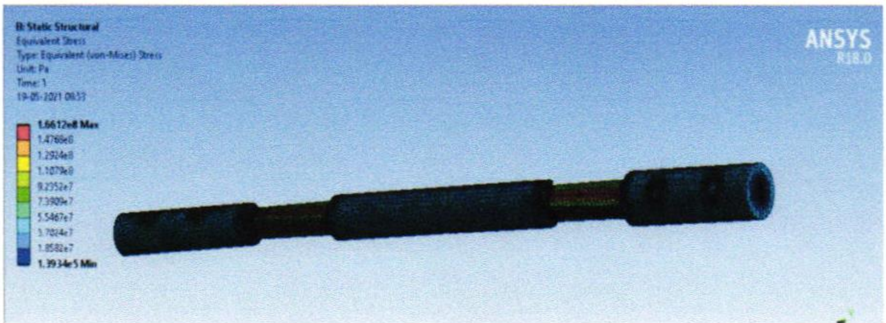


Figure 5.5.25: Steel beam subjected to torque of 10 Nm and axial load of 5 N

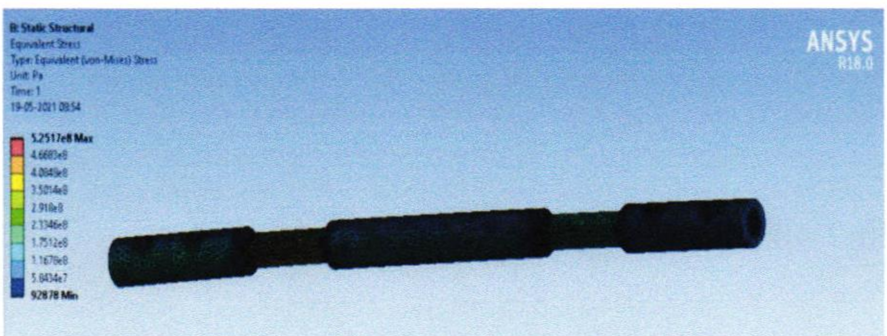


Figure 5.5.26: Steel beam subjected to torque of 10 Nm and axial load of 150 N

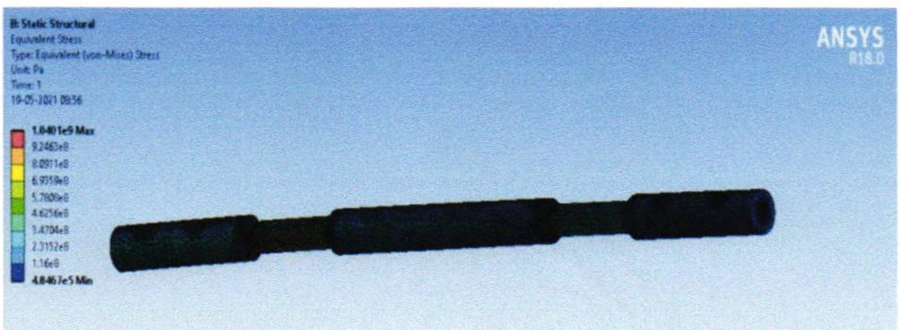


Figure 5.5.27: Steel beam subjected to torque of 10 Nm and axial load of 300 N

Figure 5.5.28: Aluminum beam subjected to torque of 2 Nm and axial load of 5 N

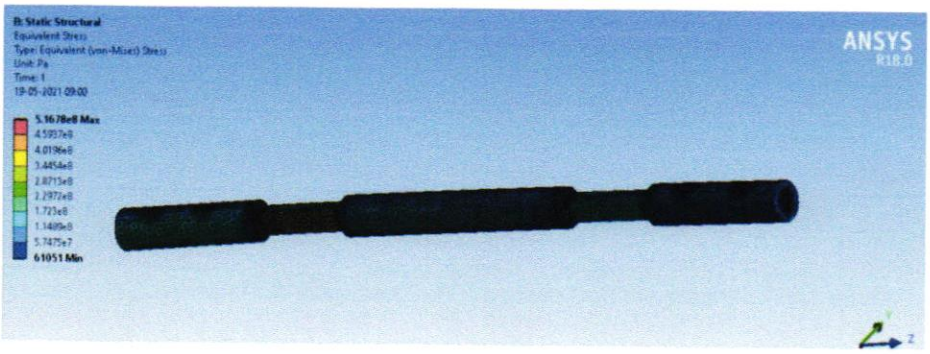


Figure 5.5.29: Aluminum beam subjected to torque of 2 Nm and axial load of 150 N

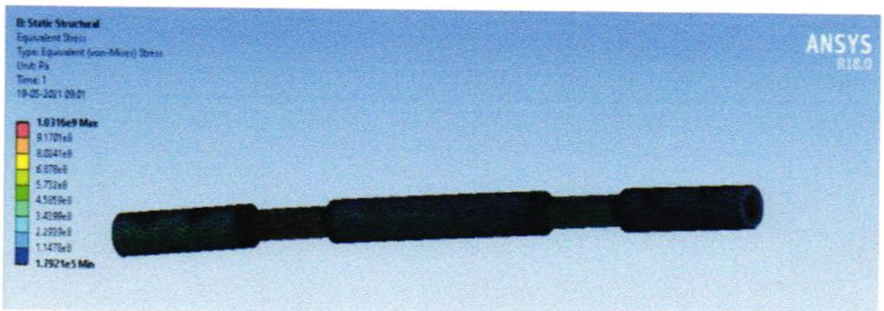


Figure 5.5.30: Aluminum beam subjected to torque of 2 Nm and axial load of 300 N

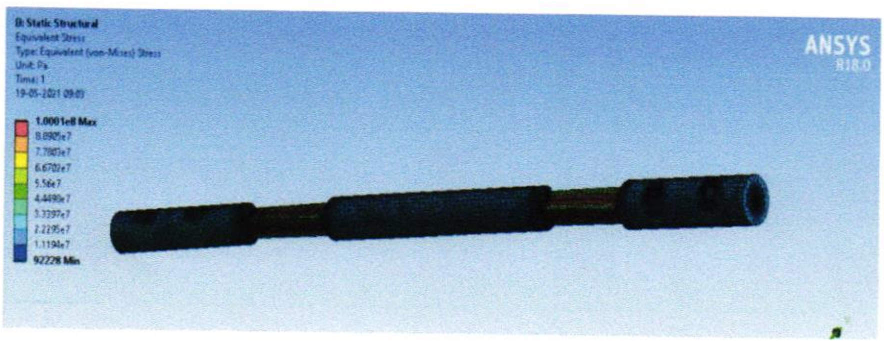


Figure 5.5.31: Aluminum beam subjected to torque of 6 Nm and axial load of 5 N

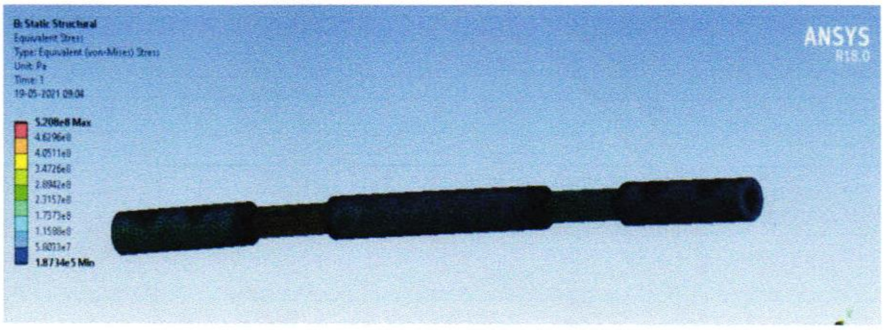


