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Design, Manufacturing and Analysis of Mild Steel and G.I Wire Composite Iso-truss Structure used in Engineering Applications.

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Abstract - In present engineering structures there are particular design for different types of loads. Bending cargo is stylish supported by 1- Beam while torsion cargo is by a concave indirect section. The ultimate end behind the change in cross section is the reduction of the weight and still provides the required strength to the element. Considering the below illustration, a 3- D stilt is been developed (to replace a solid or concave ray structure) named as ISOTRUSS. High weight and high strength mechanical elements. Due to the weight, tone weight stresses are convinced in the rudiments. colourful variations in the mechanical rudiments done to check the problem raised due to the weight of the element (e.g., I-Beam, Hollow Structures). This revision is still bettered by introducing a stilt structure named as ISOTRUSS. The Work in the design focuses on analysis, manufacturing & determining the cargo carrying capacity of ISOTRUSS. The analysis shows the relationships between the colourful characteristics (Bay length, ISOTRUSS diary distance), and the ISOTRUSS's bending cargo carrying capability.

1.INTRODUCTION

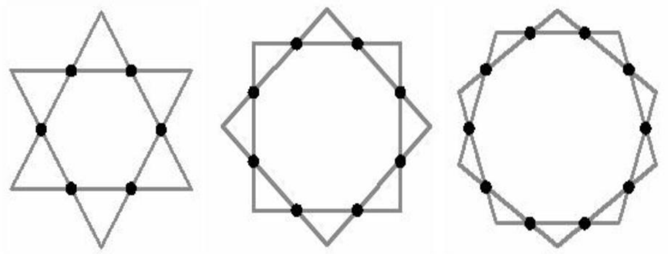
The IsoTruss is an illustration of a great idea. It is an open lattice advanced composite structure whose high strength-to-weight ratio makes it an innovative technology with many possible structural applications, from aerospace to bridge building.

Isotruss is a composite lattice structure composed of longitudinal and helical members. Multiple longitudinal members run the length of the structure spaced equally along a circumference about a central axis. These members primarily resist axial and bending forces. Pyramids with nodes at their apexes are formed as the helical members are twisted piecewise linearly around the central axis and intersect the longitudinal members.

Helical members primarily resist transverse shear and torsional forces, while stabilizing the longitudinal members against buckling. The geometry of a specific Isotruss structure is completely defined by the number of nodes around the circumference, *N*, the outer diameter, *D*, the number of full bays, N_b and the overall length, *L*.

Nodes are the furthest positions from the central longitudinal axis where the clockwise and anticlockwise helical elements connect. Antinodes are the innermost sites where the central axis and the clockwise and anticlockwise helical members cross. Antinodes are the innermost sites where the central axis and the clockwise and anticlockwise helical members cross. The intersections of inner longitudinal, clockwise, and anticlockwise helical members are known as transition nodes.

Number of nodes represents the geometry of the cross section of Isotruss. Number of nodes decides the profile of the helical members. A cross section of an isotruss with two triangles oriented at 180 degrees from one another is represented by a six-node isotruss. An eight-node configuration has two squares. A 10-node configuration will have two pentagons.



1.1 Isotruss Parameters

I. Bay length: - Bay length is the measurement of a repeating unit in longitudinal direction (distance from peak to peak).

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

II. Number of nodes: - there are two types of nodes in this classification;

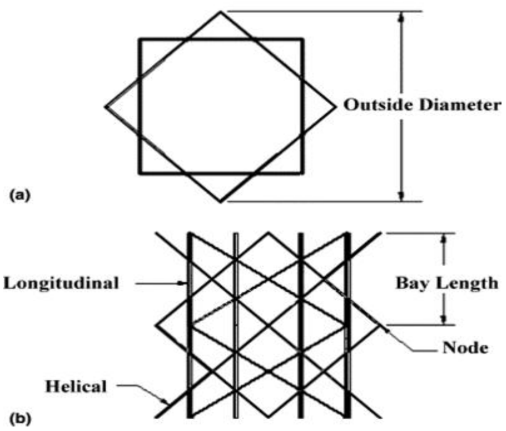
a) Six Nodes: - The six node IsoTruss structure is light weight and has a low moment of inertia, meaning that the mass distribution about the axis is minimal. The six node IsoTruss gets its name from the cross section's two triangles, which connect to form six nodes.

b) Eight Nodes: - Eight nodes are formed by the junction of the two squares in the cross section, giving it the name 8 node Isotruss. The eight-node structure is slightly heavier than 6 node structure, but has mass distribution away from the axis thus providing a larger moment of inertia. Due to the larger moment of inertia the eight-node structure is favourable in the buckling and bending loading conditions, but has poor performance in side impact loading.

