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Repairing impact damaged fiber reinforced composite pipes by external wrapping with composite patches

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ABSTRACT

Repairs made with composite patches on impact damaged fiber reinforced composite pipes offer distinct advantages over traditional repairs in addition to reduced cost. In this study, effects of number of patch layers on the burst pressure of low velocity impact damaged tubes that have been repaired with composite patches were investigated. The tubes were pressurized up to 32 bar prior to impact. The pre-stressed glass fiber reinforced plastic tubes were damaged by applying low velocity impacts at different energy levels (5, 10 and 15 J). The damaged areas of the affected tubes were repaired with 2, 4 and 6 layers of glass/epoxy fabrics. The repaired tubes were then failed catastrophically by being subjected to monotonic internal burst tests based on ASTM D 1599–99 standards. Changes in the tubes' burst pressures were recorded and the resulting damages on the tubes were studied. It was found that, for all the energy levels employed in this study, a six-layered patch repairing is suitable for the retrofitting of impact damaged tubes.

1. Introduction

Generally, metals subjected to low-velocity impact show plastic behavior before failure and it may be possible to remove the effects of deformation/damage by annealing and/or reworking the material. However; depending on the nature of the impact, non-visible, barely visible and visible irreversible failures may be occurred in the fiber reinforced layered composites [1]. The repairs made on damaged areas in order to achieve the original mechanical properties tend to vary depending on the type of failure. Once damage is detected and the effects on the residual properties of the structure have been predicted, a decision must be made as to whether this composite part should be repaired or replaced. There are cases where damage cannot be repaired. For instance, members that highly stressed may not have sufficient strength after repair [2].

If the damage level is small enough to be mended, then the repair is executed. Several methods such as bolted collars and welded collars are used for repairing damaged pipe lines. Recently, composite patches have seen an increasing usage in the repairing process too [3–6]. These patches are lighter, more resistant to corrosion and easier applied than the conventional repairing methods. In addition, an industry analysis showed that, on average, composite repair systems are 24% cheaper than welded sleeve repairs and 73% cheaper than replacing the damaged section of pipe [7].

Most of the studies conducted on repair of damaged structures have concentrated on planar plates failures. Repairs of damaged pipes and pressure vessels have been generally carried out by composite patches. Some of them are summarized as below:

Roberts [8] conducted experimental investigation on cracked steel pressure vessel that was repaired with carbon fiber composite patches. The researcher used standard tensile stress specimens to measure the effects of the repair. After the repair with the composite patches, the cracked specimens were subjected to environmental loads. Static and environmental loads were applied on the cracked steel specimens that were repaired with composite patches and their behaviors studied. It was found that the crack propagation was retarded and the life span of the specimens increased. Hu et al. [9] repaired a cracked steel pressure vessel by using steel patches with epoxy glue. In a study by Wilson [10], a damaged steel pipe was repaired with carbon/epoxy wrapping. The energy release rate of the composite wrapping/steel interface was obtained. A new laboratory specimen was created to evaluate mixed mode debonding of composite over-wrapped piping. Goertzen and Kessler [11] carried out dynamic and mechanical analysis in order to investigate mechanical and

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thermal properties of the carbon/epoxy patch material they used for pipe repair. For this, they conducted a three-point bending test. In that study, effects of heating rate, frequency and measuring methods on glass transition temperature were studied. Duell et al. [12] conducted a study in which a repair was made on steel pipes in order to reinforce them and stop their surface corrosion. They used carbon/epoxy composite as a repairing material. They carried out stress analysis for the damaged pipes having different geometries by using a three dimensional finite element method. They compared the experimental results with the ones obtained from the finite element analysis method. In both results, it was found that the maximum stress occurs at the center of the damaged area. In a study by Gunaydin et al. [13], where experimental investigation of the effects of composite patch repairing of surface-notched glass fiber reinforced plastic (GFRP) composite pipes on fatigue behavior of the pipes was made. The pipes have notch size ratios of $a/c = 0.2$ and $a/t = 0.75$. The burst pressures of the pipes repaired with 100 mm wide patches with two, three, four, five, six and seven layers of the patch were higher than the burst pressure of the un-patched notched pipes. It was found that fatigue life increases with the number of patch layers.