Figure 5.5.32: Aluminum beam subjected to torque of 6 Nm and axial load of 150 N

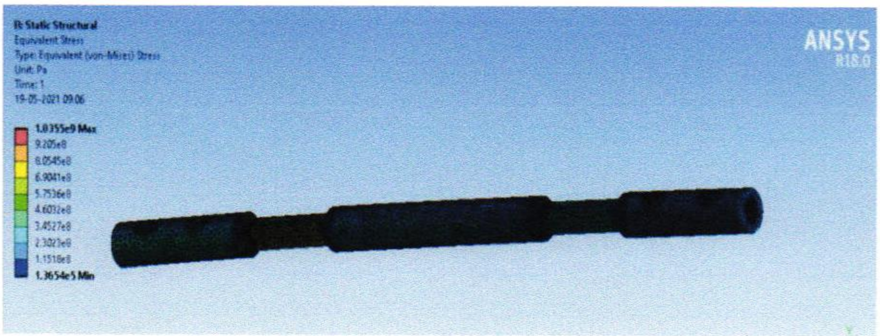


Figure 5.5.33: Aluminum beam subjected to torque of 6 Nm and axial load of 300 N

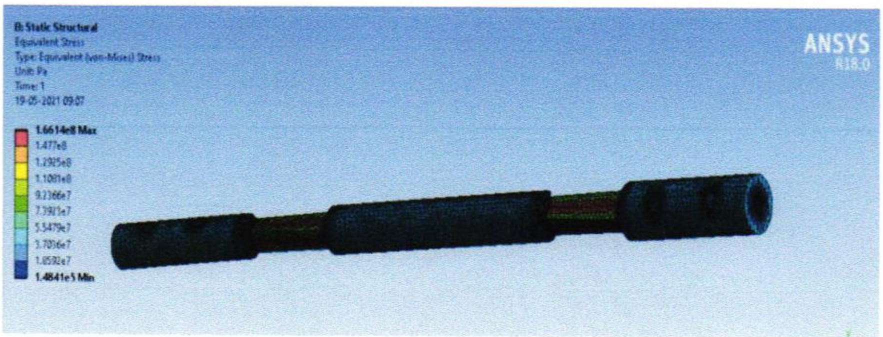


Figure 5.5.34: Aluminum beam subjected to torque of 10 Nm and axial load of 5 N

Figure 5.5.35: Aluminum beam subjected to torque of 10 Nm and axial load of 150 N

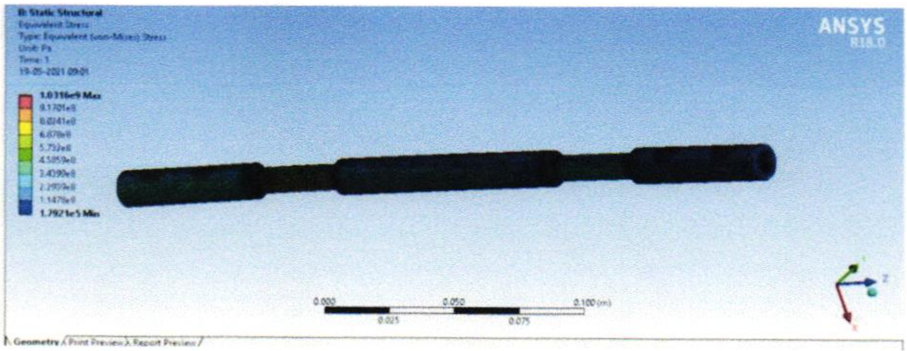


Figure 5.5.36: Aluminum beam subjected to torque of 10 Nm and axial load of 300 N

The results for the balance when it is subjected to given loading conditions are being tabulated. Table 6 shows the stress analysis results when the model is subjected to given loading conditions.

Table 6: Tabulation of simulated stress results

Torque (N/m)	**Lateral load (N)**	**Steel beam stress (N/m^2) (1*10^7)**	**Aluminum beam stress (N/m^2) (1*10^7)**
2	5	35.7	35.7
2	150	51.7	51.6
2	300	103	103
6	5	9.99	10
6	150	52.1	52
6	300	103	103
10	5	16.6	16.6
10	150	52.5	52.4
10	300	104	103

Deformation results are shown below in table 7 when the beam is subjected to given loading conditions.

Table 7: Tabulation of simulation results

Torsion (N/m)	Axial load (N)	Deflection Steel (m)	Deflection Aluminium (m)
2	5	0.00029	0.00083
2	50	0.0025	0.0073
2	100	0.0051	0.0145
2	150	0.0077	0.021
2	200	0.01	0.028
2	250	0.0128	0.036
2	300	0.0154	0.043
6	5	0.00037	0.001
6	50	0.0026	0.007
6	100	0.0052	0.0147
6	150	0.0077	0.0219
6	200	0.01	0.0291
6	250	0.0129	0.0363
10	300	0.0154	0.0435
10	5	0.0004	0.00128
10	50	0.0027	0.0077
10	100	0.0053	0.015
10	150	0.0078	0.022
10	200	0.01	0.029
10	250	0.0129	0.036
10	300	0.0155	0.044

Simulation and theoretical results are been calculated and are shown graphically below.

