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Compression Test on Epoxy-Polyurethane Blended Resin, with Nanoclay Reinforced Composite Pipeline and Finite Element Analysis

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Abstract

Objectives: The present paper demonstrates a study on properties of epoxy-polyurethane composite pipe reinforced with specially treated Nanoclay as reinforcement using finite element modeling under static conditions. **Methods/Statistical Analysis:** The analysis of composite pipe and the resulting properties of pipeline with uniform distribution of particles have been studied by the systematic procedure using the finite element model. The modeling is performed as per the pipeline construction standards and the properties were compared with test values as per ASTM standards. The pipeline for various particle orientations is studied using improved mechanical property criteria. **Findings:** Epoxy being good in mechanical properties, blended in the ratio of 60:40 percent with polyurethane for better compatibility and hence improved mechanical properties by providing with interpenetrating resin matrix. The amine treated Nanoclay increases the compression strength of the existing polyurethane pipelineby about 38% for the 3% reinforcement and shear strength for 1% Nanoclay. This also supported by Finite element analysis and also it has been shown that for 0^0 orientation of Nanoclay the composites exhibit better properties. **Application/Improvements:** The polymer composite pipes are used in varieties of applications and they have been widely used in industries such as oil,gas,transport and offshore applications. Polyurethane coated pipelines are most popular for industrial applications.

Keywords: Composite, Epoxy, Pipeline, Polyurethane, Treated Nanoclay

1. Introduction

The polymer composites owing to their less weight and tailor ability and advancements in Nanoparticles, find widespread applications in aeronautics, automobiles, chemical and aerospace industries[1]. They are also equally find application in piping, sewage, transport, oil and gas industries for making better composite pressure vessels and pipelines. The demands for composite pipes are increasing drastically as these pipes have significant properties such as less weight and high strength .Hence it is used in applications where, the weight is considered as an important criterion for design. The pipelines made up of these materials are better substitutes where there ia need for less weight and better mechanical properties[2]. These composite pipes are put into high and variable pressure environment during their operation in most of the applications. Therefore, it is vital to analyze these pipes as it is important for safety operations of these structures. There are several methods available to study the design and analysis of the reinforced polymer matrix composite pipes under different conditions for stress and deformation. The failure strength of composite pipes for different number of loads[3] is determined when the particles are oriented symmetrically. The behavior of a Nanoparticles reinforced composite vessel[4], and five different shapes of

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composite pressure vessels[5] analyzed in the previous literatures concludes that the Glass-Fiber Reinforced (GFRP) composite cylindrical pipe when subjected to transverse loading, produces large deflections[6]. The analysis of the multilayered composite pressure vessels under the influence of heat and mechanical loading were carried out for the various loads[7] and the result values were evaluated. Also the lateral crushing behavior is studied by finite element method of analysis for segmented tubes[8]. The particulate reinforced composite design and its analysis requires the association of some important decisive factors for the design to be accurate. The selection of optimum values of these factors is needed for better design of composites. In this paper the static analysis of Nanoclay reinforced epoxy-polyurethane pipes cylindrical in shape, under internal pressure is carried out. This study is performed with the help of the software ANSYS 12, by creating a finite element model in it.

2. Finite Element Modeling

2.1 The Epoxy-Polyurethane Pipe

This study was carried out with an Epoxy/Polyurethane blended resin as matrix reinforced with Nanoparticles of montmorillonite clay, surface modified with 35-45 wt% (C14-C18) dimethyl-dialkyl amine, in the composite pipe. The multilayered pipe, which is cylindrical in shape, is orthotropic in nature since it is assumed that the clay nanoparticles and the resin blends are thoroughly shear mixed to have uniform distribution. The modeling of the pipeline requires that the computations of different properties[9] because the properties of particulate reinforced composite materials are orthotropic nature. The material properties of the composite depend on the properties of both the matrix and the Nanoclay reinforcement. The epoxy has superior mechanical properties along its length[10]. The orientation angle of the Nanoclay in the composite has got a significant role in the composite properties and determination of the behavior of the composite[11].

2.2 Selection of Element Type for Modeling

The finite element modeling and analysis of the particulate composite pipelines depends on the selection of appropriate element type[12]. Various shell and solid element types are listed in the finite element software ANSYS 12 was used to model the layered particulate composite materials. The elements such as SHELL91, SHELL99, SHELL181, SOLID46, and SOLID191 are the element types that are available in Ansys 12 to model layered composite materials. The suitable element is chosen based on the application, the type of results needed, and so on. All layered elements are allowed failure criterion calculations. The individual element characteristics are analyzed and determined whether a specific element can be used in the selected application.

