Investigation on the progressive damaging failure of Kevlar hybrid composite pipe

N.Ramasamy[1], Dr.V.Arumugam[2], A.Aruljothi[3]

[1]Research Scholar, Department of Aerospace Engineering, MIT Campus, Anna University, Chennai.

[1]rams_sanj@yahoo.in

[2]Associate Professor, Department of Aerospace Engineering, MIT Campus, Anna University, Chennai.

[3]Assistant professor, Department of Mechanical Engineering, Dhaanish Ahmed college of Engineering.

Abstract — **Composite materials are continuously gaining more importance in the field of engineering. In this paper we have focused mainly on hybrid fiber reinforced polymer composite materials as pipe. This work concentrates on the hybrid (Aramid and Glass) fiber as a reinforcement of the epoxy matrix. The advantage of hybridization is to increase the strength of hoop tensile strength and stiffness of pipe used in industry application. The aim of paper is to study the progressive damage failure analysis of hybrid fibre pipe. We had produced specimen for making a lightweight, energy absorbing, glass fiber reinforced aramid fiber, Aramid fiber reinforced glass fiber composite pipe and explore through the effect of lateral compressive response was analysed. A very good agreement was observed between experimentally measured apparent hoop tensile strength of hybrid fibre reinforced epoxy pipes and predicted values employing progressive damage modelling.**

Keywords— **pipe, lateral crushing, hybrid, hoop tensile**

1. INTRODUCTION

Composite materials are increasingly used in the civil infrastructure and piping systems to transport sewage, service and potable waters Thanks to light weight, high strength and stiffness and good corrosion resistant, Glass Reinforced Polyester (GRP) pressure pipes are widely used for water transmission. [1]. Glass- and aramid-reinforced polymer laminates are commonly used as light-weight materials in a wide variety of marine applications including sporting equipment as well as military structures. However, the shortcoming of glass-reinforced plastics along with other fibre-reinforced polymer laminates is that their mechanical properties in the translaminar (through thickness) direction are relatively low. Owing to the weak bonds between the plies, even small energies imparted by out-of-plane loads (low velocity impact) can result in damage, which, although hardly detectable, causes considerable strength losses in tension and, especially, in compression [3]

Studies have confirmed that the stiffness of fiber reinforced polymer tubes under compression loading decreases considerably as a result of the weakening of the fiber–matrix interfacial bonding. Furthermore, when glass fibers are exposed to aqueous conditions, ions are removed from the fibers, resulting in a deterioration of the fibers' surface [4].

The foam filled corrugated panel was found to have strength and energy absorption much greater than the sum of those of an empty corrugated sandwich panel and the aluminum foam alone. It was demonstrated that the core members in the foam-filled panel were considerably stabilized by the filling foam against lateral deflection [6]. Libo Yan was investigated the study of crashworthiness characteristics of natural flax fabric reinforced epoxy Composite tubes under quasi-static lateral compression. The parameters considered include two tube inner diameters, three arrangements of plies and the use of polyurethane-foam filler. The lateral crushing characteristics of these flax/epoxy tubes are compared with the existing circular tubes. The test results show that empty tube with more laminate layers has larger peak load. The increase in peak load is almost directly proportional to an increase in tube laminate layers [7]

The author was revealed that sequential failure modeling is developed accounting for LPF in GRP pipes considering sand layer. The developed SFM is a progressive modeling examining occurrence of failure layer by layer. When a layer is failed during the analysis, its primary mechanical properties are replaced by degraded properties based on the experienced mode of failure [9].

The present study focuses on the combined effect of the hybridization of Kevlar composite pipe with glass fiber for constant volume fractions of fiber with reinforced epoxy matrix. It has been studied in hoop tensile strength and stiffness behavior of hybrid pipe.