III. Members of Isotruss

i) Longitudinal member: - These members are placed parallel to the axis of the Isotruss structure. Longitudinal members are for carrying axial and bending loads.

ii) Helical Members: - These members spiral around the longitudinal members like a helix. Depending on the nodes they form a triangle or a square cross section. Helical members resist the torsional and shear loads applied on the Isotruss structure. These members decrease the buckling length of the longitudinal members.



2. LITERATURE SURVEY

2.1 *Isotruss structures with outside longitudinal members in uniaxial compression: Dimensional Analysis and Optimisation.*

- Hanna B. Opdahl and David W. Jensen

The current study's goal is to describe how 8-node IsoTruss structures with exterior longitudinal elements buckle. The relationships between the governing design parameters and the critical buckling load are examined using a dimensional analysis. The critical buckling loads of diverse geometric dimensions are predicted using finite element (FE) modelling in ANSYS Workbench. The best-fit curves that indirectly relate the longitudinal radius, the helical radius, and the bay length to the critical buckling load are characterized as quadratic and power expressions. The FE predictions are also plotted with analytical predictions to assess the accuracy of the analytical expression for bay-level buckling with respect to FE methods. Similar patterns in the FE and analytical predictions are induced by changes in the longitudinal radius and bay length. However, the analytical and FE predictions do not show the same trends as increasing the helical radius. While the FE forecast grows as the helical radius does, the prediction from the analytical formula remains unchanged on.

2.2 *Local and Global buckling of ultra-lightweight Isotruss Structure.*

- Mary E. Rackliffe, David W. Jensen, Warren K. Lucas

This study investigates the local and global buckling behaviour of cantilevered IsoTruss composite grid structures that are lightly loaded and have a high aspect ratio. These structures have significant benefit in a variety of applications varying from towers to drive shafts to space structures. We looked at how different bay lengths and two counts in the longitudinal and helical elements affected buckling behaviour. By creating four alternative 3.0 m (118.0 in.) long IsoTruss structures using epoxy-pre-impregnated carbon fibre tows and testing them to failure in axial compression, the compressive behaviour of the 8-node configuration under study was examined and experimentally verified.

It was observed that the intersection between the local and global buckling curves occurs coincident with the optimal bay length.

2.3 *Buckling failure modes of one-dimensional lattice truss composite structures.*

- Qianqian Sui, Changliang Lai, and Hualin Fan

Through the research, compression failure modes of 1D LTCS composite column were revealed. Based on the buckling modes observed in experiments and FEM, theoretical models were proposed to predict the buckling load. It is found that with shorter column length, shorter

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bay length, thicker struts and smaller ratio of strut strength to stiffness, the lattice structure would collapse at fracture of the strut. Global buckling occurs when the column is long enough to cause it to fail. Column failure could be controlled by reducing the length of the column, shell-like buckling, and mono-cell buckling, in that order. Bay length is the key to distinguish the shell-like buckling and the mono-cell buckling. A longer bay length (higher helical member inclination) may cause the 1D LTCS to buckle immediately from global to mono-cell. All these failures can be well predicted by the theoretical models proposed in his paper.

3. METHODOLOGY

I. Design of Mandrel
- Using CREO software.

II. Mathematical Modelling
- Selecting dimensions for structure.
- Calculating co-ordinate points for design in ANSYS software.

III. Design of Structure
- Modeling of structure using ANSYS software.

IV. Analysis
- Structure analysis for various applied loads.
- For compression load carrying capacity.
- For bending load analysis.

V. Manufacturing of Mandrel
- Cut-off Machine: cutting of L-plates.
- Laser cutting Machine: for end-plates.
- Hand Grinder: slotting of L-plates.
- Radial Drilling Machine: end-plates and L-plates drilling.