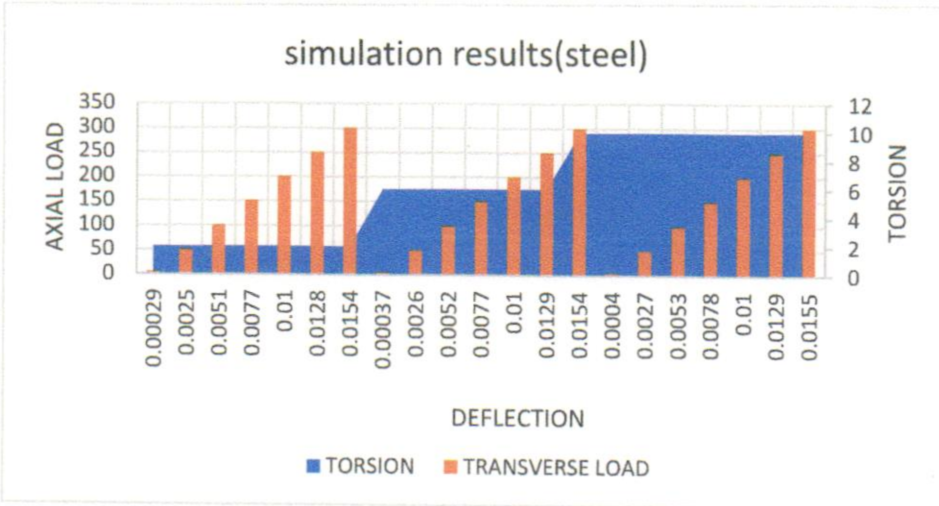


Figure 5.5.37: Graphical representation of steel balance when subjected to torque and axial load

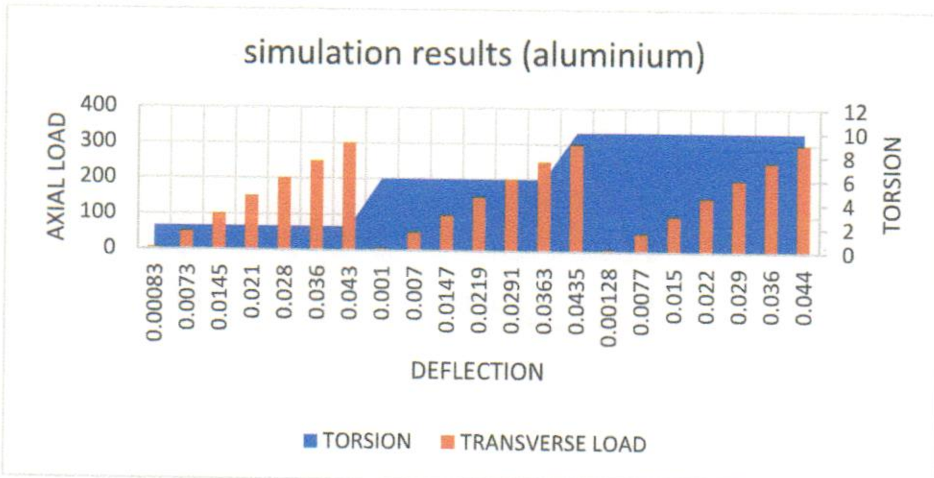


Figure 5.5.38: Graphical representation of aluminum balance when subjected to torque and axial load

5.6 Theoretical calculation

Here torsion produces angle of twist and the transverse force produces deflection

For aluminium;

Deflection due to longitudinal loading = $Wl^3/ 3EI$

For example, if 5 N longitudinal load is acting then;

$$\text{Deflection} = (5*0.3*0.3*0.3)/ (3*71.7*10^9 * 1.04*10^{-9})$$

$$= 0.000603 \text{ m}$$

For aluminium;

Deflection due to longitudinal loading = $Wl^3/ 3EI$

For example, if 5 N longitudinal load is acting then;

Deflection = (5*0.3*0.3*0.3)/ (3*210*10^9 * 1.04*10^{-9})

= 0.000206 m

Angle of twist = (TL)/(GJ)

WHERE; T = torsion

L = length of beam

G = rigidity modulus

(For aluminum = 26.9 Gpa and for steel 77.2Gpa)

J = Polar moment of inertia (3.14*(d^4))/32

On subsisting these values

We get;

Table 8: Tabulation of angle of twist results

Torsion (N/m)	Angle of twist (aluminum) (rad)	Angle of twist (STEEL) (rad)
2	0.257	0.179
6	0.772	0.538
10	1.28	0.89

Deformation results are shown in table 9 when the model is subjected to given loading conditions.

