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# Development and qualification of a new polymeric matrix laminated composite for pipe repair

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ABSTRACT

Nowadays the use of polymeric matrix composites to repair and strengthen the damaged pipe structures in the oil industry has become a common practice. Hence, it is essential to validate the performance of new developed composite laminate materials for the damaged pipe repair. In this study, the effectiveness of a new composite laminate for the pipes repair was investigated. First, the mechanical and thermal properties of the new developed composite laminate were determined. Next, two defect types, Type A (non-through wall) and Type B (through wall) were manufactured into the pristine pipe specimen and the evaluation of the performance of the repaired pipe was carried out by hydrostatic tests. The performance of the repaired pipe using the new developed composite laminate material was satisfactory in both defect types.



## 1. Introduction

Pipe and pipelines are extensively used to carry/transport fluid (oil, gas, water) over a long distance. Generally, the pipe is made up of steel metal due to its high strength, low cost, efficient and safe compared to other materials [1]. However, it is more sensitive to corrosion in harsh environment, particularly in the presence of sea water and sulfur ingress media [2,3]. As is known, the pipelines are exposed to a harsh environment such as submerged in water (offshore unit), underground pipe (sewage pipelines, oil pipelines) and above the ground pipe (water pipelines). Almost, in all practical applications the pipes are subjected to harsh environmental conditions which lead to an internal and an external damage, specially corrosion damage and deterioration. An external damage also occurs in the form of cracking, wear, dents caused by impact during transportation and installation process [4]. In the past, it was common practice to completely replace the affected sections of pipe. However, as this always involves a transport stoppage, repair systems are seeing as fast and economical alternatives as do not interrupt operations.

Traditionally, welding technique is used to repair the damaged part by cutting or replacing the damaged section and use of a steel patch. However, this technique requires to stop the operation while the repair is being performed and the process also involves the hotwork [5,6]. Recently, fiber reinforced polymer (FRP) matrix composite repair systems have emerged as an alternative repair system to the welding technique. The application of adhesive bonded joints in structural components made of fiber-reinforced composites have increased significantly in the last years [7]. Repairs made with FRP materials offer distinct advantages such as reduced cost [8], corrosion prevention [8–10], more safety [11] and quick repair [10] etc.

The use of fiber reinforced composites has already been proven an effective tool for the repair of damaged structures [12–15]. To evaluate the effectiveness of a given repair system, it is important to study the critical parameters that affect the performance of the repair composite (i.e. geometry of the repair including thickness, type of composite materials including fiber and resin, orientation of fibers and method of installation etc). [13,15,16]. In the last years, several researchers [17–21] investigated the mechanical and thermal properties of the composite repair material in order to have the best possible combination of composite material and assure the repair performance. Successful application of composite repair material for the corroded or damaged pipe was found [22–25]. However, the pipeline repair still presents some difficulties regarding its long term durability. These difficulties are related to the lack of a sufficient number of test results and the validation of the composite material properties.

The present paper deals with an experimental analysis of a new glass fiber reinforced repair system for metallic pipelines with a standard defect size as per the standard ISO/TS24817 [26].

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The primary focus of this research program was the development of the glass-based composite repair system and further the system was tested and validated by the standard ISO/TS24817 [26]. Hydrostatic tests were performed to validate the performance of the composite repair system.

## 2. Materials and methods

### 2.1. Materials

#### 2.1.1. Woven fabric

The selection of woven fabric composite material for tube repair should have the following characteristics: light-weight which offer in greater ease for resin impregnation. The resin-woven proportion used was 2:1. The fabric should have approximately 66% of their fibers orientated in its longitudinal direction (circumferential direction of the duct) and 34% in the transverse direction (axial duct direction). The choice of this setting is based on the stresses acting on a thin-walled cylinder (circumferential stress is equal to 2 times of axial stress). A bidirectional fabric of glass fibers oriented at 0° in its longitudinal direction and 90° to the transverse direction was used. A weight of 434 g/m$^2$ and 261 g/m$^2$ to the longitudinal and transverse direction, in percentage 62% and 38%, respectively was used.

