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Finite Element Analysis of Composite Buried Pipe

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ABSTRACT:

The previous project focuses on the stress analysis of Glass Reinforced Polymer (GRP) pipes. Pressure piping made from GRP is becoming increasingly popular due to its high corrosion resistance and high strength to weight ratio. The development is driven by the need for lighter and more corrosion resistant components. This project involves stress analysis of Eglass/Epoxy and Carbon/Epoxy by replacing GRP. Eglass Epoxy and Carbon Epoxy have high corrosion property and their lighter in weight same as GRP. In this project, structural analysis is carried out on the pipe for external load and internal load of pressure by fluid. This project also involves change in orientation of layers for two composite materials. The project extends in comparison of results of two composite materials to find best suitable material for pipe. 3d modeling of pipe is generated by using CAD software. Structural analysis of pipe is done in ANSYS software. In this project, at first analysis is carried for steel material then followed with Eglass Epoxy and Carbon Epoxy. And then results are compared between the two materials which suits best for buried pipe.

1. INTRODUCTION:

Pipelines are a safe and economical means of transporting gas, water, sewage and other fluids. They are usually buried in the ground to provide protection and support and the construction techniques involve either conventional trenching and backfilling, or trenchless methods such as micro tunnelling. Pipelines are generally designed on the basis of the, flow requirements and the operating pressure.

For buried pipelines, additional design requirements are needed such as the maximum and minimum cover depth, the trench geometry and backfill properties. Failure of a critical pipeline is extremely serious and has major consequences in terms of economic loss, social impacts and environmental issues. The failure of a pipe occurs when the applied stresses in the pipe exceeds the structural capacity of the pipe. The structural capacity reduces over time due to material deterioration, the mechanisms of which are dependent on the pipe material. The failures in the pipe barrel and joint result from a combination of causes such as operational condition (i.e., traffic load and pressure load), environmental factors (i.e., soil corrosivity and reactivity) and intrusion (i.e., third party damage). Figure (1) shows the causes of pipe failures and its contribution to the total number of failures in buried water pipeline. The corrosion has significant influence on the failure of buried pipeline followed by ground movement and pressure transient.

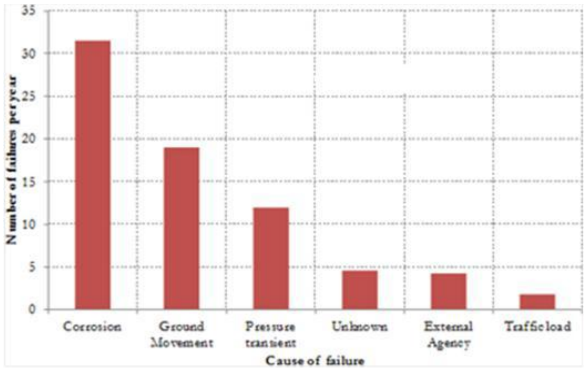

Fig.1shows Causes of failures in buried pipe

2. LITERATURE REVIEW:

Stress Analysis of Underground GRP Pipe Subjected to Internal and External Loading Conditions by Nimish Kurien Thomas, Saj P. George, Steve Mathews John, Sam P. George. This project focuses on the stress analysis of Glass Reinforced Polymer (GRP) pipes. Pressure piping made from GRP is becoming increasingly popular due to its high corrosion resistance and high strength to weight ratio. This development is driven by the need for lighter and more corrosion resistant components. Initially, GRP piping was limited mainly to applications with moderate fluid pressurization. With increasing knowledge of failure mechanisms, improved damage predictability and pipe quality, GRP piping is increasingly being considered in the field of high pressure fluid transmission with pressurization in excess of several megapascals. Since the GRP material consists of several layers, the analysis of stresses developed in it is complicated. Therefore, as the initial approach towards the project, the stress analysis of steel pipes is performed using ANSYS, which was followed by a comparative study of steel and GRP pipes.

3. PROBLEM DEFINITION AND METHODOLOGY

Methodology

- 3d model of buried pipe is generated by using NX-CAD software.
- 3d model is converted to parasolid file.
- The parasolid file is imported to ANSYS software to perform analysis on buried pipe.
- Static analysis is done on buried pipe for pressure loads.
- Compare the results of both and best one is selected.
- Analysis is done for best buried pipe for pressure loads by changing the layer orientation for Eglass/Epoxy material.
- Analysis is also done for best buried pipe for pressure loads by changing the layer orientation for Carbon/Epoxy material.
- Results of both materials are compared and best material is selected.

