Damage and failure analysis of short carbon fiber reinforced epoxy composite pipe using FEA

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Composite pipes are extensively used in various automobile and aeronautical applications due to their high strength to weight ratio. The aim of this work is to numerically analyze the damage and failure of short carbon fiber composite pipe with short carbon fiber as reinforcement and epoxy as matrix. A finite element model was developed in ANSYS workbench 19. A method is discussed to generate short fibers randomly oriented in the volume of composite pipe and the material properties were given to the fibers and matrix. A method is developed to model a composite pipe having anisotropic properties. Hydrostatic pressure was applied on inner and outer surface of the composite pipe. The results were compared with the laminated composite pipe and neat epoxy composite pipe. It was observed that under the same loading conditions the strength of the short carbon fiber composite was comparable with the laminated composite pipe. Short carbon fiber composite pipe which are less costly having good strength can be a good replacement for the costly filament winding pipe .

***Keywords*:** Carbon fiber (CF), finite element analysis(FEA), hydrostatic pressure test (HPT)

1 INTRODUCTION

In various fields use of light weight structures are being involved to increase the energy efficiencies in automobile, aerospace and marine industries. Fiber reinforced composite have various application due to its high specific strength and high stiffness [1] also they have high thermal expansion and corrosion resistance [2].

Composite material composed of a material system with two or more macro constituents that differ in form and chemical composition and are in soluble in each other. There is considerable attention over the years to understand the behavior of hollow composite rods due to many applications. Application ranges from power drive shafts, aerospace design like wings, satellite truss structures, robot arms [3]. Filament winding is the conventional method and most effective method of manufacturing any composite vessel and composite pipe. This method is mainly used due to its high accuracy in fiber positioning, high fiber volume fraction, and process automation [4]. There are many factors which influence the strength of the composite tube like winding tension, sequence of stacking, gradient of winding tension, winding time between layers, cut versus uncut helices [5].

On the other hand manufacturing of randomly reinforced fiber composite is controlled by less factors like mixing method, mould preparation ,resin fiber transfer method. Ozosy et. al worked on finding the tensile, bending, impact, hardness properties of the chopped carbon fiber epoxy composite. Results were based on the (0%, 6%, 8%, 10%) weight fraction of reinforcement in the epoxy composite. It was observed that the tensile, bending and impact performance increase up to 8% of the reinforcement after which only the hardness increase by increasing the weight fraction of the chopped carbon fiber[6]. Harper et. al worked on effect of fiber length on random carbon fiber composite. Shorter fiber shows good mechanical properties as compared to the longer carbon fiber composite. Strength of the composite follows decreasing power law relationship with the increasing length. 3 mm is the critical length at which good properties of the composites are observed[7].

In the present work a method is discussed to model the pipe having randomly distributed short carbon fiber as the reinforcement and epoxy as the matrix in ANSYS 19. As the cost of traditionally fabrication of composite by laminates is very high. Random short fiber composite pipe can be a good alternative with light weight structures with low cost. Numerical analysis of the pipe based on short carbon fiber composite pipe which can be made by casting method. The parameters are compared with the laminated composite pipe and neat epoxy pipe under the same loading condition.

2 MODELLING AND SIMULATION

2.1 Generation of randomly distributed chopped fiber

Generation of random fiber was done using a program in the MS Excel sheet. Six columns of random function to generate the six random numbers that describes the x, y, z position of one end of the fiber and dx, dy, dz offsets to other end of the fiber. The spreadsheet creates required number of straight fibers and length of fibers as 3 mm which can vary as per the requirement. Then the specific text file format is imported as 3D curves in the design modeller of ANSYS . Fig 1 shows the representative volume with reinforcement as carbon fiber in pipe along the length of pipe and within the thickness of the pipe.