VI. Manufacturing of Isotruss Structure
- Winding over the Internal mandrel.
- Joining of Nodes using Gas (CO_2) welding.

VII. Experimental Testing
- Experimental testing of structure, using UTM.

VIII. Comparison of Result
- Comparison between experimental result and analysis software results.

IX. Conclusion
- Conclusion based on the comparison of the results.

4. DESIGN OF MANDREL

The internal mandrel consists of the following parts, as per the requirement of the final Isotruss structure: -

I) End-plate
II) Base-plate
III) L-plate

4.1 End-plate

The end-plate is shown in figure 3.1. This type of end plate is used for eight nodded Isotruss structure. There is total sixteen holes provided on the end-plate. Eight holes are provided on the end-plates to support helical and longitudinal members. The remaining eight holes are provided to attach the base plates to end-plates, by using nuts and bolts. The position of the holes is decided on the basis of the diameter of the Isotruss structure.

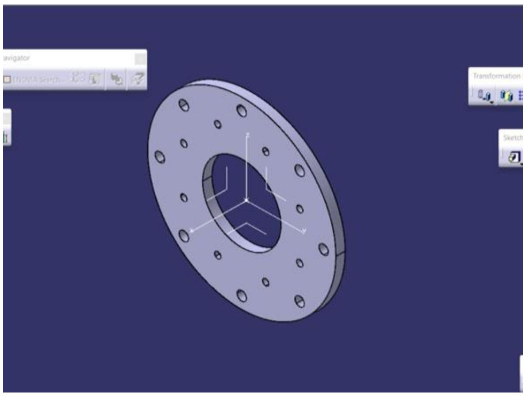

Fig-1: End Plate

4.2 Base-plate

The base plate, which is mounted between the two end-plates, is shown in figure 3.2. Eight base-plates are used for the mandrel manufacturing, all being at angle of 45 degrees with each other. Holes are provided on the base plate at a distance equal to the bay length of the Isotruss structure, for mounting the L-plates.

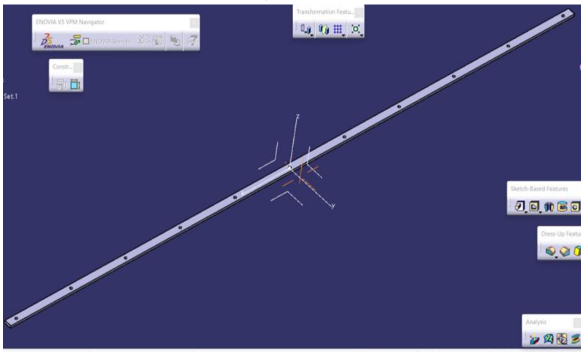

Fig-2: Base Plate

4.3 L-plate

L-plate, which acts as the base for joining of the helical members, is shown in figure 4.3.1. At the L-plates the external nodes of the Isotruss are formed as a result of two intersecting helical members. L-plates are provided with a

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slot at one end, to act as base for the intersecting helical members, and a hole at the other end, for the bolting.

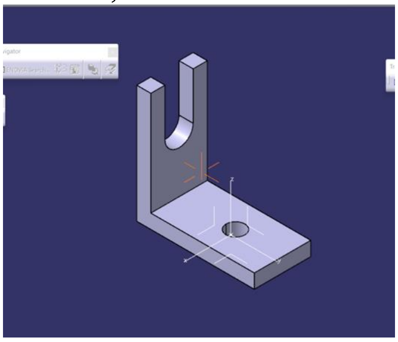

Fig-3: L-plate

5. MATHEMATICAL MODELLING

Isotruss Structure is to be designed of following specification:
1. Length : 1000mm
2. Inner diameter : 80mm
3. Bay length : 160mm
4. Crown length : 100mm

Co-ordinate	X	Y	Z
L1	36.953	15.307	0
L2	15.307	36.953	0
L3	-15.307	36.953	0
L4	-36.953	15.307	0
L5	-36.953	-15.307	0
L6	-15.307	-36.953	0
L7	15.307	-36.953	0
L8	36.953	-15.307	0

Table-1: **Co-ordinates of Internal Node Points**
Table-2: Co-ordinates of External Node Points

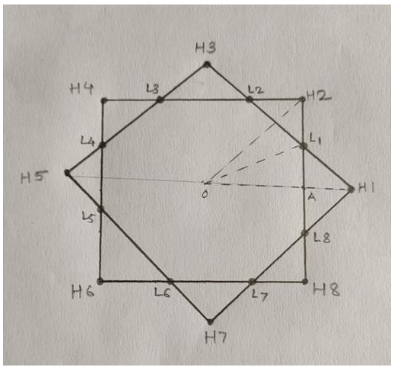

Fig-4: Top view of Isotruss Structure

By using Trigonometric Functions, we calculated co-ordinates of each node.

