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Effect of non-penetrating impact damages of pre-stressed GRP tubes at low velocities on the burst strength

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ABSTRACT

In this study, failure behavior of pre-stressed Glass Fiber Reinforced Plastic (GRP) tubes subjected to low velocity impact was investigated. Filament wound E-glass/epoxy composite tubes with a winding angle of ±55° were used in the experiments. The tubes pre-stressed to 32 bars internal pressure, one of the specified operating pressures according to ANSI/AWWA C950 standards. Both prestressed and non-pre-stressed GRP tubes were subjected to low velocity impact tests at 5, 10 and 15 J low energy levels. Plots of contact force and internal pressure with respect to time and those of force–displacement were obtained and damages occurred on the specimens were examined by means of reflected and transmitted light photography and light microscope. No marked fiber breakages are observed; however, debonding and some sort of delamination on the layers were observed. The GRP tubes with impact damages were subjected to monotonic burst pressures up to failure based on the ASTM D 1599-99 standards. Burst damages on the tubes were studied and variations of their corresponding burst strengths were spotted. Besides that, diameter changes with internal pressures were determined during the tests. Diameter changes with internal pressures for the impacted and the non-impacted tubes were found to be the same.

1. Introduction

Glass Fiber Reinforced Plastic materials (GRP), are composite materials obtained by adding glass fibers as reinforcing materials into resin. Due to their superior features such as high strengths, resistant to chemicals, weathering resistance glass fiber reinforced plastics have had diverse industrial applications. In ANSI/AWWA C950 standards GRP tubes are classified based on pressure grades and are specified with their operating pressure values. In relation to their respective pressures, the GRP tubes are used in numerous engineering applications such as holding and transferring fluids that contain chemical matter, carrying and discharging of industrial wastes, influx and transferring of sea water, being used as petroleum and natural gas pipe lines, installed as natural gas piping systems in submarines and as pressurized and non-pressurized sewage piping networks. Due to various causes, composite tubes are generally, susceptible to impacts during their manufacturing, operation and maintenance. Unlike metallic structures, composite structures are more sensitive to impact damages and hence tend to develop failures at microscopic levels that cannot be detected by knocking or naked eyes. These micro damages deteriorate the strengths of the materials and intensify as loading increases. For this reason the blow effects of foreign materials within composites need be known and necessary measures taken during the design phase of the components. The blows tend to influence the performance of composite structures thereby imposing restricting effects on their uses.

There are a number of studies in the literature dealing with the investigations of impact behaviors of GRP composite tubes. Some are listed as below;

In their study, Alderson and Evans [1] conducted impact tests on ±55° filament wound glass fiber reinforced pipes at both monotonic and low velocity operating conditions. In one of these types of connections, a GRP specimen was left free on the floor while in the other the specimen was fixed on its ends. The researchers used a simple illuminating technique to analyze the magnitude and the duration of the damaged areas on the pipes took. They found that the failure process occurred on the specimens have two characteristic features. First of all, they found that, regardless of the type of support, the elastic behavior ends at the same load. As for the second part, they found that progression of the other damages (delamination) following the elastic behavior mostly depends on the manner the specimen is supported and the test method is used.

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Doyum and Altay [2] investigated weight effects falling onto (±45°, 90°) S-glass and (±54°, 90°) E-glass filament wound thin cylinders and their subsequent damages. They used a device that could generate impacts at the range of 3.5 J and 8.5 J energy levels. They determined the type and magnitude of damages imposed on a specimen based on the impact energy applied. In their study, they found that, most of the E-glass tubes had undergone surface cracks and delamination was a common damage.

Kim et al. [3] conducted finite element (FE) analysis to study the effects of a curve on dynamic responses of cylindrical composite panels. According to that study, the response of panels with few curves to impacts is similar to that of plain layers, however, the contact force increases as the curvature increases. Since impact tests conducted on same energy levels, layer separation occurred on a curved specimen is more important than plane surfaces. This is due to the fact that the contact force and its duration tend to increase when applied on these materials.

An experimental and numerical study by Kistler and Waas [4] investigated the effects of unexpected impacts on curved cylindrical carbon epoxy composites used in aircraft fuselages. Effects of a number of parameters on striking and target behavior were numerically compared, however; damages imposed by impacts could not be predicted.

Gning et al. [5] studied the effects of impact damages of ±55° filament wound glass epoxy cylinders on hydro monotonic pressure resistances. The cylinders used were 110 mm long with diameters of 55 mm and thickness of 6 mm. First, the non-impacted specimens were subjected to external pressure where their burst pressures were determined. Then, the pressure was applied on the specimens impacted at different energy levels where variations on the specimens' burst pressures were found. The reason for applying external pressure on the specimens was to find out the required damage tolerances for the continuous underwater applications. They showed that impact failures, significantly, decrease burst pressures of glass/epoxy cylinders. For example, 12 J of impact energy was found to decrease burst pressure to 40%. This study proves quite important in terms of predicting damage tolerances and in improvement of structures.