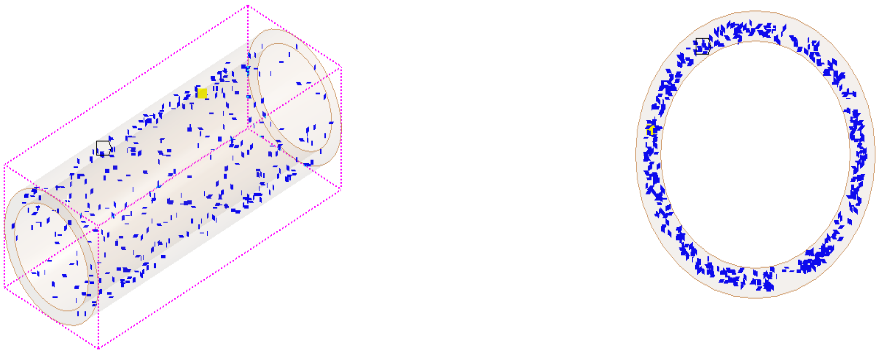


Fig.1. Pipe with random carbon fiber reinforcement

2.2 Model Development

Composite pipe was developed in ANSYS Workbench 19 software tool using HP workstation, processor of Intel Core i7, 16GB RAM, 1TB ROM and windows 8.1Pro. The dimensions of the composite tube are taken in accordance with the model of Humberto et. al [8]. Length of the pipe was taken as 381 mm and internal radius of 60 mm with wall thickness of 3mm. The cross section is assigned to the generated fiber with diameter of 0.1 mm. The properties of carbon fiber are shown in table 1[9]. Properties of epoxy are taken from the library of ANSYS as tabulated in table 1. Pure epoxy resin pipe is shown in fig.2 and the composite pipe with reinforced carbon fiber is shown in fig.3.

Table1: Properties of carbon fiber and Epoxy

Material	Tensile strength (MPa)	Young's modulus (GPa)	Density (g/cm^3)
Carbon fiber	3950	238	1.77
Epoxy resin	-	3.78	1.16

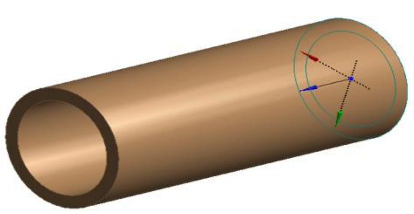


Fig. 2. Neat epoxy pipe

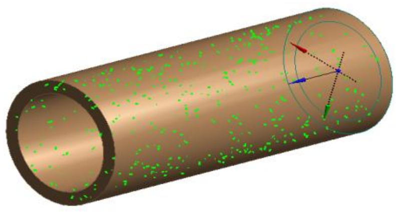


Fig. 3. CF reinforced epoxy composite pipe

2.3 Meshed Model

In meshed model, quadrilateral element was used over whole domain as shown in Fig.4. Meshing was done under user-controlled mesh in which ‘extra fine’ element size given to pipe and fibers. The complete mesh consists of 6816 elements and number of nodes 13752.

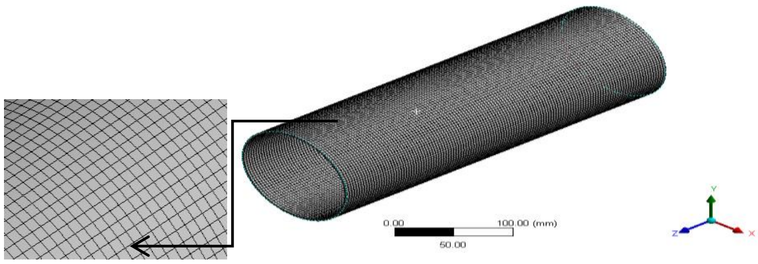


Fig.4. Meshed model of the composite pipe

3. NUMERICAL RESULTS

3.1 Hoop displacement and total deformation under external pressure

The axial displacement along the z direction of both the end was restricted and hydrostatic pressure was applied on the external surface of the pipe. The results were compared with the filament winding model, $[90/\pm55_8/90]$ as proposed by Humberto et. al [6] and short carbon fiber epoxy pipe of present study with vol. fraction of 5% CF. It was observed that the hoop displacement of the CF composite shows approximately same trend as of the filament winding pipe upto certain level of pressure, about 120 bar as shown in fig. 5. As the filament winding is a very costly therefore for low to medium pressure application it can be replaced with the short fibre composite.