6. DESIGN OF ISOTRUSS STRUCTURE

For element creation, line geometry is required in the software. By joining generated node points to form the Isotruss structure, the pre-processing of the element

Co-ordinate	X	Y	Z
H1	52.26	0	100
H2	36.953	36.95	100
H3	0	52.26	100
H4	-36.953	36.953	100
H5	-52.26	0	100
H6	-36.953	-36.953	100
H7	0	-52.26	100
H8	36.953	-36.953	100

creation is done. Node by node joining is required for finer element creation. The sequence of node joining process is as follows

- Joining of helical members
- Joining of crown members

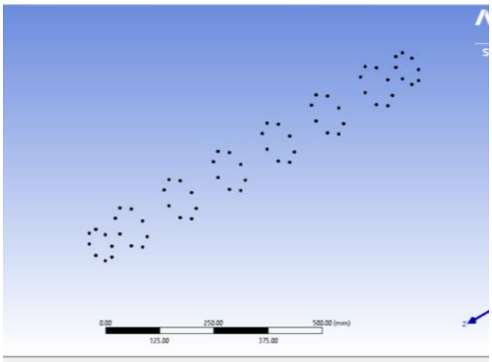

Fig-5: Plotting of Node Points

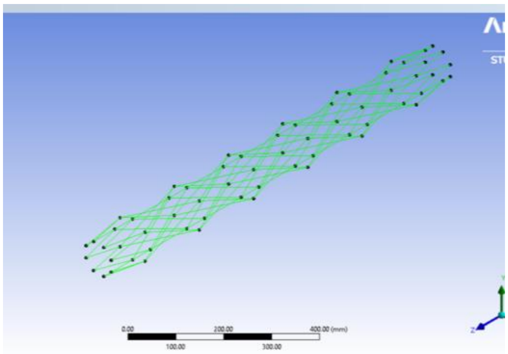

Fig-6: Final Isotruss Structure after joining of Node Points

6.1. Creation of Elements and Geometry

The elements are created according to the design of the Isotruss structure. The diameter of the G.I. wire used, for the formation of Isotruss structure, is 3 mm and properties of the G.I. wire are assigned to the elements.
Once the final geometry has been formed, the next step is the modelling of the geometry. The first step in modelling is meshing. The element size for meshing was kept as the

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

default value in ANSYS, for analysis. The geometry after meshing is shown below:

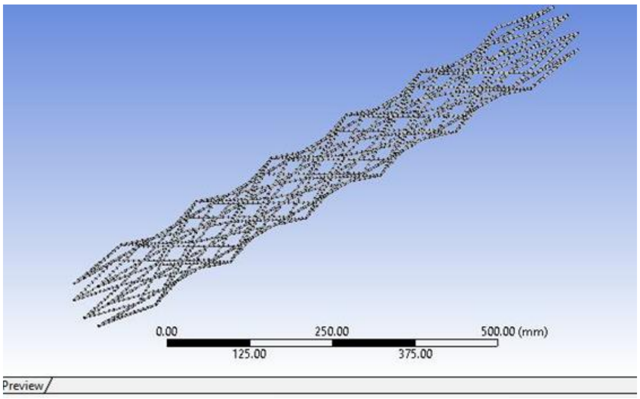

Fig-7: Meshed Geometry of Isotruss Structure

6.2 Analysis of Structure and Results

The meshed structure is analysed for the bending. The two ends of the Isotruss structure were fixed and three-point bending test was performed on ANSYS. Following results were obtained for the bending analysis. Total deformation obtained is shown in figure below.