4. FINITE ELEMENT ANALYSIS OF BURIED PIPE

Finite Element Modelling (FEM) and Finite Element Analysis (FEA) are two most popular mechanical engineering applications offered by existing CAE systems. This is attributed to the fact that the FEM is perhaps the most popular numerical technique for solving engineering problems. The method is general enough to handle any complex shape of geometry (problem domain), any material properties, any boundary conditions and any loading conditions. The generality of the FEM fits the analysis requirements of today's complex engineering systems and designs where closed form solutions are governing equilibrium equations are not available. In addition it is an efficient design tool by which designers can perform parametric design studying various cases (different shapes, material loads etc.) analyzing them and choosing the optimum design.

4.1 Material properties:

Density = **7850 Kg/m^3**
Young's modulus = **200 Gpa**
Yield strength **= 250 Mpa**

4.1. 10 NODE Solid 92 element description:

SOLID92 has quadratic displacement behaviour and is well suited to model irregular meshes (such as produced from various CAD/CAM systems). See SOLID95 for a 20-node brick shaped element. The element is defined by ten nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions.

4.1.2 Boundary conditions:

- The outer area of buried pipe is constrained in all dof.
- An internal pressure of 25 Mpa is applied on inner areas of pipe.

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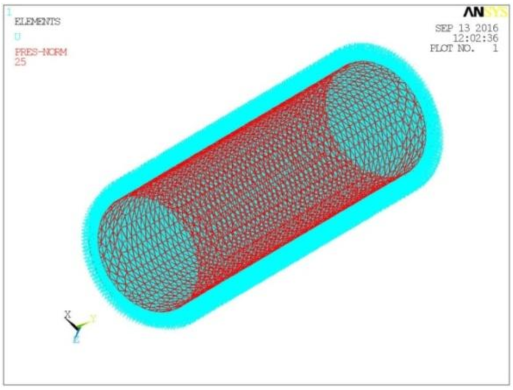

Fig 2 shows boundary and load conditions on buried pipe

4.2 RESULTS:
4.4.1Displacements:

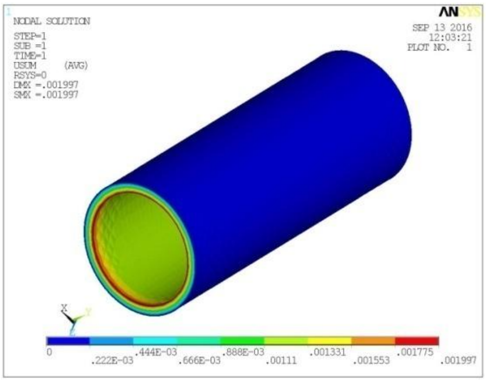

Fig 3 shows Resultant displacement on Buried pipe

4.2.1 (b) Stresses

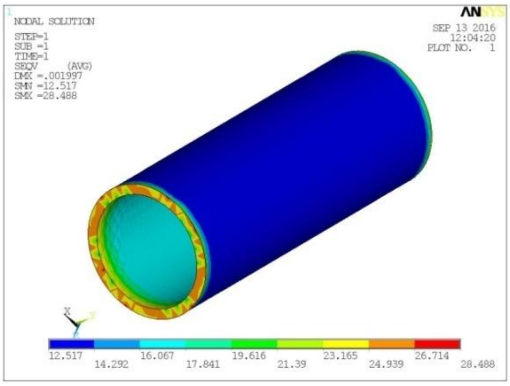

Fig 4 shows Von mises stress of Buried pipe

From analysis results, the resultant displacement observed on buried pipe is 0.001 mm. The Von mises stress observed on buried pipe is 28.488MPa.

The yield strength of steel material is **250Mpa**. The Von mises stress of buried pipe is lesser than the yield strength of the material. Hence the buried pipe is a safe in design for steel material.

4.3 Structural Analysis of Buried Pipe for Eglass/Epoxy Material:
4.3.1 Introduction:

Structural analysis is carried out on Buried pipe for external and internal pressure to determine displacements and stresses. Analysis is carried out on buried pipe for Eglass/Epoxy material. This analysis is also carried out on buried pipe for different layer orientation for Eglass/Epoxy material.

4.3.2 Element type used SOLID 191 descriptions:

SOLID191 is a layered version of the 20-node structural solid designed to model layered thick shells or solids. The element allows up to 100 different material layers. If more than 100 layers are required, the elements may be stacked. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. SOLID191 has stress stiffening capabilities.