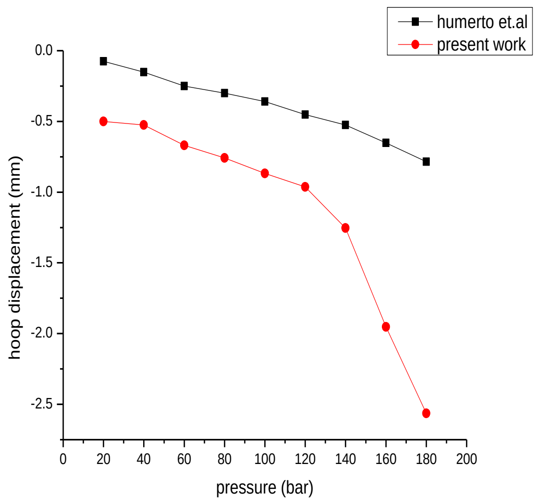
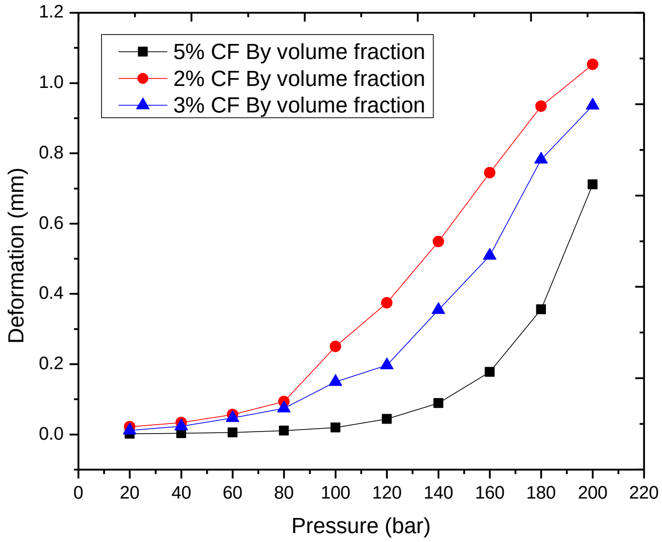
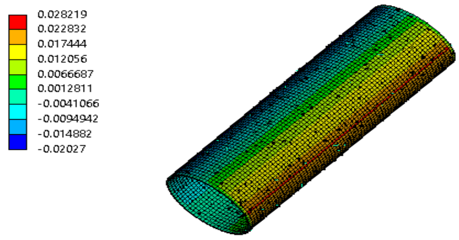


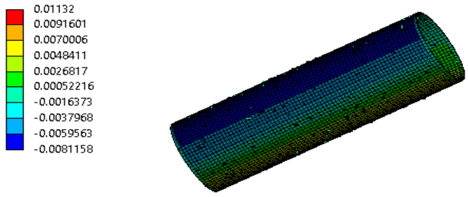
Fig 5. Depicting the variation of hoop displacement as a function of applied pressure

For the same loading conditions that is under the HPT the variation of total deformation and contours for deformation at 20 bar is represented in fig. 6.

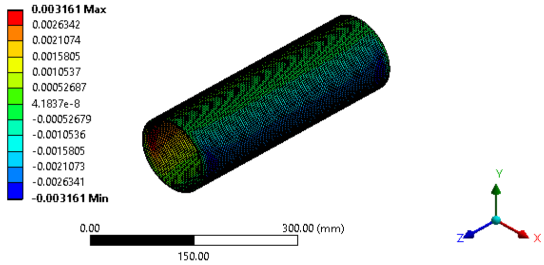




2% Vol. fraction of CF epoxy pipe



3% Vol. fraction of CF epoxy pipe



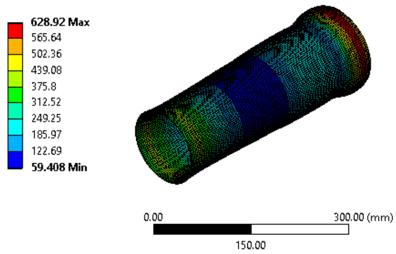
5% Vol. fraction of CF epoxy pipe

Fig. 6. The variation of total deformation with external pressure for CF epoxy composite

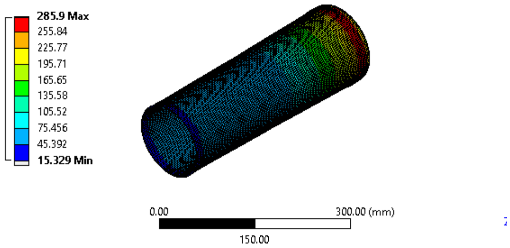
From fig.6, it can be seen that the less deformation taking place in case of higher vol. fraction CF composite as a function of applied pressure. As the vol. fraction of composite is increased the deformation in composites are reduced in every level of applied pressure. In composites, the load applied to the structure is basically carried by the reinforcement and then transfer to the matrix medium; therefore by adding more and more the reinforcement the properties of the composites get enhanced.