2. EXPERIMENT

2.1*Materials*

Filament wound GRP pipes were manufactured using a CNC filament winding machine (Fig.1) with winding Angles of 90°. FG STRAND 1200 TEX, E-Glass which is alumino-borosilicate glass with less than 1% w/w alkali oxides, mainly used for glass-reinforced plastics and Araldite Epoxy Resin Grade LY556 -A epoxy resin system and Huntsman - Grade - ARADUR HY951 is a hardening agent were used to make specimens. Before winding operation, resin was mixed for 4–5 min at 40°C resulting in an appropriate viscosity with a 4-h gel Time. Five layer specimens were produced by winding onto the release agent and resin coated and preheated Mandrel heated to 60°C. Filament wound composite pipes were produced with dimensions of 300 mm in length, 50 mm inner diameter and 2.5 mm in an average thickness and were cured for room Temperature / 24 - 48 hours on the mandrel in a slow motion rotary oven. The four Different specimen (Fig. 2) are produced by filament winding machine are glass fiber pipe, Kevlar fiber pipe, glass reinforced Kevlar pipe(25% glass and 25% kevlar) and Kevlar reinforced glass pipe (25% Kevlar and 25% glass)with 50% volume fraction of epoxy resin .All production stages were repeated to make 90° filament wound pipes. The Pipes were cut into the designed test length as 150mm using a diamond Wheel saw.

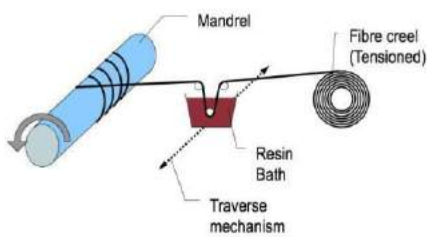

Fig1.Filament winding machine

Fig. 2.Specimens for lateral crushing.

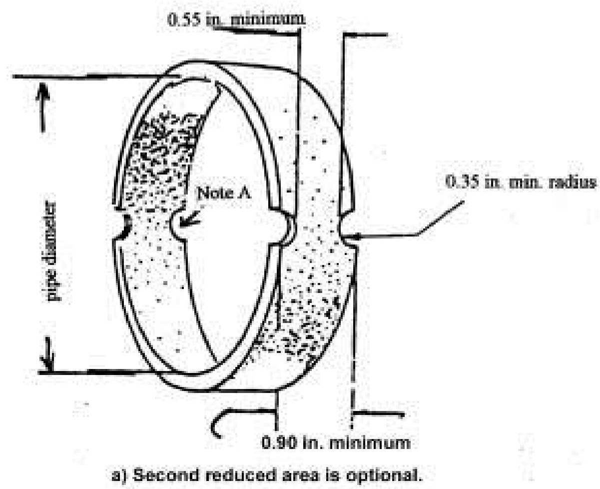

Fig .3.ASTM Standard for hoop tensile strength.

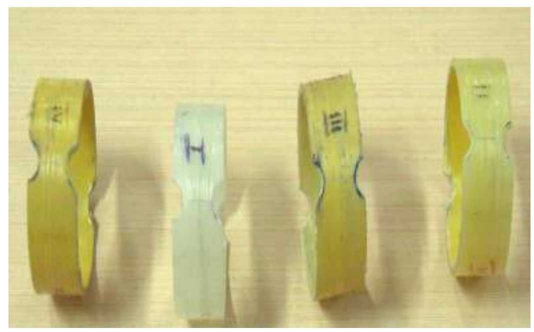

Fig. 4.Specimens for hoop tensile strength.

2.2 *Experimental procedure*

2.2.1 *Hoop tensile strength*

Fig. 5 shows the test set-up in UTM machine. Loading was applied by a hydraulic actuator with an axial capacity of 10000 kN. The specimen was cut as per standard ASTM D2290 (Fig.3-4 and Fig.4) and placed vertically inside the steel frame using the standard fixture of split disk method. The dial gauge setup has been used to precise the composite specimen. The tensile pipe specimen was connected in between two steel half roller plates. A displacement controlled loading process was designed for the columns in this study. The displacement rate was 1 mm per minute. According to standard experiments were conducted to determine the apparent hoop tensile strength and the tensile modulus of GFRP and Kevlar composite.