Table 9: Tabulation of theoretical results when balance is subjected to axial load and torque

Torsion (N/m)	Axial load (N)	Deflection Steel (m)	Deflection Aluminium (m)
2	50	0.002	0.006
2	100	0.004	0.012
2	150	0.0061	0.018
2	200	0.008	0.024
2	250	0.0103	0.03
2	300	0.0123	0.036

6	5	0.0002	0.0006
6	50	0.002	0.006
6	100	0.0041	0.0120
6	150	0.0061	0.0181
6	200	0.0082	0.024
6	250	0.0103	0.030
10	300	0.0123	0.036
10	5	0.0002	0.0006
10	50	0.002	0.006
10	100	0.0041	0.012
10	150	0.006	0.018
10	200	0.0082	0.0241
10	250	0.0103	0.0301
10	300	0.0123	0.0362

Theoretical and simulation results are calculated and the results are shown as a comparison between the balance with different materials.

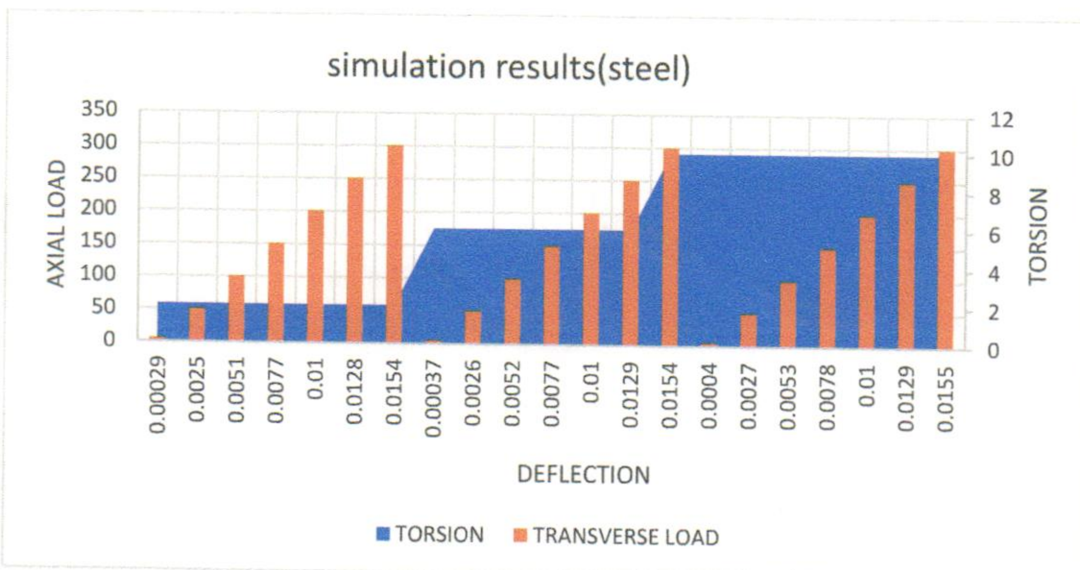


Figure 5.5.39: Graphical representation of steel beam when subjected to torque and axial load

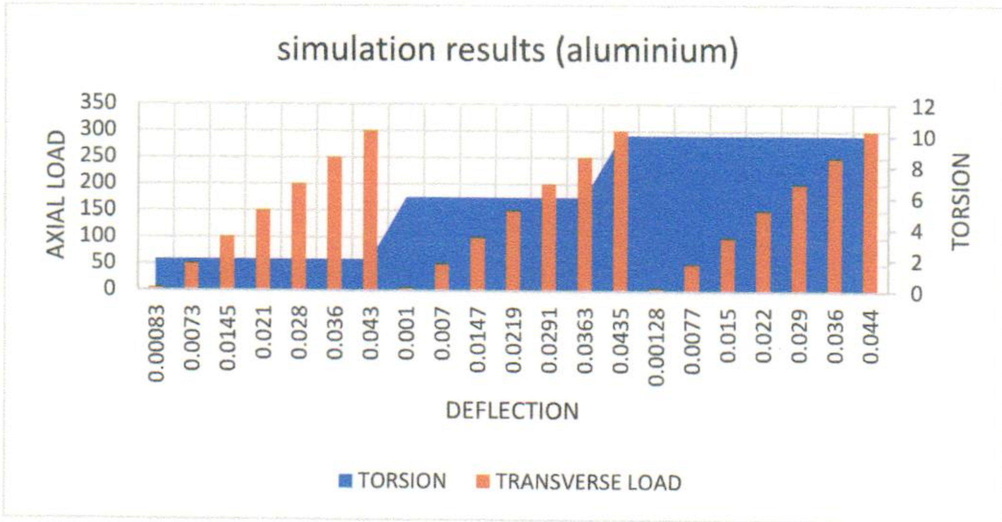


Figure 5.5.40: Graphical representation of aluminum beam when subjected to torque and axial load