4.3.3 Material properties of Eglass/Epoxy:

Sl.No	Property	Units	E-Glass/Epoxy
1.	E_{11}	GPa	50.0
2.	E_{22}	GPa	12.0
3.	G_{12}	GPa	5.6
4.	ν_{12}	-	0.3
5.	$S^t_1 = S^c_1$	MPa	800.0
6.	$S^t_2 = S^C_2$	MPa	40.0
7.	S_{12}	MPa	72.0
8.	ρ	Kg/ m^3	2000.0

Table 4.1 explains Material properties of Eglass/Epoxy

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4.4 Case-1: Layer Orientation (i.e. 90, 0, 90) of Buried pipe for Eglass/Epoxy material:

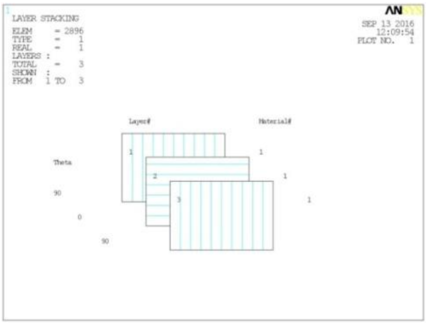

Fig 5 shows Layer orientation for Eglass/Epoxy material of Buried pipe

4.4.1 Boundary conditions:

- The outer area of buried pipe is constrained in all dof.
- An internal pressure of 25 MPa is applied on inner areas of pipe.

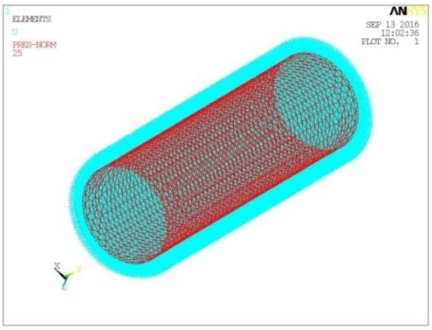

Fig 6 shows boundary and load conditions of Buried pipe

4.4.2 RESULTS

4.4.2(a) Displacements:

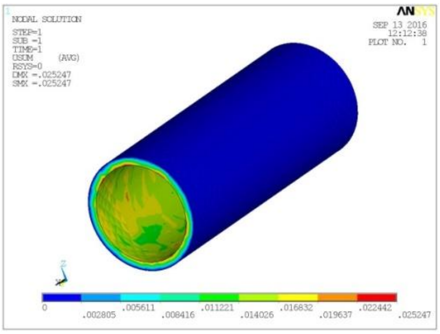

Fig 7 shows Resultant displacement on Buried pipe

4.4.2(b) Stresses

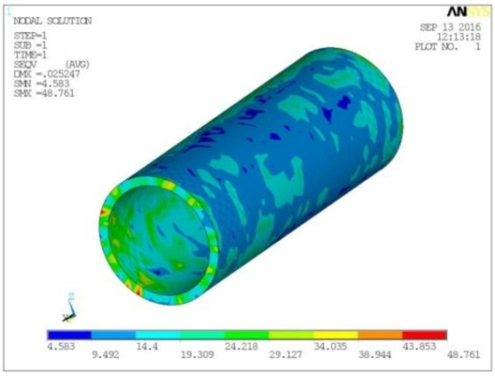

Fig 8 shows Von mises stress of Buried pipe

From results, the maximum displacement of 0.025mm is observed on the buried pipe. The von misses stress of Buried pipe is 48.76 MPa**.** The yield strength of Eglass/Epoxy material is 800 MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

4.5 Case-2: Layer Orientation (i.e. 45, 0, 45) of Buried pipe for Eglass/Epoxy material:

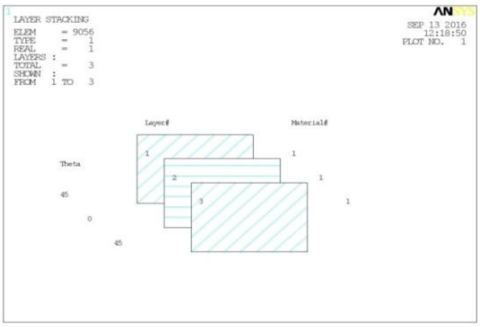

Fig 9 shows Layer orientation for Eglass/Epoxy material of Buried pipe

4.5.1 Boundary conditions:

- The outer area of buried pipe is constrained in all dof.
- An internal pressure of 25 MPa is applied on inner areas of pipe.

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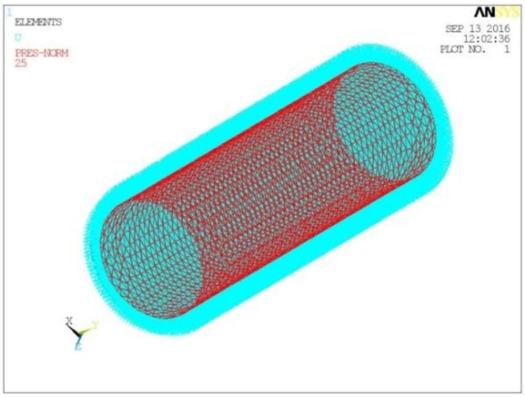

Fig 10 shows boundary and load conditions of Buried pipe

4.5.2 RESULTS:

4.5.2(a) Displacements:

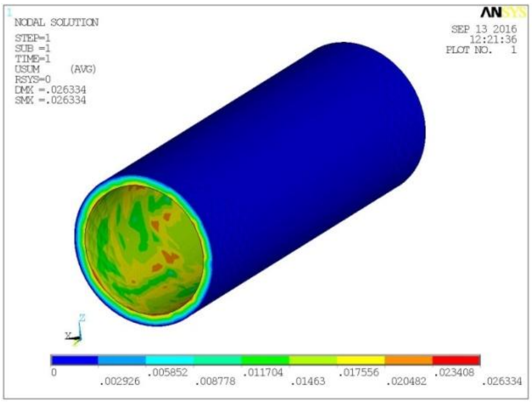

Fig 11 shows Resultant displacement on Buried pipe

4.5.2(b) Stresses:

From results, the maximum displacement of 0.026mm is observed on the buried pipe. The von misses stress of Buried pipe is 45.02 MPa**.** The yield strength of Eglass/Epoxy material is 800 MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

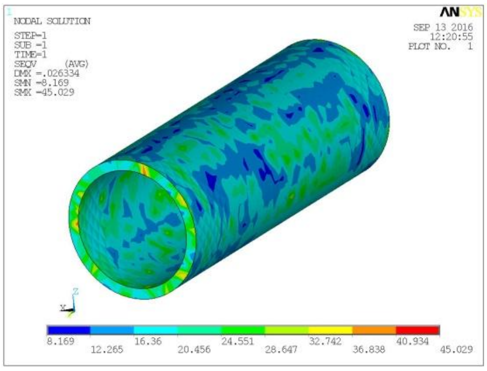

Fig 12 shows Von mises stress of Buried pipe

4.6 Case-3: Layer Orientation (i.e. 60, 0, 60) of Buried pipe for Eglass/Epoxy material:

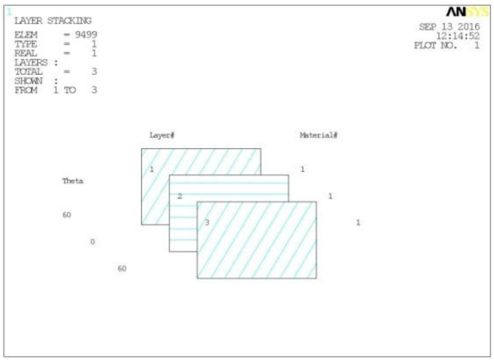

Fig 13 shows Layer orientation for Eglass/Epoxy material of Buried pipe

4.6.1 Boundary conditions:

- The outer area of buried pipe is constrained in all dof.
- A internal pressure of 25 MPa is applied on inner areas of pipe.

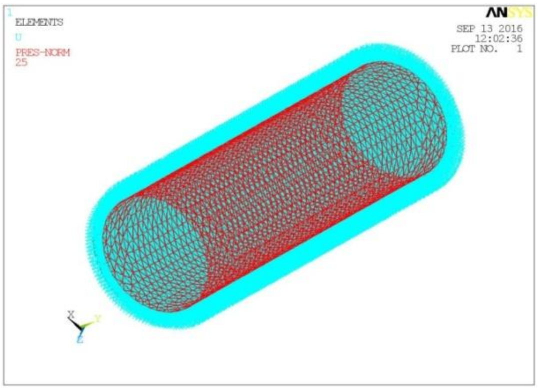

Fig 14 shows boundary and load conditions of Buried pipe

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4.6.2 RESULTS:

4.6.2(a) Displacements:

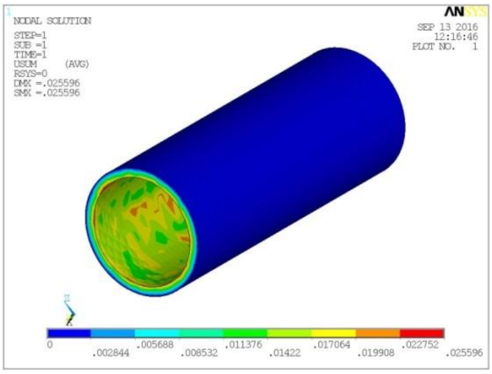


Fig 15 shows Resultant displacement on Buried pipe

4.6.2(b) Stresses:

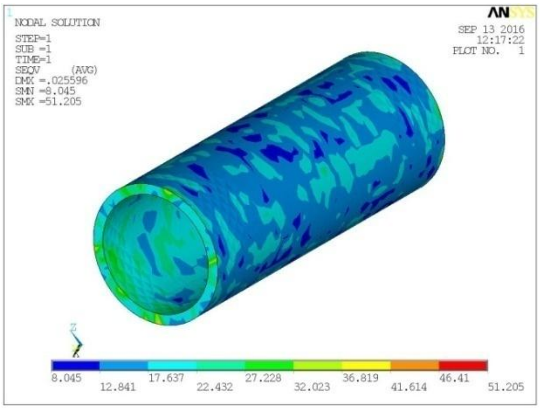
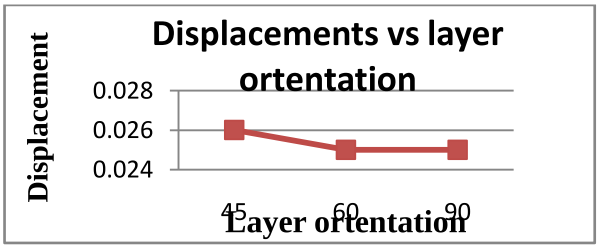