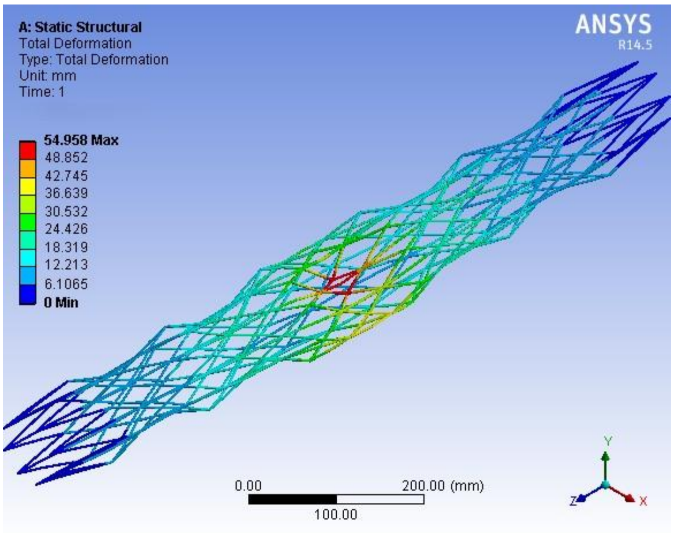

Fig-8: Maximum deformation obtained in bending analysis

The same structure, G.I. wire Isotruss structure, is analysed under the compressive loading condition, giving the maximum deformation of 0.0889 mm. The result for total deformation is shown below, with the maximum and minimum values of the deformation.

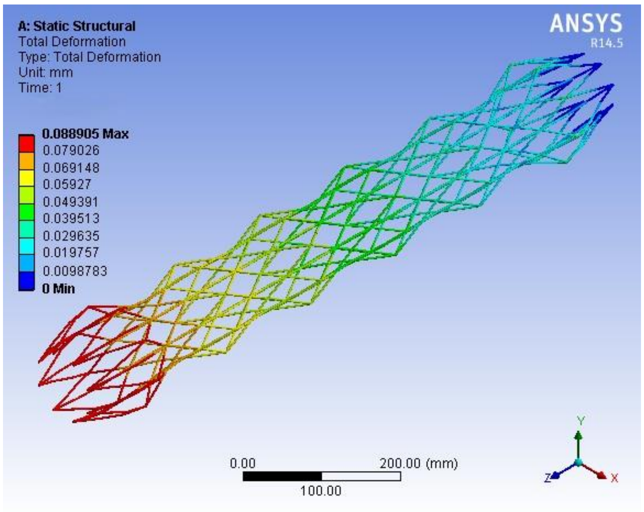

Fig-9: Maximum deformation of G.I. wire Isotruss structure in compression analysis

Compression analysis is also performed for the carbon fibre Isotruss structure, to have a comparison between the two structures. Under the compressive load, the total maximum deformation of the Isotruss is 0.0711 mm, which is closer to the maximum deformation of the G.I. wire Isotruss structure, under similar loading conditions. The result of total deformation, under compressive load, is shown below.

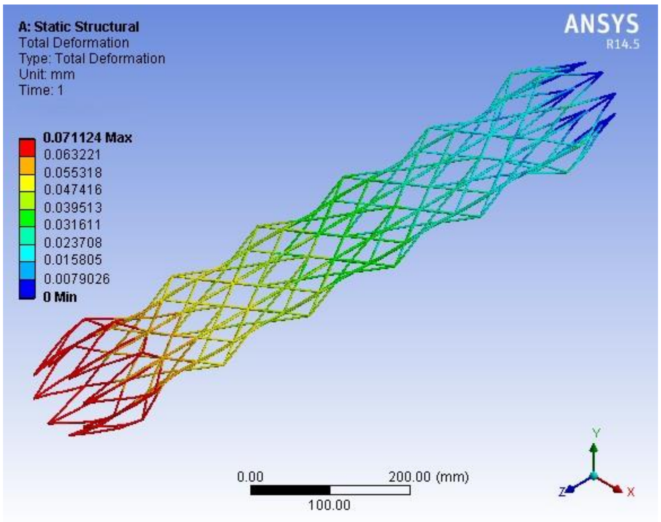

Fig-10: Maximum deformation of carbon composite Isotruss structure in compression analysis.

