Experimental analysis of compressive behavior of E-Glass fiber reinforced IPN (vinyl ester/polyurethane) composite pipes

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Abstract. The manuscript discusses about the effect of compressive load on the E-Glass fiber reinforced interpenetrating polymer networks (IPNs). In this work, a series of combination of vinyl ester (VER) loaded polyurethane (PU) IPNs have been taken as the matrix material with the E-Glass reinforcement, with the loading of 0%, 10%, 20%, 30%, 40%, 50% PU respectively. Besides hand-layup technique was used to fabricate the cylindrical shells in order to get the final shape of the IPN composite pipe. Simultaneously to validate the compressive strength behavior of the IPN composite pipe, experimental analysis was carried out as per the ASTM D695 standard at normal room temperature to extract compressive strength value of the PU loaded IPN composite pipes. During this test, it was observed that physical strength of the composite pipes reduces gradually as much as PU addition into the IPN composite pipe increases. Surprisingly, another important notification was that, the geometric structure of the composite pipes is not affected as like as the crushing observed on the pure VER pipe. As much as loading of the PU into the IPN, increases the structural integrity of the composite pipes in outstanding (retains structural ability) manner. Further the experimental analysis values are validated with numerical analysis software ANSYS, obtained values and numerical values are shown good agreement each other.

Keywords: E-Glass, interpenetrating polymer networks, vinyl ester, Polyurethane, ANSYS.

1. Introduction
In recent days, glass fiber reinforced composite materials have been very extensively used in most of the industrial applications. Especially its applications in the area of composite pipe manufacturing become as the nerve system for most of the pipe manufacturing industries [1-2]. The reason behind that use of composite material in this particular sector is that, the issues, the engineers faced with the usage of the conventional metallic pipes. Because the usage of the metallic pipes lead to the prolong and sophisticated repairing mechanism to put forth to overcome the issues like rust, abrasion etc. even though numerous studies are performed to strengthen the metallic pipes in order to overcome the routine negative issues, still it is not treated as the worthwhile mechanism as well as it leads to much amount of over head and maintenance cost to come across the issues [3-4]. Moreover, the...
technology related to the usage of the metallic pipes are become obsolete, as well it needs the lost of men and machine power to get rid of the regular and routine issues. Hence the composite pipes are capturing the predominant market place in most of the sectors, start from transporting the oil, water and natural gases. Since its completely against the corrosive nature which often seen in the metallic pipes, it is very widely considered as the irreplaceable material in the place of metallic pipes [5-6].

Although, the research activities are routinely happens in order to improve the special coatings on the metallic pipes, still the cost incurred towards that coating become as the huge as compared with the installing of the composite pipes in the place of metallic pipes. Most often the composite pipes are transported from fabrication facility to the end usage area through the heavy carrying trucks and other mediums. This set of transportation of the pipes are routinely happens since the erection site is very far away from the manufacturing industrial sector [7-8]. It seems that, during the transportation and erection of the composite pipes, it completely come across the lot of compressive load through longitudinally and circumferentially. Hence, due to this the possibility of the failure during transportation and erection of pipes are become inevitable. So maximum failure happens before the failure is been erected and transported. With the intention of overcome this issue, researchers are often trying to find out the suitable solution to overcome such a problems with their state of art technology. In the pretext of the above, the pipe manufacturers are frequently use the various set of resin material and fiber components along with some set of filler materials. Despite the fact that epoxy and vinyl ester are majorly occupies and positions itself as the prime matrix material in most of the pipe manufacturing industries [9].

Similarly the different set of glass fibers are widely considered as the major reinforcement material in pipe industries since it is easily availability and cheap cost. In this study, to keep the issues which faced out by the engineers in their routine pipe erection and transportation problems, the new way of study has proposed by properly extracting the elastic behavior of the polyurethane. It’s the one type of matrix material having high tensile strength, corrosion resistence, tear resistance and good youngs modulus. By inculcating all the physical and chemical property of the polyurethane, the idea of blending the polyurethane with vinyl ester has been used as the matrix material in this study proposed work [10]. The E-Glass fiber has been chosen as the reinforcement materials along with the several of ratio of IPN blends have been chosen as the matrix material. The compressive strength analysis as well carried out in order to find out the withstanding (compressive stress) capability of the IPN pipe. Along with that, to validate the experimental analysis, numerical studies as well carried out with help of the ansys software. It seems both the studies have shown good agreement with each other during the study [11-12].

2. Materials and methods

2.1. Materials
To fabricate the composite shell, hand layup technique was used in this research work. The reinforcement material E-Glass fiber was purchased from sakthi fibers, Chennai with the aerial density of 350 gsm. In addition to that, the vinyl ester with exact promoter, accelerator and catalyst was purchased from vasavi bala resins. The polyurethane resin was purchased cross link technology, Hyderabad, india. All the chemicals were used for the fabrication purpose as such received from the manufacturers as shown in figure 1 [13].