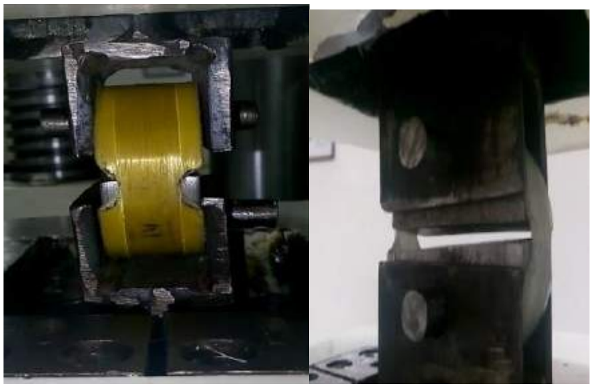

Fig .5. Failure of specimens under axial loading at a rate of 1 mm/min during tensile test a) Aramid pipe specimen b) Glass pipe specimen

2.2.2 *Lateral crushing strength*

In this research, lateral crushing strength was tested in UTM machine (Fig.6). Four different specimen was tested for observing the stiffness factor and stiffness strength.Accordng to ASTM D2412 the specimen was cut and placed in between the parallel plate's in UTM machine. Crushing Load with respect to deflection was observed from experiments.

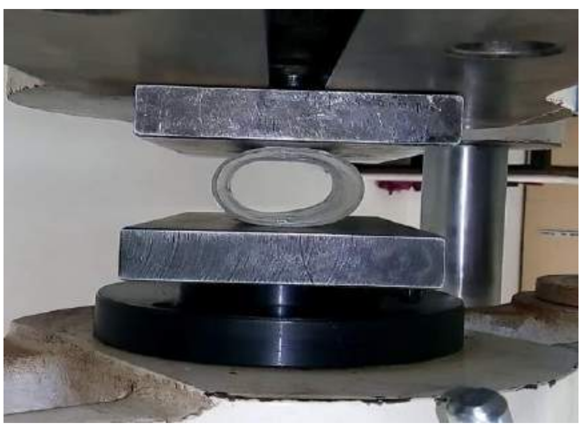

Fig. 6. Failure of specimens under lateral crushing loading at a rate of 1 mm/min

3. RESULT AND DISCUSSION

3.1 *Progressive failure of hybrid pipe*

The hybrid structure pipe was designed to absorb the crushing energy and to satisfy the crashworthy structure. The progress damaging failure mechanism was identified as parameter to evaluate the stiffness strength of composite pipe. The photographs (Fg.7-8) are presented for tensile loading and lateral crushing loading. It was illustrated in the photographs, Failure occurred with increasing of time. The damaging failure was initiated at 140s for the hoop tensile glass reinforced aramid pipe and peak loading of the specimen can be achieved at 220s.The hybridization was effected on all composite pipe. For the same composite pipe the failure was imitated at 200s and ultimate lateral crushing progressive damage was reached on around 500s.

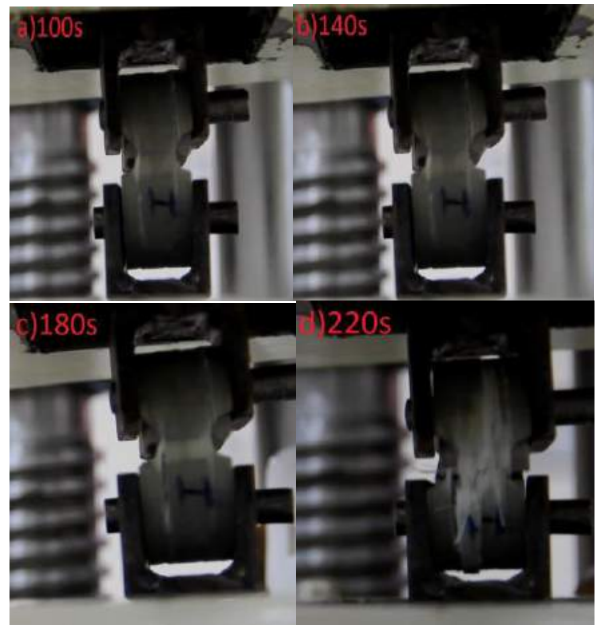

Fig.7. Progressive Failure of specimens under tensile loading at a rate of 1 mm/min with respect to time