#### 2.1.2. Laminating resin

For the selection of laminating resin the following factors were taken into account: fiber wettability, viscosity, curing time and glass transition temperature ($T_g$). A bi-component epoxy resin, PIPEFIX® developed by Novatec ltd (spin-off of Laboratório de Adesão e Aderência – UERJ, Nova Friburgo RJ, Brazil). The curing time was 2 h, followed by a 1 h post cure at 130 °C. A heating ramp of 3 °C per minute was used. The properties of the constituent materials used in the hand lay-up process supplied by the manufacturer are presented in Table 1.

#### 2.1.3. Steel pipe

The pipe material was an API-5L X56 steel with the following basic properties: Youngś Modulus $E_{pipe}$ = 210 GPa; yield stress **S**y = 450 MPa and ultimate strength = 627 MPa.

### 2.2. Methods

#### 2.2.1. Acid digestion test

A flat plate was manufactured by hand lay-up technique and it consists of four stacking layers of laminate. The flat plate preparation process is shown in Fig. 1. A sample of approximately 0.3 g weight was cut from the plate before the post curing process for the acid digestion test in order to determine the percentage of fiber and resin by weight.

The acid digestion test was performed according to the procedure described in ASTM D3171 [27]. Fig. 2 shows the stepwise procedure for acid digestion test.

#### 2.2.2. Thermal test (glass transition temperature test)

Eight samples were cut out from the same flat plate for the determination of glass transition temperature. The dimension of each sample was 20 × 12.5 × 1.5 mm in accordance with ASTM D7028 standard [28] (see Fig. 3). Glass transition temperature of composite laminate was characterized using DMA (Q800, TA instrument). The range of testing temperature was controlled from 40 °C to 250 °C with a heating rate of 2 °C/min.

**Fig. 1.** Flat plate preparation process for the specimens.

**Table 1**
Material properties used for manual lamination.

| Material | Density (g/cm$^3$) | Youngs modulus (GPa) |
|---|---|---|
| Fiber glass | 2.55 | 72 |
| Epoxy resin | 1.18 | 3.5 |

#### 2.2.3. Tensile test

The flat plate was kept in an oven for the post curing process at 130 °C for 1 h. After post curing, the flat plate was cut at required dimensions for tensile test specimen as per the standard ASTM D3039 [29]. Tensile specimens were conditioned at 23 °C and 50% relative humidity for a minimum of 24 h.

The specimens were tested in a universal testing machine (Shimadzu AGI 100 kN) at room temperature and relative humidity of 50% ± 10%. The test speed was 2 mm/min. Five specimens were tested at each condition. The load–deformation curve of specimens obtained from the machine and an extensometer (model SG50-50 Shimadzu) was recorded. Fig. 4 shows the tensile test setup with an extensometer attached to the specimen.

#### 2.2.4. Hydrostatic test

The specimens for the hydrostatic test were fabricated according to the procedure described in ISO/TS24817 standard [26]. In this work, two types of defect were studied, one is defect Type A, in which the substrate is not leaking and not expected to leak within the lifetime of the repair system, requiring structural reinforcement only and defect Type B, in which the substrate requires structural reinforcement and sealing of through-wall defects (leaks).

*2.2.4.1. Defect Type A.* The test samples were prepared from carbon steel API 5L X56 SCH40 pipe sections with a nominal diameter of 152.4 mm and axial length of 600 mm. The carbon steel pipe, SCH40 designation corresponds to a wall thickness (t) of 7.11 mm and an outer diameter (D) of 168.3 mm. The tube specimens were prepared by machining the defect into the pipe to simulate an 80% external wall loss thickness. The defect was machined by electrical discharge machining (EDM). The basic dimensions of pipes and defect size are shown in Fig. 5a.

The defect area of steel tube (Fig 5b) was initially degreased with water and then cleaned with sandpaper (P100), in order to remove oil residues coming from the machining process and promote a better adhesion between pipe and composite. Initially