In another study, Gning et al. [6] applied semi-monotonic indent and low velocity impact tests on thick ±55° filament wound glass epoxy tubes. The weight dropping tests were conducted on 55 mm internal diameter tubes with 6 mm thickness up to an energy level of 45 J. First, the failure zones were spotted with a help of ultrasonic investigation. Then a number of samples were cut and leveled and the damaged areas were marked with the dye penetration technique. This helped with determining the damage propagation in details. In addition, the effects of impact failure on burst pressure were defined. It was found that an increase in impact energy leads to corresponding decrease in burst pressure.

Tarfaoui et al. [7] conducted a study where the influences of scales and sizes on failure and dynamic responses of glass epoxy cylindrical structures were investigated. ±55° E-glass epoxy specimens with different sizes and scales were used in their study. They found that manufacturing parameters had substantial effects on dynamic responses and on the damages inflicted on the specimens. The damages on the specimen, the largest contact force, the deepest penetrating and contact time are directly proportional to the specimen sizes.

Minak et al. [8] have been studied carbon/epoxy tubes subjected to twisting moment. All tubes were subjected to a transverse impact. According to the test results they suggested a non-linear model of the tube flexural stiffness.

Curtis et al. [9] have been studied E-glass filament wound composite tubes subjected to either impact or quasi-static indentation. The tubes that subjected to lateral indentation and low velocity strikes were tested in order to determine their residual burst strength. They noted that higher energy indentation reduces the tubes' burst strength by 60%.

Uyaner et al. [10] investigated strengths of GRP tubes after the low velocity impacts. In their study, the researchers conducted low velocity impact tests by exerting a 6.350 kg, 24 mm diameter semi-spherical indenter and at striking velocities of 2.0, 3.0 and 4.0 m/s on the ±55° filament wound GRP tubes. The impacted tubes were exploded with monotonic burst pressure based on the ASTM D 1599 [11] standard. According to the results obtained, as the striking velocity increases in the low velocity impact tests, the largest contact force, contact time interval, displacement, quantity of energy absorbed by the material and the extent of damages on the specimens increase too. Moreover, as a result of monotonic burst test, it was found that, the increase in impact energy causes decreases in the value of burst pressure of the tubes.

In this study, GRP tubes made of E-glass/epoxy material by using the filament wound technique and with a ±55° winding angle were used. The GRP tubes were manufactured in a 6-layer manner by a Turkish company, Izoreel Turkey. The specimens were subjected to 32 bars internal pressure based on the ANSI/AWWA C950 standard. The specimens were then, exposed to low velocity impact tests at energy levels of 5, 10 and 15 J, where their responses to these tests were determined. The impact tests were separately repeated nine times for each test. The damaged areas of the specimens as a result of the applied low velocity impact and the varying impact energy levels were studied and their failure modes were determined. The GRP tubes with impact failures were subjected to monotonic internal pressure burst tests according to the ASTM D 1599 standard. The monotonic tests were repeated six times for each test. Progression of the damages due to the exerted monotonic internal pressure, burst failures and variations of the tubes' burst strengths were determined.

The current study differs from Ref. [9] in many aspects such as projectile mass, impact energy and tube characteristics. The number of ply, the diameter, the length and the thickness of the tubes used by Curtis et al. [9] are completely different from our samples and they used 50 mm semi spherical indenter. By this reason, a comparison between them cannot be made directly. Therefore, the results for the prestressed tubes were compared with the non-prestressed tubes.

2. Experimental study

2.1. Production of GRP tubes

The GRP composite tubes used in this study were produced with filament winding technique in such a way that the winding angle becomes ±55°. The fiber material used in the tubes was Vetrotex 1200 tex E-glass with 17 μm diameters whereas the matrix material was Bisophenol A, Epoxy CY 225. After being manufactured, the tubes were cured in an oven at a temperature of 135 °C for two hours. The lengths, inner diameters, and thicknesses of the tubes were 300 mm, 72 mm, and 2.375 ± 0.04 mm respectively. The properties of the fibers and matrices used are given in Table 1 while the mechanical properties of the GRP tubes produced are shown in Table 2.

Table 1
Mechanical properties of the fiber and the resin.

	E (GPa)	σ_{TS} (MPa)	ρ (g/cm^3)	ε_t (%)
E-glass	73	2400	2.6	1.5–2
Epoxy resin	3.4	50–60	1.2	4–5