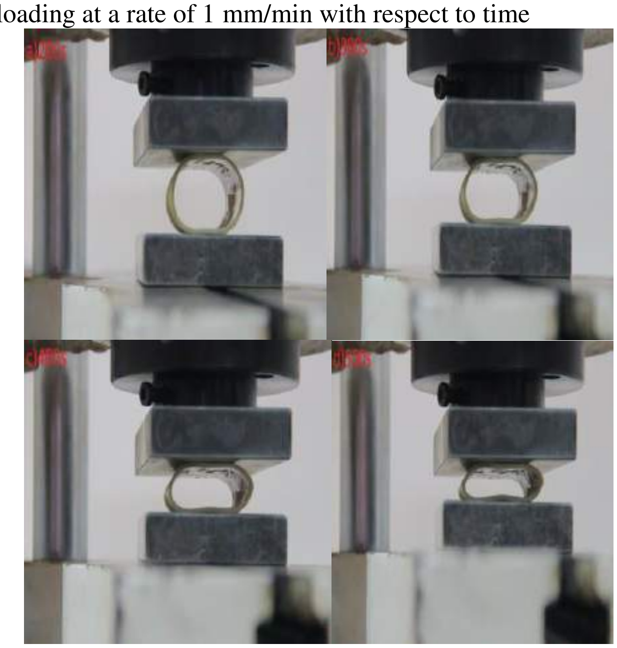

Fig.8. Progressive Failure of specimens under lateral crushing loading at a rate of 1 mm/min with respect to time

3.2 *Hoop tensile strength behaviour*

Load–displacement plots illustrating that energy absorption potential of the samples showed that in homogeneous and hybrid condition (Fig. 9).The elastic energy has absorbed in the surface area of outer layer and the fracture was initiated at the curve surface of composite pipe under axial tensile load. Glass reinforced Kevlar pipe has increased hoop tensile strength compared to others samples due to delay in debonding at outer layer of composite pipe.Fig.10 shows for increasing strain with increased stress in glass reinforced Kevlar composite, which is indicative of hoop tensile strength of Kevlar fiber with glass. Fig.11 shows apparent hoop tensile strength has raised for glass reinforced aramid pipe. This indicates that energy dissipated for plastic deformation at the outer layer and elastic deformation at inner layer of aramid pipe. The damage is not significantly changed due to hybridization of pipe. It was observed that the glass hybrid pipe with stand the high load when compared to other composite pipes. Thus it possesses good hoop tensile strength. The average experimental value was arrived to draw the graphs from the value of three samples for each composite pipe.