A solid element is used to model thick-layered composites, provided with the condition that the number of material layers must be the same as the mesh divisions in thickness directions. But there is an increase in the time for the analysis and the time for the calculation of these elements. These shell elements used does not require the mesh divisions along the thickness direction .The calculation as well as the analysis time for these elements is much lower compared to that of the solid elements. SHELL 99 is a linear layered structural shell element. It is a 3D shell with 11 – nodes and six degrees of freedom at each node. Because of these properties, SHELL 99 is selected as the suitable element type from the list of shell elements for the purpose of this study. Very thin elements and moderately thick layers can be modeled using this element. It is assumed that there is no slippage between the element layers. Shear deflections are included in the element. It is assumed that the normal to the center plane before deformation remain straight after deformation. The elastic properties for this element allow the user to define, density for each layer and layer orientation. The meshing model of composite pipeline developed in Ansys 12 is shown[13] in Figure 1.

2.3 The Layered Configuration Definition

By specifying the individual layer properties[14], the layered configuration is determined. Therefore, the properties of the composite greatly depend on the properties of the layered configuration. The material properties, the layer thickness, the particle orientation angle and the number of integration points per layer must be specified for individual layer for the definition of the complete layered configuration, which is the most important characteristic of a composite material. The epoxy-polyurethane layers in the composite pipes are assumed orthotropic properties. These are required for the purpose of the analysis. The deformation of pipeline under the internal stress is shown in Figure 2, for 0^0 orientations of particles in the composites.

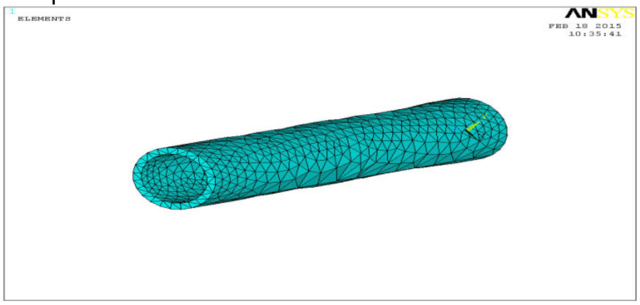

Figure 1. Meshing model of pipeline.

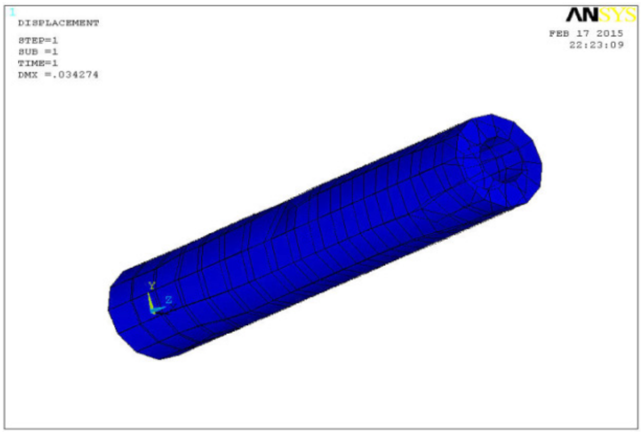

Figure 2. Deformation of pipeline.

3. Finite Element Analysis

Depending upon the constraints applied on the meshed model, the Solution menu appeared will be either "abridged" or "unabridged". When the analysis type is specified as modal analysis[15], a solution menu that is appropriate for modal analysis appears. The abridged menu contains only those solution options that are recommended for modal analysis. This option is used to specify the default formulation (which is element-dependent) or lumped mass approximation. The default formulation is used for the selected application. However, the lumped mass approximation often yields better results for problems involving skinny structures such as slender beams or very thin shells. In addition, the lumped mass approximation can result in a shorter run time and lower memory requirements.

The Epoxy-Polyurethane/nanoclay composite pipe is analysis is done by loading it to high internal pressures. The criterion of improved mechanical property is used for the purpose of this analysis. The analysis is performed based on the internal pressure calculation of the pipe. Separate model formation is required for the calculation of the pipe pressure. By increasing the internal pressure from zero pressure to 50MPa systematically, the pipeline pressures are predicted. It is required to compare the value of maximum stress obtained with value of ultimate stress for every increment in the internal pressure, in the pipeline by using the equation given by the following eq. 1.

$$\sigma_{\max} \le \sigma_u \tag{1}$$

Where, σ_u,σ_{max} are the ultimate stress and the maximum stress of the pipe respectively. The Figure 3 gives the stress distribution and the Figure 4 gives the deflection or displacement for the composite pipeline[16].