CHAPTER 6

RESULTS AND DISCUSSION

Understanding the configuration of strain gauges involves, the placement and the connection of the strain gauges. The strain gauges should be placed in a Wheatstone bridge configuration and the circuit should be a closed circuit. If in a Wheatstone bridge, only one resistor is replaced by a strain gauge then the concerned circuit is said to be in quarter bridge configuration and if two resistors are replaced by strain gauges then it is said to be half bridge configuration. Similarly, if in a Wheatstone bridge configuration all the resistors are replaced by strain gauges then it is said to be full bridge configuration. Comparatively full bridge configurated circuit gives the maximum sensitivity.

The analysis is done by considering the loading in two different directions

Uni-directional loading

Combined loading

Uni-directional loading

Firstly, as of uni-directional loading the balance is subjected to longitudinal loading (lift) and observed a gradual increase in the deformation with respect to load. When the balance is subjected to axial loading (drag), the deformation is very small to consider. Deformation due to axial loading is to be considered in case of bi directional loading. When the balance is subjected to torque (pitching moment), the deformation due to moment is negligible but it produces twist in the balance which is a major concern of structural damage. Angle of twist is observed throughout the loading.

Combined loading

It comes into effect when two or more forces act on a balance. When both longitudinal load (lift) and axial load (drag) is acted on a balance, the major contribution for deflection is due to longitudinal loading. When longitudinal load (lift) and torque (pitching moment) is acted on the balance, longitudinal load produces the major deflection and the torque produces the twist. This is the case to be considered as there are more chances for structural failure. When axial load (drag) and torque (pitching moment) is acted on the balance, the deformation is observed under different loading conditions. In the case of combined loading, stress is also a major concern for the structural damage so the stress analysis is also been observed.

The sensitivity of the beam is been calculated by using the formulae for different strain gauge configuration. It had been observed that the sensitivity of the balance with full bridge configuration is more than any other different configurations. Generally, the sensitivity of full bridge configuration is twice the sensitivity of the quarter bridge configuration. The configuration also depends on type of loading. We had tried with quarter bridge configuration and the sensitivity had also been noted for different materials.

The model is mounted on the balance rigidly with the screws provided on the balance. The model gets in contact with the balance only at the point of contact with the strain gauges. The model is mounted on the balance with no contact for the sake of error less result extraction. The balance is connected with data acquisition system through the wires provided from the strain gauges. DAQ is connected to the balance with the help of serial connector. The wiring is done accordingly. The results are extracted in the form of report and graph using the DAQ report software.

The further scope of work is to practically analyze the beam under various loading conditions.

Figure 6.1: Fabricated Model

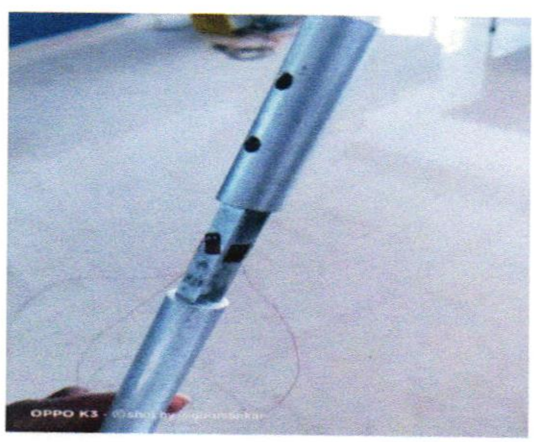


Figure 6.2: Fabricated Model with strain gauge

CHAPTER 7

CONCLUSION

If aluminum is used to fabricate three component internal strain gauge balance the load carrying capacity will be in the range of 1N to 100N. The sensitivity of this beam will be 1N if we use full bridge configuration. But the sensitivity decreases if we use half bridge configuration or quarter bridge configuration. If steel is used to fabricate three component internal strain gauge balance the load carrying capacity will be in the range of 5 N to 300 N. The sensitivity of this beam will be 5 N if we use full bridge configuration. But the sensitivity decreases if we use half bridge configuration or quarter bridge configuration. Reliability of steel and aluminum beam had also been verified using Ansys software,

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