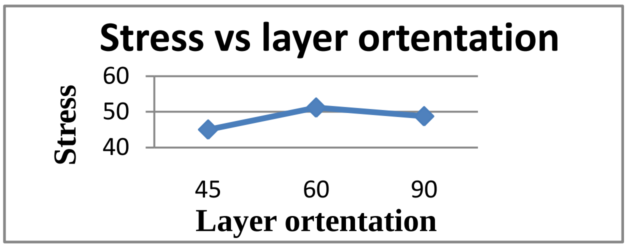
Fig 16 shows Von mises stress of Buried pipe

From results, the maximum displacement of 0.025mm is observed on the buried pipe. The von misses stress of Buried pipe is 51.2 MPa**.** The yield strength of Eglass/Epoxy material is 800 MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

Graphs:



Graph 4.1 shows displacements vs. layer orientation of Buried pipe for Eglass/Epoxy material



Graph 4.2 shows stresses vs. layer orientation of Buried pipe for Eglass/Epoxy material

4.7 Structural analysis of buried pipe for carbon/epoxy material:

4.7.1 Introduction:

Structural analysis is carried out on Buried pipe for external and internal pressure to determine displacements and stresses. Analysis is carried out on buried pipe for Carbon/Epoxy material. This analysis is also carried out on buried pipe for different layer orientation for Carbon/Epoxy material.

4.7.2 Element type used SOLID 191 descriptions:

SOLID191 is a layered version of the 20-node structural solid designed to model layered thick shells or solids. The element allows up to 100 different material layers. If more than 100 layers are required, the elements may be stacked. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. SOLID191 has stress stiffening capabilities.

4.7.3 Material properties of Carbon/Epoxy:

Sl. No	Property	Units	Carbon/Epoxy
1.	E_{11}	GPa	134.0
2.	E_{22}	GPa	7.0
3.	G_{12}	GPa	5.8
4.	ν_{12}	-	0.3
5.	$S^t_1 = S^c_1$	MPa	880

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6.	$S^t_2 = S^C_2$	MPa	60.0
7.	S_{12}	MPa	97.0
8.	P	Kg/m^3	1600.0

Table 4.2 explains Material properties of HS Carbon/Epoxy

4.8 Case-1: Layer Orientation (i.e. 90, 0, 90) of Buried pipe for Carbon/Epoxy material:

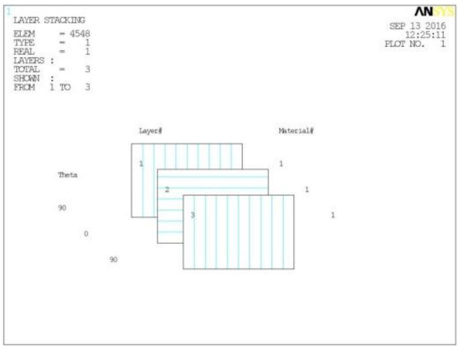

Fig 17 shows Layer orientation for Carbon/Epoxy material of Buried pipe

4.8.1 Boundary conditions:

- The outer area of buried pipe is constrained in all dof.
- A internal pressure of 25 MPa is applied on inner areas of pipe.

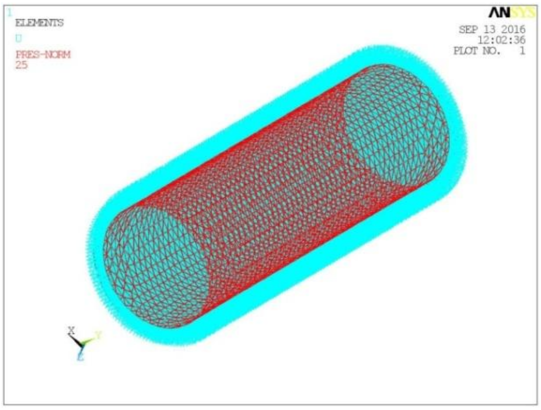

Fig 18 shows boundary and load conditions of Buried pipe

4.8.2 RESULTS:

4.8.2(a) Displacements:

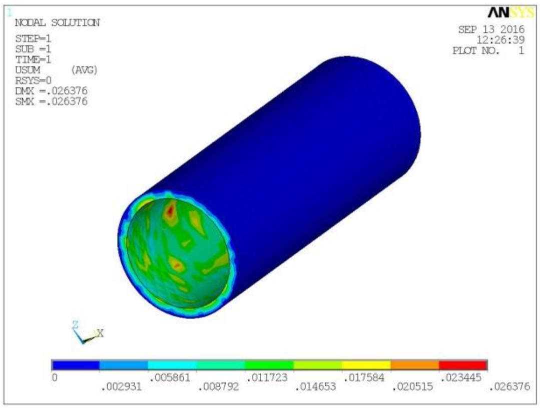

Fig 19 shows Resultant displacement on Buried pipe

4.8.2(b) Stresses:

From results, The maximum displacement of 0.026mm is observed on the buried pipe. The von misses stress of Buried pipe is 81.41 MPa**.** The yield strength of Carbon/Epoxy material is 945MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

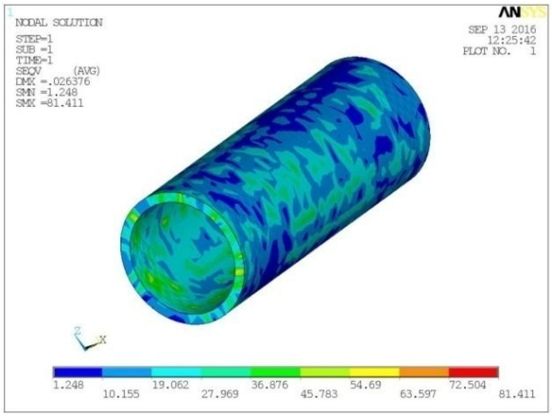

Fig 20 shows Vonmises stress of Buried pipe

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4.9 Case-2: Layer Orientation (i.e. 45,0,45) of Buried pipe for Carbon/Epoxy material:

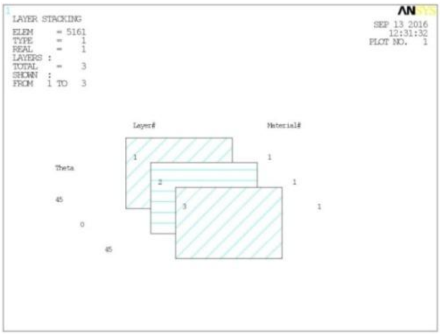

Fig 21 shows Layer orientation for Carbon/Epoxy material of Buried pipe

4.9.1 Boundary conditions:

- The outer area of buried pipe is constrained in all dof.
- A internal pressure of 25 MPa is applied on inner areas of pipe.

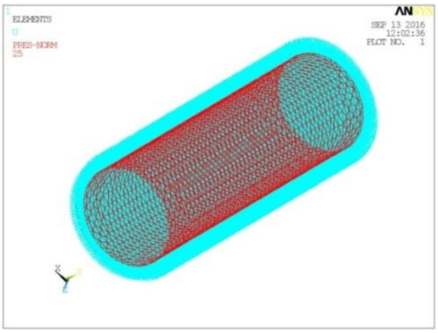

Fig 22 shows boundary and load conditions of Buried pipe

4.9.2 RESULTS:

4.9.2(a) Displacements:

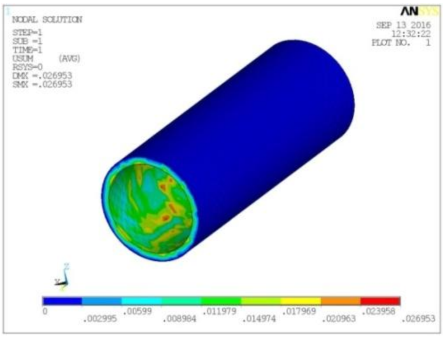

Fig 23 shows Resultant displacement on Buried pipe

4.9.2(b) Stresses:

From results, The maximum displacement of 0.027mm is observed on the buried pipe. The von misses stress of Buried pipe is 77.96 MPa**.** The yield strength of Carbon/Epoxy material is 945MPa in fibre direction. The von misses stress of Buried pipe is less than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

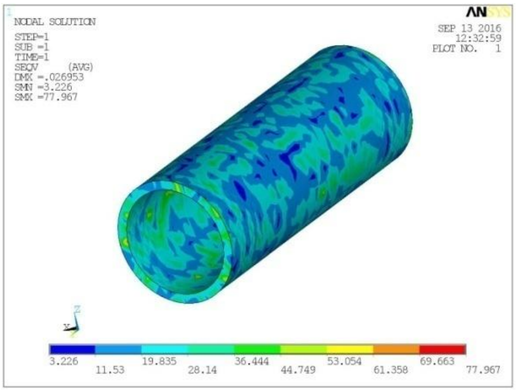

Fig 24 shows Vonmises stress of Buried pipe

From results, The maximum displacement of 0.027mm is observed on the buried pipe. The von misses stress of Buried pipe is 77.96 MPa**.** The yield strength of Carbon/Epoxy material is 945MPa in fibre direction. The von misses stress of Buried pipe is less than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