Composite patches are not only used for reinforcements and repairing but can also be used in joining composite pipes end to end. Pang et al. [14], joined two 54° winding angle glass/epoxy composite pipes end to end by winding them with a fiber reinforced composite material. The joined pipes were subjected to internal pressure and four-point bending tests. In a study by Peck et al. [15], two composite pipes were joined end to end by using glass fabrics having different thicknesses and by using chopped glass fibers having different sizes with UV cured vinyl ester resin. The joined pipes were cured with UV lights. Mechanical properties of the pipes were determined with internal pressure and four-point bending tests. At the end of the tests, it was found that the pipes with three and five layers of glass clothes exhibit higher burst strengths than the eight layered glass cloth joints. This is so because; the latter had not undergone sufficient curing. In order to determine the bending strength and bending rigidity of the joint, the researchers carried out bending tests. Li et al. [16], joined 54° winding angle glass/epoxy composite pipes end to end by using four different adhesives and a cross layer glass prepreg. To determine the effectiveness of the joining method, the internal pressure tests and finite element analysis were conducted.

According to the authors' knowledge there is no study that has been encountered on the repairing of the damaged GFRP pipes under low velocity impacts in literature.

In this study, GFRP tubes that were wound with filament winding method were used. The GFRP tubes were made of E-glass/epoxy material with ± 55° winding angle. The tubes were manufactured as $[\pm 55°]_3$ (six-layered) manner at Izoreel Company, Turkey. The manufactured test specimens were subjected to low velocity impact tests by applying 32 bar internal pressure on them at energy levels of 5, 10 and 15 Joules. 2, 4 and 6 layered patches were applied as a repair on the damaged area which emerged as a result of various energy levels being exerted on the tubes. The repaired tubes were subjected to monotonic internal pressure tests based on the ASTM D 1599–14 standard [17]. Then evaluation on the effects of patching on burst pressure of the tubes and their failure behavior was carried out.

2. Materials and methodology

2.1. Material properties

In this study, six-layered glass/epoxy composite pipe specimens with ± 55° winding angle were used. The composite tubes were 300 mm long, having inner diameters of 72 mm and 2.375 mm

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

Table 2
Mechanical properties of the GRP tubes.

θ: Fiber winding angle	±55°
σ_t: Tangential failure stress (MPa)	428.96
ν_y: Poisson's ratio	0.53
E_y: Modulus of elasticity (GPa)	20.48
V_f: Fiber volume fraction	0.50

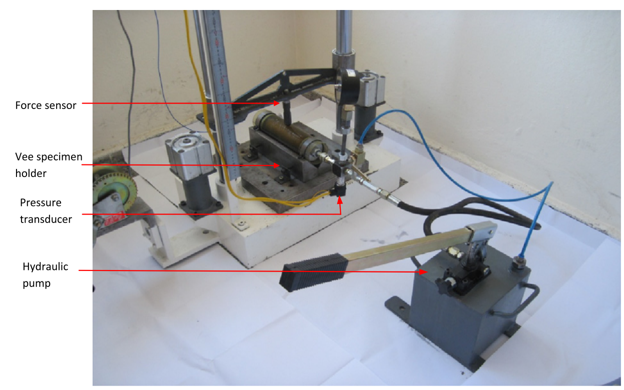

Fig. 1. Low velocity impact test rig and hydraulic pump [18].

Table 3
Mechanical properties and dimensions of the composite patches.

$E_x = E_y$: Modulus of elasticity (GPa)		22
σ_y: Tensile strength (MPa)		292
$\nu_{xy} = -\varepsilon_y/\varepsilon_x$: Poisson's ratio		0.16
Number of patch layers	w_p (mm)	t_p (mm)
2 Layered patches	0.30	100
4 Layered patches	0.60	100
6 Layered patches	0.90	100

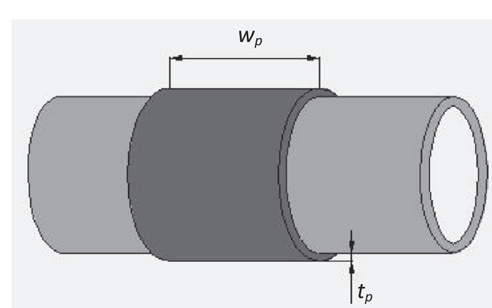

Fig. 2. Repairing of the specimen with patch.