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An alternative methodology to repair localized corrosion damage in metallic pipelines with epoxy resins

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ABSTRACT

The present work is concerned with the analysis of epoxy repair systems for metallic pipelines undergoing elastic or inelastic deformations with localized corrosion damage that impair the serviceability. In the case of trough-thickness damage, the main focus is to assure an adequate application of the epoxy filler in such a way the pipe wont leak after repair. Such a procedure can be used or not associated with a composite sleeve that assures a satisfactory level of structural integrity. Examples concerning the use of repair systems in different damage situations are presented and analyzed showing the possibilities of practical use of the proposed methodology.

1. Introduction

Corroded pipelines with part-wall metal loss defects can be repaired or reinforced with a composite sleeve system. In these systems, a piping or vessel segment is reinforced by wrapping it with concentric coils of composite material after the application of epoxy filler in the corrosion defect. Nevertheless, so far, composite repair systems are not effective for through-thickness corrosion defects because generally they cannot avoid leaking. Information about requirements and recommendations for the qualification, design, installation, testing and inspection for the external application of composite repairs to corroded or damaged pipeline in petroleum, petrochemical and natural gas industries can be found in [1,2].

Composite repair systems (patches) are also used in aircraft industry to repair cracks in order to extend the service life of metallic components ([3,4]). In this case, the size of the patch and bonding properties are very important. In the case of corroded pipelines conveying liquids, the geometry of the composite repair is simpler (a sleeve), but the main difficulties are the definition of the adequate composite thickness to assure a satisfactory level of structural integrity and to avoid leaking in the case of through-thickness defects.

The present paper is concerned with the analysis of epoxy repair systems for metallic pipelines undergoing elastic or inelastic deformations with localized corrosion damage that impair the serviceability. In the case of through-wall corrosion damage, the focus is to assure that the pipe wont leak after repair. The main motivation for the study presented on this paper is the rehabilitation of corroded pipelines conveying produced water in offshore oil platforms. Since these platforms are hydrocarbon atmospheres, any repair method using equipment that may produce heat and/or sparkling is forbidden.

The damage derived from corrosion process in produced water pipelines in platforms cause very important economical losses because the operation must be stopped while the repair is being performed. The rehabilitation of this kind of corroded pipeline may eventually require an industrial climber and hence the application of the repair system must be as simple as possible (Fig. 1). Although the operation pressure of these pipelines is not very high, the water temperature is between 60 °C and 90 °C, which can be a major shortcoming for the use of polymeric material as repair systems.

Initially, it is presented in this paper the thin-walled elastic orthotropic and thin-walled elasto-plastic cylinders under pressure – closed-form expressions for stress, strain and displacements. Then, is presented a simple methodology to define the necessary thickness of the composite sleeve to assure the safe operation of corroded pipelines with part-wall metal loss defects. Most of the studies about these systems are concerned with the materials (matrix, fibers, adhesive) and application procedures. Only a few studies are concerned with the mechanical analysis of the repair system (see [5–9], for instance). It is summarized a new methodology to define the minimum thickness of composite material to assure: (a) the safety of repairs under operation conditions and/or (b) the lifetime extension under operation conditions. Such methodology, although simple, is able to account for different failure mechanisms (plasticity, corrosion, etc.).

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Fig. 1. Corrosion damage in produced water pipelines.

It is also presented a complementary procedure to repair through-thickness corrosion defects in pipelines using epoxy resins. The objective is to assure the pipeline wont leak under the operation pressure and temperature. Composite sleeves can assure a satisfactory level of structural integrity for part-through corrosion defects but are not necessarily effective to avoid leakage for localized through-thickness corrosion defects. The repair methodology proposed can be used or not associated with a composite sleeve in order to improve the effectiveness of the epoxy repair system. Hydrostatic tests were carried out with water at room temperature and at 80 °C to validate epoxy repair systems applied in offshore produced water pipelines. Examples concerning the use of repair systems in different damage situations are presented and analyzed showing the possibilities of practical use of the proposed methodology.

2. Thick-walled elastic orthotropic and thin-walled elasto-plastic cylinders under pressure – closed-form expressions for stress, strain and displacements

2.1. Thick- walled elastic orthotropic cylinder under pressure

In the present study it is considered an elastic cylinder with inner radius r_i and external radius r_e submitted, respectively, to an internal pressure P_0 and to an external pressure P_1 as shown in Fig. 2.

The model equations for this problem, using a cylindrical coordinates system are:

2.1.1. Balance of linear momentum

Under the hypothesis of a plane state of stress and neglecting body forces, the balance of linear momentum for a pipe in static equilibrium can be expressed as

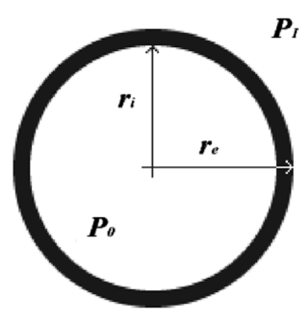

Fig. 2. Pipe under external and internal pressure.

$$\frac{\partial \sigma_r}{\partial r} + \frac{1}{r}\frac{\partial \sigma_{r\theta}}{\partial \theta} + \frac{\sigma_r - \sigma_\theta}{r} = 0; \quad \frac{1}{r}\frac{\partial \sigma_\theta}{\partial \theta} + \frac{\partial \sigma_{r\theta}}{\partial r} + \frac{2\sigma_{r\theta}}{r} = 0 \tag{1}$$

where σ_r and σ_θ are, respectively, the radial and tangential components of the stress tensor.

2.1.2. Constitutive equations

Assuming a linear orthotropic elastic behavior, the constitutive equations can be expressed as follows:

$$\varepsilon_r = \frac{1}{E_r}\sigma_r - \frac{v_{r\theta}}{E_r}\sigma_\theta; \quad \varepsilon_\theta = -\frac{v_{r\theta}}{E_r}\sigma_r + \frac{1}{E_\theta}\sigma_\theta; \quad \varepsilon_{r\theta} = \frac{1}{2G_{r\theta}}\sigma_{r\theta} \tag{2}$$

where ε_r is the radial strain and ε_θ the tangential strain. E_θ is the extensional modulus in the tangential direction and E_r the extensional modulus in the radial direction. $v_{r\theta}$ is the coefficient relating contraction in the circumferential direction to extension in the radial direction. $G_{r\theta}$ is the shear modulus.