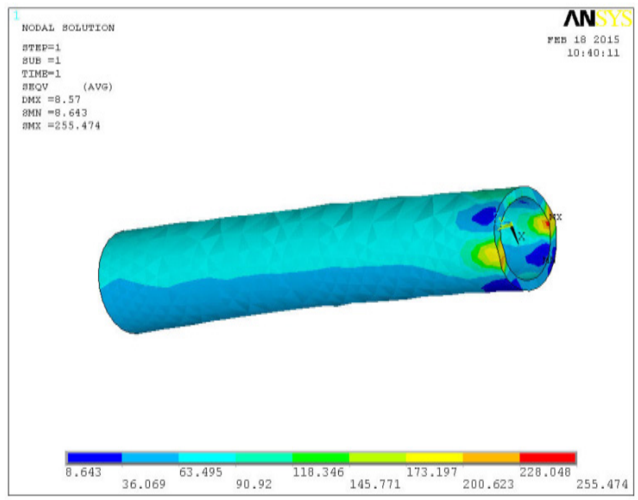

Figure 3. Von mises stress distribution at 0^0.

4. Experimental Test Results

4.1 Compression Test

The Nanoclay reinforced pipeline is subjected to two equal and opposite axial pushes (also called compressive load), then the stress induced at different sections of the body is plotted. It is observed that due to the compressive load, there will be a decrease in length of the body and an increase in cross-sectional area of the material as the lateral dimensions change. The compressive strain is computed for different load values. The advent of more powerful scanning electron microscopes has helped to avoid opinions that may have been heavily speculative in the past and to provide a more fact based foundation for opinions. As some very spectacular failures and failures that have caused great pain and loss, materials engineers have been asked to find out the reason for the causes that lead to failures. It has been found that in many cases there is no single cause or single train of events that lead to a failure. Compression strength is nothing but the capabilities of a reinforced polymeric composite material to withstand the pushing forces which are axially directed are applied on the material of the pipeline. When the ultimate limit of compression strength is reached, materials are crushed. The ultimate load at which the specimen breaks was noted. The compression test is performed as per ASTM standards. The difference in values may be due to the following:

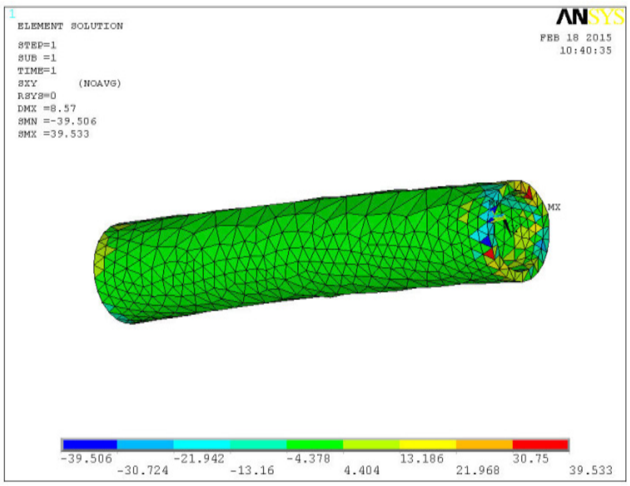

Figure 4. Displacement vector sum at 0^0.

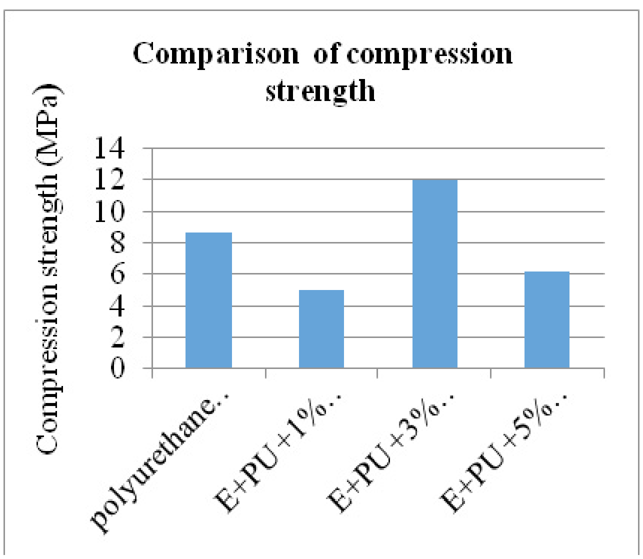

Figure 5. Comparison of compression strength.

On compression: 1. the specimen will be shortened and the material will tend to elongate in the lateral direction and hence there is increase in the cross sectional area and 2. if the specimen is clamped at the edges, and hence a frictional force arises will oppose the lateral spread in the pipeline. Therefore, work has been carried out in order to oppose this frictional force. This in turn increases the energy consumption during the process. This results in a slight deviation of value of stress, obtained from the experiment as shown in Figure 5.