Figure 1. (a) E-Glass fiber-Biaxial woven mat (350 GSM) (b) vinyl ester (c) polyurethane
2.2. Preparation of IPN formulation

Initially, the vinyl ester was taken into the beaker with the required quantity, the necessary accelerator; promoter and catalyst were added into it. The required amount of polyurethane was added along with the vinyl ester with the series of proportionate as stated in the table 1.

| Sample No. | Vinylester (g) | Prepolymer of PU (g) |
|------------|----------------|----------------------|
| 1          | 100            | 0                    |
| 2          | 90             | 10                   |
| 3          | 80             | 20                   |
| 4          | 70             | 30                   |
| 5          | 60             | 40                   |
| 6          | 50             | 50                   |

2.3. Fabrication of IPN composite pipes

First, the mandrel with the diameter of 124 mm was placed on the roller support as simply supported hinge, following this, the necessary poly vinyl alcohol was applied over the mandrel as the releasing agent. Secondly the silk mat was made available on the entire mandrel surface by wetting the same with the IPN blend. Following that, the E-Glass mat was rolled over the mandrel, upto the thickness of the 3 mm (5 rolls) as shown in the figure 1. After finishing the complete rolling of the mat, it was allowed for cure for the period of 24 hours. Once the mandrel was taken out from the mandrel, the specimens with different proportionate of the PU loaded pipe specimens were kept into the hot air oven for the period of 2 hours by maintaining the temperature of 80°C for the period of 3 hours to get the complete polymerization [14].

Figure 2. Hand lay-up of E-Glass fibre reinforced IPN composite pipe

2.4. Sample preparation

The prepared specimens with various proportionate of PU loaded IPN samples were cut as per the standard specified in ASTM D695-10. From the original sample made, the necessary specimens were cut for the length of 150 mm and the ends were finely grinded with the emery sheet grinder handy machine for the leveling purpose as shown in the figure 2.

Figure 3. Dimensions of the trial specimens
2.5. Compressive strength analysis
The specimens were kept into the universal testing machine in vertical direction as shown in the figure 2, following this the gradual load was applied on the edges of the pipe (standing vertical) with the cross speed of 2 mm/min until the specimen fractures and their corresponding readings were noted down automatically through the system connected with the universal testing machine (500 TON) as shown in the figure 3 [15].

![Figure 4. Experimental analysis of compressive strength (UTM)](image)

2.6. Numerical Analysis
To verify the compressive experiments, the FEA analysis was carried out. This analysis through numerical method was done with the help of ANSYS 18.2 software. To carry out this numerical analysis, a similar model of cylinder was designed in CATIA V5, following the same dimensions that are used in experimental analysis. Now the modeled component was saved as a stepfile. This format of saving of the model was used in the importing process that was performed in ANSYS 18.2. At first, a series of laminates were made, possessing the similar materialistic configuration of the fabricated cylinders. These laminates were being tested by following the same procedures of the experimental analysis. The different laminate composition of E-Glass fiber reinforced and IPN resins (0%, 10%, 20%, 30%, 40%, 50%) are fabricated separately, such as a laminate structure of IPN resins and a laminate structure of E-Glass fiber was obtained as the test specimen individually.

Table 2 showcase the engineering data’s that were determined input values for analyzing the cylindrical samples. The solid layered 46 element was made to perform the execution, as it provides with a quadratic nodal structure of solid elements. This approach provides us with stacking ability of about 250 layers construction with a three degree of freedom along x,y and z direction. The ANSYS analysis procedure was followed by the operation of meshing. Then the compressive loading was done. The ASTM D695-10 standard followed in this modeling of cylinder and the experimental details that were given as the engineering data provides the accurate behavior of the cylinder due to the load applied at the one end and the lateral surface fixed at the other end [16-17].

| Mechanical Properties | Mixture ratio of VER/PU Resin | Mixture ratio of VER/PU E glass woven fabric |
|-----------------------|-----------------------------|-------------------------------------------|
|                       | 0%  | 10% | 20% | 30% | 40% | 50% | 0%  | 10% | 20% | 30% | 40% | 50% |
| E1 (MPa)              | 73.5| 72.2| 70.2| 67.9| 65.4| 64.1| 12050| 11980| 11890| 11750| 11690| 11520|
| E1 (MPa)              | 73.5| 72.2| 70.2| 67.9| 65.4| 64.1| 8570 | 8252 | 8195 | 7983 | 7910 | 7820 |
| u12                  | 0.32| 0.34| 0.35| 0.37| 0.38| 0.39| 0.27 | 0.27 | 0.28 | 0.28 | 0.29 | 0.31 |
| G12 (Mpa)            | 28.1| 26.82| 25.85| 24.75| 23.72| 22.72| 4558 | 4530 | 4452 | 4446 | 4423 | 4355 |
3. Results and discussion

3.1. Stress – strain response
The figure 4 illustrates the compressive behavior of E-Glass fiber reinforced IPN composite pipes with different proportionate of PU loading such as 0%, 10%, 20%, 30%, 40%, 50% respectively into IPN matrix. During the test, the precut specimen was subjected with the compressive stress by fixing both the ends of the pipe on the universal testing machine, standard cross speed of 5 mm/min was maintained throughout the entire test, until the fracture occurs.