3.2 Comparison of different structures of CF epoxy composite pipe

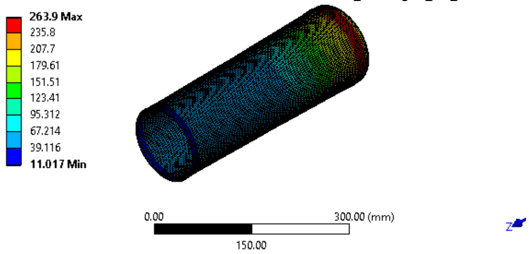
Three pipe models with varying vol. fraction of reinforcement were subjected to same loading conditions. Pipe were fixed from both the ends and hydrostatic pressure was applied on the inside surface of the pipe. Stress level at different pressure was found and plotted in fig.7 The variation of the stress is represented by the four models for different applied pressures.



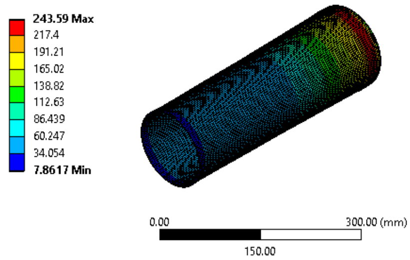
0.0% Vol. fraction of CF epoxy pipe



2.0% Vol. fraction of CF epoxy pipe



3.0% Vol. fraction of CF epoxy pipe



5.0% Vol. fraction of CF epoxy pipe

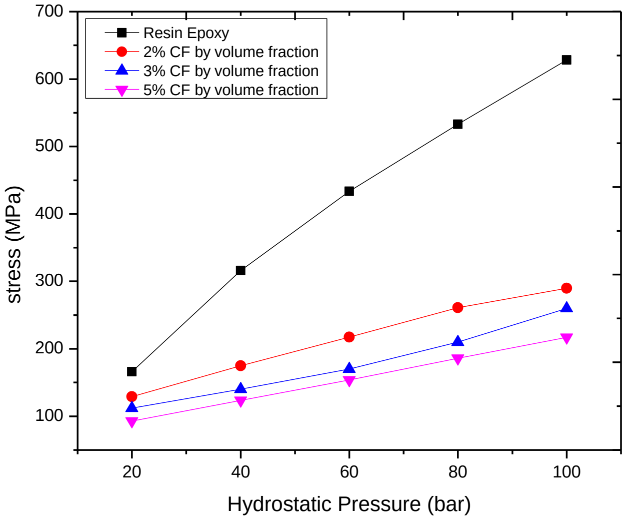


Fig. 7. Depicting the variation of the Von Mises stress in Hydrostatic Pressure Test

Fig 7 depicts that the stress level in the neat epoxy pipe is very high as compared to the other model of CF composites pipe. It is also clear from the plot that the value of Von mises stresses are decreasing as the vol. fraction of CF is increased. Therefore the chances of failure for in case of composites with higher vol. fraction will be less.

4 CONCLUSION

Mechanical performance of short carbon fibre reinforced epoxy composites is investigated numerically with FEA simulation. A novel method is discussed to model the pipe with randomly oriented short carbon fibers. The results show that reinforcement of short carbon fibre has significant affects on the performance of composite under hydrostatic pressure testing conditions. It has been found that in case of low to medium pressure application as well as some structural applications, the costly filament winding pipe can be replaced with less costly CF reinforced composite pipe. The hoop displacement up to 120 bar of pressure is almost linearly propositional to filament winding pipe. The chances of failure for composites of higher vol. fraction is less as both the total deformation and Von mises stress levels are low.

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