7. EXPERIMENTAL WORK

7.1. Mandrel Manufacturing
7.1.1 Base Plate
Base plate is the part of the mandrel which could deform during the winding process. To account for this deformation, due to the bending, material with higher

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Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

stiffness like Mild Steel (M.S.) or Stainless Steel (S.S.) can be selected. Due to cost effectiveness, M.S. was preferred over SS. For L-plates, M.S. angle was selected because of low cost and ease of machining. It provided the added advantage of both faces being perfectly perpendicular to each other. As per the design, holes of size 4mm were drilled, using Radial Drilling Machine on base plate.

Fig-11: Base Plate

7.1.2 L-Plate

For L-plates, M.S. angle was selected because of low cost and ease of machining. It provided the added advantage of both faces being perfectly perpendicular to each other. Standard available size of M.S. angle is 25 x 3 mm; from these 72 pieces of 12mm length were cut. The M.S. angle was cut in 72 pieces, of 12 mm length each, using Cut-Off Machine. Holes of 4mm were drilled on one face of the L-plates, for fixing it to the base plate and 6mm holes were drilled on the other face, which were used for making the slots, using Radial drilling Machine. L-plate slots are used to support helical members of Isotruss structure during winding. Slots were made on face having 6mm holes by using Hand Grinder, and later finished using the flat files. The slots were finished to 10 x 08 mm, size.

Fig-12: L-Plate

7.1.3 End Plate

While manufacturing the Isotruss, the GI wire is to be welded at the end-plates, Mild Steel (M.S.) is selected as both of them, GI and M.S. can be welded together. The M.S. plates available in the size 130 x 128 x 5 were selected, considering the dimensions of the end plates to be manufactured. The M.S. plates were cut to the required dimensions using Laser Cutting, considering the accuracy required for the end plates. According to design, 6mm holes were drilled for assembling the mandrel using nut and bolts. And for the joining of the helical and longitudinal members at the end plates 8mm holes were drilled, using the Radial drilling machine

Fig-13: End Plate

7.1.4 Assembly of Mandrel

Final assembly of the mandrel started with assembling the L-plates and the base plates using 4mm bolts. Then, once all the eight base plates were ready with the L-plates, they were bolted to the end plates using eight 6mm, bolts at each end.

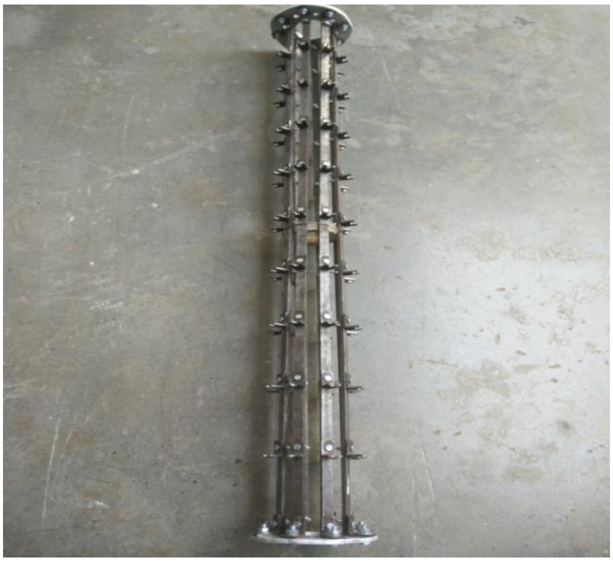

Fig-14: Final Assembly of Mandrel

8 FABRICATIONS OF ISOTRUSS STRUCTURE

The windings on the mandrel can be done manually or with the help of automatic braiding machine. In this project the fabrication of Isotruss is carried out manually. Material used for winding is G.I. wire. After the mandrel is assembled, the Isotruss structure is wound over the assembled mandrel. First the helical members are wound and then the longitudinal members are passed through the holes in base plate. The intersection points of helical and longitudinal members are held in place with the help of thin G.I. wire and then welding is done for the joints of helical and longitudinal members to provide additional strength to the Isotruss structure.

7.1 Procedure of Fabrication

Helical members are wound on the mandrel first. Total helical members are 16. Two helical members pass through one hole in end-plate. Out of two helical members one is wound in anticlockwise direction and the other in clockwise direction. In this way all the 16 helical members pass through 8 holes in the end-plate with 8 members wound in clockwise directions and the remaining 8 in anti-clockwise direction. All 16 helical member windings are completed on the internal mandrel.