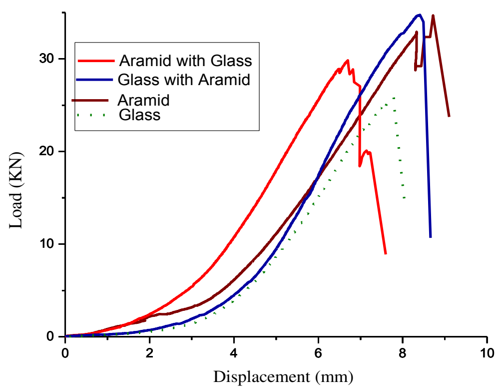

Fig .9. Graphs showing tensile load with deflection

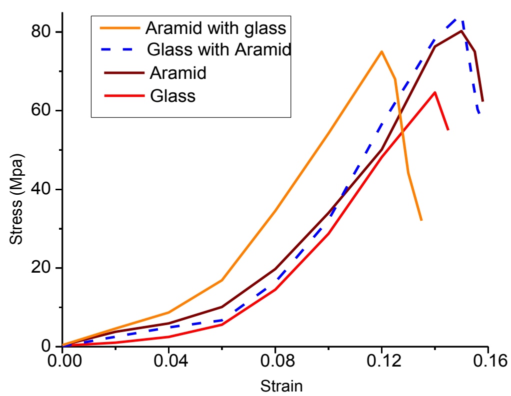

Fig .10. Graphs showing stress with strain

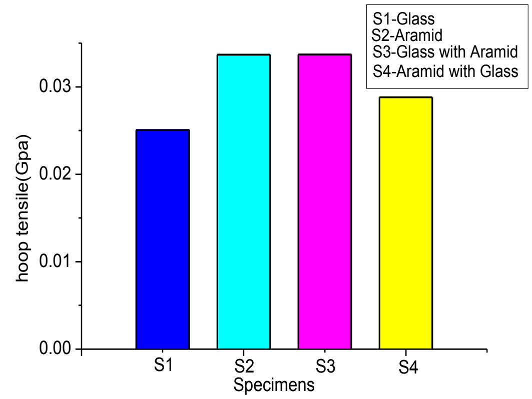

Fig .11. Graphs showing Apparent hoop tensile strength with different pipe specimen

3.3 *Lateral crushing strength behaviour*

From the Fig.12, the deflection was increased with increasing of crushing load applied. The glass reinforced aramid pipe has maximum load absorbing capacity. The elastic region is reached at the displacement of 20mm and initiated to get fracture after the peak load 14.56 kN. The outer layer has more load carrying capacity compared to inner layer. The interaction effects between the layers are delay in debonding with epoxy matrix. Fig 13-14 shows evaluate the effect of stiffness parameter in glass hybrid pipe which has more stiffness strength with change of displacement.