Figure 5. Experimental analysis of compressive behavior of PU loaded IPN composite pipes

It was observed that, 0% PU loaded specimen has shown the compressive stress value as 84.15 MPa, the consecutive 0% PU loaded specimen is holding the highest compressive strength withstanding capacity as compared with the all other set of PU loaded proportionate. The hard segment presence of VER played a major role in getting such an significant behavior of rise in the compressive stress. Besides, the 10% PU loaded specimens had shown the compressive strength value as 81.45 MPa, this value was nearly 3.5% lesser than the value of the original pure neat vinyl ester matrix E-Glass reinforcement. Similarly the 20% PU loaded specimen had shown the value of 77 MPa, this value too was 4.25% lesser than the value of the 10% PU loaded specimens. It evidences that, the PU loading into the VER shown the significant strength reduction, the same kind of down rise trend as well as seen in the 30% PU loaded specimen also. The strength reduction value was observed as nearly 2.5% as compared with the earlier PU loaded specimen (20% PU). It clearly shows that, the presence of soft segment in the PU completely entangles itself with the hard segment of VER and enhances ductility property of the IPN as much as it loaded with the PU. Again to have the proof for that, the 40% PU loaded specimens as well had shown the compressive stress value as 72 MPa, this was nearly 2.75% lesser than the previous PU loaded specimen. At last the 50% PU loaded specimen as well showed the same kind of negative trend, the observed value was 69 MPa, this was nearly 2.2% lesser than the 40% PU loaded specimen. From all the tests, conducted on the various proportionate of the PU loaded specimens, the 0% PU loaded specimen had shown the complete crushing on the specimen, the geometric structure of the specimen collapses and could not regain its original shape since it is completely crushed as shown in the figure 5. But there was interesting note that, as much as loading of the PU increases into the IPN, the geometric structure and integrity of the specimen could not damage itself as observed in the neat (0%PU) VER - E-Glass fiber reinforced specimen. As much as loading of PU into the VER completely retains the geometric structure of the specimen to the significant level, along with that, as seen in the 0% PU loaded specimen, the complete crushing of the tube is not been visualized in the PU loaded specimens. It clearly shows that, the plasticizing effect of the PU plays the major factor into the IPN matrix. The PU loaded specimens, regains its structure once the subjected load is removed from the specimens, this was clearly evidenced from the figure 6 [18-19].
3.2. Numerical Analysis of IPN composite models

The ANSYS analysis, determines the unaged dry specimen for 0% PU providing the total withstandable compressive stress of about 82.03 MPa. Whereas their experimental analyses showcase that the compressive stress that the cylinder could bear was about 84 MPa. The experimental value and the
numerical value were both in good concordance with each other. The numerical value for 0% PU unaged specimen was 98.15% in accord with the experimental value. Similarly the 10%, 20%, 30%, 40%, 50% PU incorporated specimens were tested. The results of the process were 79.26 MPa, 75.43 MPa, 72.79 MPa, 70.72 MPa, 67.89 MPa respectively. The experimental results were found to be 81 MPa, 77 MPa, 75 MPa, 72 MPa, 69 MPa. The obtained numerical values and the observed experimental value correlate with each other with the % level of 97.23%, 98.34%, 96.97%, 98.56%, 99.75% respectively [20-21].

4. Conclusions

The elucidation of the following research work can be expressed from the incorporation of E-Glass fibers with IPN resin at various (0%, 10%, 20%, 30%, 40%, 50%) proportionate. IPNs were involved successfully in the field of GFRP composite pipe fabrication.

- The various proportionate of PU loaded IPN composite specimens (Pipes) were analyzed both experimentally and numerically.
- The IPN composite with 0% PU content exhibited maximum compressive strength provided with, irreversible stage of repairing. Whereas the specimens involved with various PU proportionate (10%, 20%, 30%, 40%, 50%) had showed the agreeable compressive stress with deformation partial (not affecting the geometric structure) on compressive loading.
- The experimental values obtained from the compressive stress analysis were neatly correlated with the numerical analysis (FEA) values, both the values shown the significant relation between them minimum error.

5. References

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