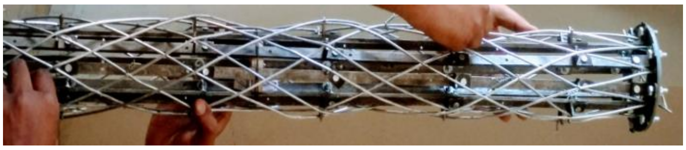

Fig-15: Winding of Helical Members

Once the winding of helical members is completed, winding of the longitudinal members is started. The longitudinal members are passed through the holes in both the end-plates, for a total length of 1000 mm. Total eight longitudinal members are used in this Isotruss structure.

In this project CO_2 gas welding is used. The feeding motor automatically feeds the feed wire, wrapped like a coil, into the weld torch while using CO2 gas welding. The feed wire that is electrified through the contact tip becomes the electrode to strike an arc between itself and the base metal. The arc heat melts the wire and the base metal to join two pieces of base metal. In this case CO_2 gas is supplied from the nozzle of the welding torch to shield the weld pool, to avoid any contact with the atmosphere.

Fig-16: Welding of Structure

The base-plates, along with the L-plates, are disassembled from the end-plates and taken out from the central hole provided in the end-plates. The final Isotruss structure, after disassembling of the base-plate, is shown below.

Fig-17: Final Isotruss Structure

9 EXPERIMENTAL ANALYSES

9.1 Testing

Materials' compressive and tensile strengths are examined using a universal testing machine (UTM). Once the specimen is inserted into the apparatus between the grips, an extensometer will automatically record any gauge length changes that occur throughout the test, if necessary. The machine itself can measure the distance between the cross heads on which the specimen is held if an extensometer is not installed.

Isotruss was loaded on UTM machine with the help of fixtures. The Isotruss of length 1000mm rest on two fixed supports at a distance of 125mm from each end. The structure was subjected to concentrated load at the center with the help solid metal cuboid

Fig-18: Structure on UTM Machine

Once the setup was ready on the UTM, loading of the Isotruss structure was started. The deformed Isotruss structure is shown below.

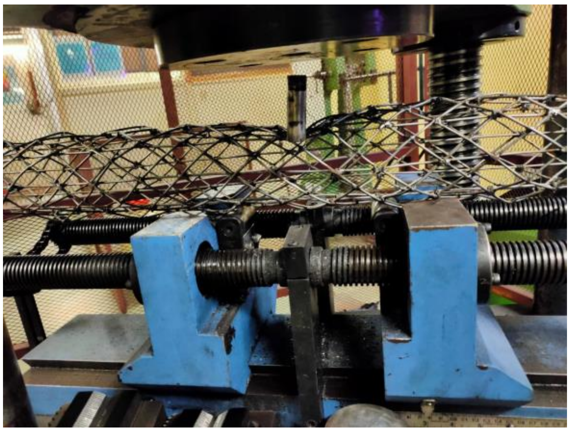

Fig-19: Structure after Loading

9.2 Test Results

After the bending test, which was carried out on the UTM, following observations can be made:

1) The first fracture point was observed at load of 950 N, causing a deformation of 4.5 mm.
2) After a load of 950 N, load started decreasing after a continuous increase in the load till load of 705 N. This indicates that either there was slip of the pusher from its position or it was the second fracture point.
3) At a load of 705 N deformation of 8.33 mm was observed, after that slight decrease in the applied load was observed due to slip of pusher from its original position.

There was a continuous decrease in the applied load observed, after the load point of 1476 N; therefore, the test was stopped at a load of 1476 N.

CONCLUSION

- The purpose of this project was to design and analyze isotruss for bending load conditions and validate the results by conducting the experiment under UTM machine.
- The analytical result is obtained by using ANSYS software. The structure was tested for 1500N load and deformation obtained was of 54mm.
- The experimental result is obtained by using Universal Testing Machine for testing maximum load applied was 1476N and maximum deformation obtained was 35mm.
- The prime application of isotruss in the project is into mountain Foot Bridge where buckling and bending loading is expected. Thus an 8-node structure is selected over the six-node structure for the isotruss of the mountain foot bridge.

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