4.10 Case-3: Layer Orientation (i.e. 60, 0, 60) of Buried pipe for CARBON/Epoxy material:

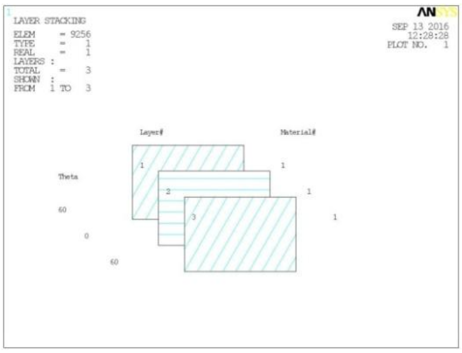

Fig 25 shows Layer orientation for CARBON/Epoxy material of Buried pipe

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4.10.1 Boundary conditions:

- The outer area of buried pipe is constrained in all dof.
- A internal pressure of 25 MPa is applied on inner areas of pipe.

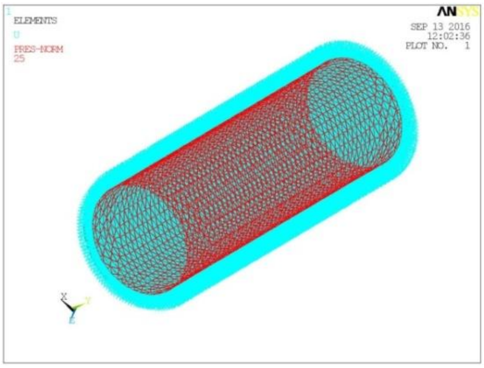


Fig 26 shows boundary and load conditions of Buried pipe

4.10.2 RESULTS:

4.10.2(a) Displacements

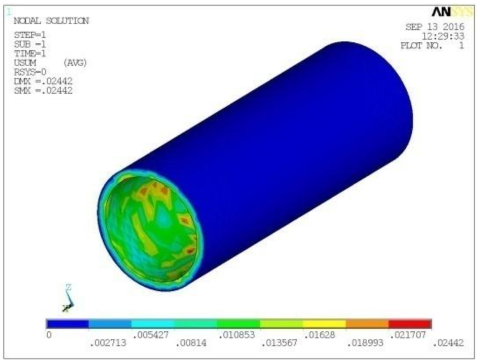


Fig 27 shows Resultant displacement on Buried pipe

4.10.2(b) Stresses:

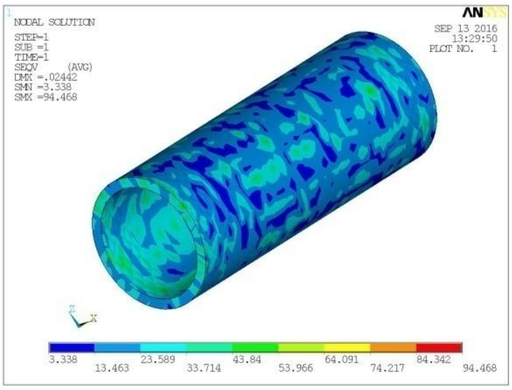
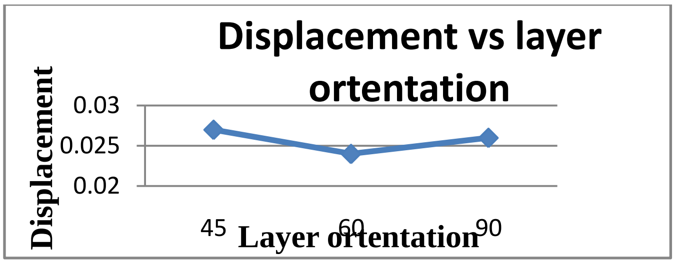


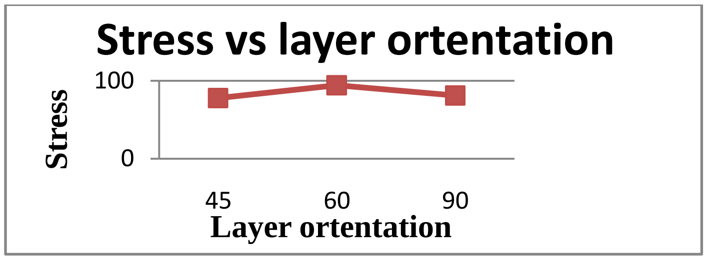
Fig 28 shows Vonmises stress of Buried pipe

From results, The maximum displacement of 0.024mm is observed on the buried pipe. The von misses stress of Buried pipe is 94.46MPa**.** The yield strength of Carbon/Epoxy material is 945MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads

GRAPHS:



Graph 4.3 shows displacements vs. layer orientation of Buried pipe for Carbon/Epoxy material



Graph 4.4 shows stresses vs. layer orientation of Buried pipe for Carbon/Epoxy material

5. RESULTS

5.1 Structural analysis of buried pipe for steel material:

From analysis results, the resultant displacement observed on buried pipe is **0.001 mm**. The Von mises stress observed on buried pipe is **28.48 MPa.** The yield strength of steel material is **250MPa**. The Von mises stress of buried pipe is lesser than the yield strength of the material. Hence the buried pipe is a safe in design for steel material.