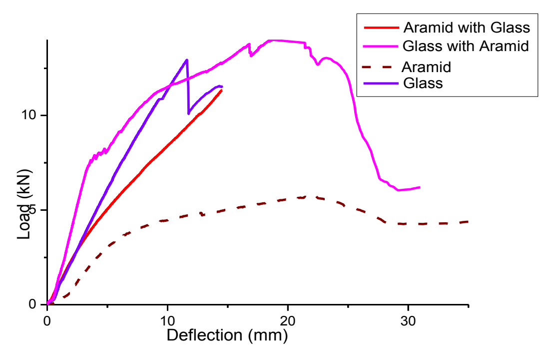

Fig .12. Graphs showing crushing load with deflection

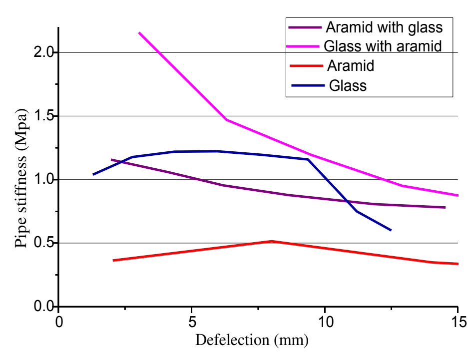

Fig .13. Graphs showing pipe stiffness with deflection

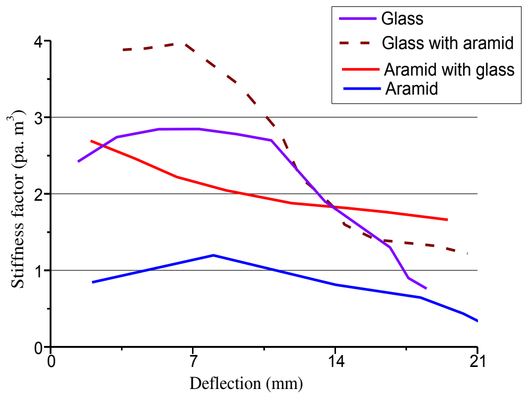

Fig .14. Graphs showing stiffness factor with deflection

3.4 *microscopic observations*

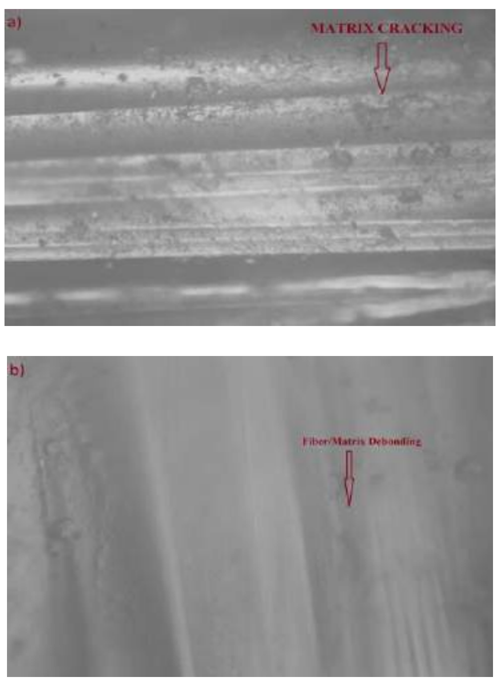

Fig.15. Optical microscopy image of Kevlar composite after deformation

Optical microscopy (OM) photographs were taken after deformed specimen. In Fig.15 compares the fracture surfaces of the glass reinforced kevlar fiber/epoxy composite pipe and Kevlar reinforced glass pipe , there was proper bonding and adhesion between matrix and fibers in this both specimen, but exposure to the harsh environment resulted in the degradation of the fiber–matrix interface. From these figures, it can be observed that when the period of aging rises, the reduction in the amount of resin around the fibers becomes more significant and leads to an increase in the weakening of the fiber–matrix interface strength.

4. CONCLUSIONS

Four different woven glass–aramid fibre/epoxy hybrid pipe were subjected to progressive failure mechanism under by lateral compression and hoop tensile method .The lateral compressed pips were retested statically to determine residual strength for the assessment of damage tolerance. The affected microstructural Integrity of the two composites hybrid pipe causing numerous internal defects and layers debonding.No important effect has been found of glass–aramid fibre pipe. Threshold damage (fibre/matrix debonding) load was in hoop tensile load is 34kN and crushing load is 14.56 kN. Due to low fibre–matrix adhesion, the prevailing failure modes were fibre/matrix debonding and interfacial cracks for all specimens. This damage area was slightly less extensive in hybrid samples, which is suggested to be the result of the propagation of interfacial damage which absorbed energy and inhibited the delamination formation.

REFERENCE

[1] Roham Rafiee, Experimental and theoretical investigations on the failure of filament wound GRP pipes, Composites: Part B 45, 257–267, 2013.
[2] Manuel A.G. Silva, Aging of GFRP laminates and confinement of concrete columns, Composite Structures 79, 2007.
[3]Krystyna Imieli_nska,Laurent Guillaumat, The effect of water immersion ageing on low-velocity impact behaviour of woven aramid–glass fibre/epoxy composites, Composites Science and Technology 64 2271–2278, 2004.
[4] Shahram Eslami, Abbas Honarbakhsh-Raouf, Shiva Eslami, Effects of moisture absorption on degradation of E-glass fiber reinforced Vinyl Ester composite pipes and modelling of transient moisture diffusion using finite element analysis, Corrosion Science 90 168–175, 2015.
[5] M.F.M. Alkbir, S. M. Sapuan, Nuraini A.A AndM. R. Ishak, Effect of Geometry on Crashworthiness Parameters of Natural KenafFibreReinforced
Composite Hexagonal Tubes, Materials and Design, S0261-3069(14)00139-3, 2014.
[6] L.L.Yan ,B.Yu, B. Han,C.Q. Chen,Q.C. Zhang,T.J. Lu, Compressive strength and energy absorption of sandwich panels with Aluminum foam-filled corrugated cores, Composites Science and Technology 86 142–148,2013.
[7] Libo Yan, Nawawi Chouw, Krishnan Jayaraman, Lateral crushing of empty and polyurethane-foam filled natural flax fabric reinforced epoxy composite tubes, Composites: Part B S1359-8368(14)00129-2,2014.
[8] Libo Yan, Nawawi Chouw, Krishnan Jayaraman, Lateral crushing of empty and polyurethane-foam filled natural flax fabric reinforced Epoxy composite tubes, S1359-8368(14)00129-2, 2014,
[9] Roham Rafiee, Experimental and theoretical investigations on the failure of filament wound GRP