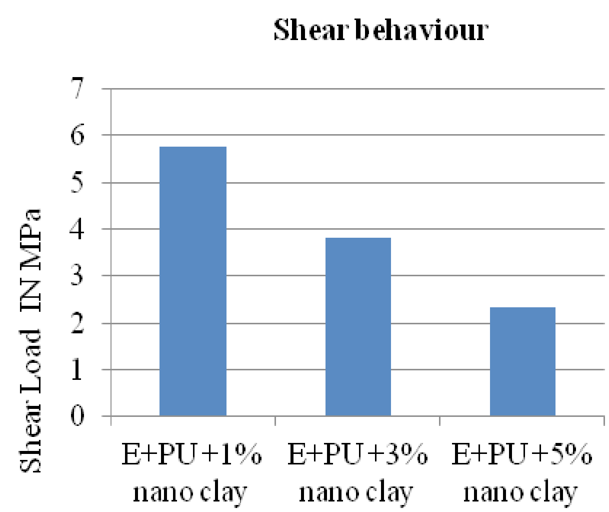

Figure 6. Shear load.

The normal Epoxy/polyurethane pipe compression strength is 8.652MPaonly. When it is reinforced with 1% Nano clay the compression strength is 5MPa.There is a slight decrease in the strength as the small particle loading fail to produce significant improvement in stopping the dislocation movement by providing enough strain boundaries. But, if the particle loading is increased to 3% there is a significant improvement in the compressive strength. For the 5% Nano clay reinforced epoxy-polyurethane/nanoclay composite again there is a decrease in the compression strength is as there is a problem of agglomeration of nanoparticles and improper wetting and bonding between the agglomerated particles and the mixed resin. Hence it is finally, concluded that 3% Nano clay reinforced epoxy-polyurethane gives maximum increase in compression strength so as to avoid burst of the pipeline.

4.2 Shear Test

In the composite materials, a yield zone is formed at the tip of a crack in polymers. Therefore, in the case of shear yielding, the damage zone resembles the plastic zone in metals. This is because the slip in metals and the shear in polymers are governed by the similar yield criteria. Craze yielding, however, produces a Dug dale-type strip-yield zone ahead of the crack tip. Crazing is more likely ahead of a crack tip, between the two yielding mechanisms in polymers, because of the triaxial tensile stress state. Shear yielding; however, can occur at crack tips in some materials, depending on the temperature and specimen geometry. The experimental test results got from Central Institute of Plastics Engineering and Technology (CIPET) are used to apply a pressure to a material and record the materials response to this pressure. As with composite, a yield zone typically forms at the tip of a crack in polymers. The damage zone in the case of shear yielding resembles the plastic zone in metals. This is because the slip in metals and shear in polymers are governed by similar yield criteria.

Shear testing is performed as control procedures during manufacturing as part of routine quality and as part of the final inspection. Shear testing is also a critical step in determining the strength of the composite pipe especially during research and development of new materials. The degree and complexity of the shear test is usually dictated by the application or the service/end-use conditions of the part. Shear testing of the composite is done by exerting pressure (shear force) in the transverse plane until shear failure occurs. Shear force causes the two contiguous portions of the pipeline to slide in opposite directions parallel to their contact plane. The test results plotted in Figure 6. The shear strength is more for 1% reinforcement of the particles. This is due to strengthening of the structures by nanoclay particles as it is occupying the interstices of the matrices and thus providing resistance to deformation or slip. However, if the percentage of nanoclay is increased, the formation of crack in the materials increases certainly resulting in easier propagation of crack leads to lower shear strength of the materials.

5. Conclusion

In this study, the model of epoxy-polyurethane/Nanoclay reinforced composite cylindrical pipe is developed using the finite element software ANSYS 12. The model is obtained for 0^0 orientations, using a linear structure shell element SHELL 99 and is meshed. The systematic analysis method for the cylindrical polymer composite pipe is discussed, is subjected to a load of zero internal pressure. Using the von mises criteria, the pipe pressures for 0^0 orientations are predicted. At the 0^0 orientation angles for the epoxy-polyurethane/Nanoclay composite, the pipe is subjected to a load under 1000N.m and zero internal pressure. It has been concluded from this study that the capacity of the Nanoclay reinforced epoxy-polyurethane composite pipe will bear high internal loading and it gives the greatest values for the orientations angle of 0^o of Nanoclay particles in the composite materials.

The evaluation of the mechanical properties of the epoxy-polyurethane/nanoclay composite using the finite element analysis shows similar trend to that of the experimental results and thus the following conclusions can be derived. The deviations in the strength values are due to the assumptions made in the finite element analysis and the limitations of the element type and boundary conditions. Proper cross-sections for and the thickness of pipeline are selected depending on the pressure to which the pipeline is subjected.

The compression strength of the polyurethane pipe is 8.652MPa. The Nano clay reinforcement initially decreases the compression strength of epoxy-polyurethane composite and then the value of strength increases as the percentage of particles loading increases. The 3% Nano clay reinforced epoxy-polyurethane compression strength is 12MPa and gives maximum of 38% increase in compression strength so to avoid burst of the pipeline.

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