5.2 Structural analysis of buried pipe for Eglass/epoxy material for different layer orientation:

5.2.1 Case-1: Layer Orientation (i.e. 90,0,90) of Buried pipe for Eglass/Epoxy material:

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From results, the maximum displacement of 0.025mm is observed on the buried pipe. The von misses stress of Buried pipe is 48.76MPa**.** The yield strength of Eglass/Epoxy material is 800 MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

5.2.2 Case-2: Layer Orientation (i.e. 45,0,45) of Buried pipe for Eglass/Epoxy material:

From results, the maximum displacement of 0.026mm is observed on the buried pipe. The von misses stress of Buried pipe is 45.02 MPa**.** The yield strength of Eglass/Epoxy material is 800 MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

5.2.3 Case-3: Layer Orientation (i.e. 60,0,60) of Buried pipe for Eglass/Epoxy material:

From results, the maximum displacement of 0.025mm is observed on the buried pipe. The von misses stress of Buried pipe is 51.2MPa**.** The yield strength of Eglass/Epoxy material is 800 MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

5.3 Structural analysis of buried pipe for carbon/epoxy material for different layer orientation:

5.3.1 Case-1: Layer Orientation (i.e. 90,0,90) of Buried pipe for Carbon/Epoxy material:

From results, The maximum displacement of 0.026mm is observed on the buried pipe. The von misses stress of Buried pipe is 81.41 MPa**.** The yield strength of Carbon/Epoxy material is 945MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

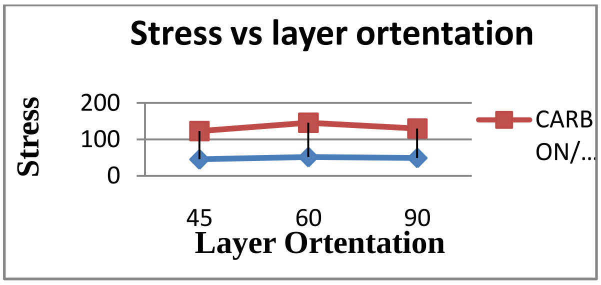
5.3.2 Case-2: Layer Orientation (i.e. 45,0,45) of Buried pipe for Carbon/Epoxy material:

From results, The maximum displacement of 0.027mm is observed on the buried pipe. The von misses stress of Buried pipe is 77.96MPa**.** The yield strength of Carbon/Epoxy material is 945MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

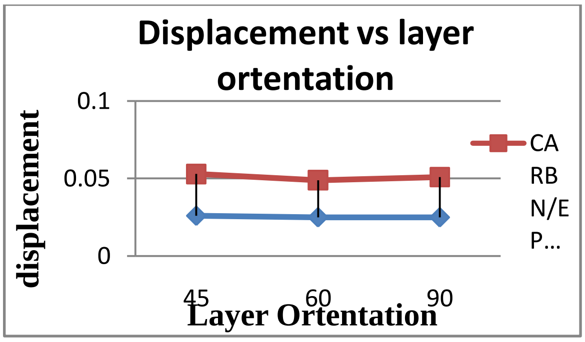
5.3.3 Case-3: Layer Orientation (i.e. 60,0,60) of Buried pipe for CARBON/Epoxy material:

From results, The maximum displacement of 0.024mm is observed on the buried pipe. The von misses stress of Buried pipe is 94.46MPa**.** The yield strength of Carbon/Epoxy material is 945MPa in fibre direction. The von misses stress of Buried pipe is lesser than the yield strength of material. Hence, the Buried pipe is safe for pressure loads.

GRAPHS:



Graph 5.1shows Comparison of stress vs. layer orientation of Buried pipe for two composite materials



Graph 5.2 shows Comparison of displacement vs. layer orientation of Buried pipe for two composite materials

CONCLUSION:

In this project, 3d model of buried pipe was generated in NX-CAD software. Buried pipe was studied for structural analysis for internal pressure load for steel material and two composite materials (i.e. Eglass/Epoxy and Carbon/Epoxy materials) with different layer orientation. From analysis, the Von mises stress of Buried pipe for steel, Eglass/Epoxy material and Carbon/Epoxy material with different layer orientation was lesser than the yield stress of the materials. From analysis, the Von mises stress of Buried pipe for Eglass/Epoxy material with different layer orientation is less compared to Buried pipe for Carbon/Epoxy material with different layer orientation. Hence, it is concluded that Eglass/Epoxy material is alternative material for Buried pipe.

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