Review Paper on the Reparation and Reinforcement of Cracked Pipes with Composite Patch Technique

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Abstract

Over the last decade, pipeline owners have begun widespread use of fiber-reinforced polymer (FRP) composites, as a strengthening and repair technique. This paper aims to provide an overview on the work done in the field of non-metallic bonded repair of pipes. Reinforcement and repair of components using composite patches can be used for cracked piping to reduce the stress intensity at the crack-tip. Several researches have covered experimental investigation as well as finite element analysis to evaluate the effects of composite patch on the behavior of cracked pipes. Some of the advantages of the composite patch repair technique over classical methods, such as plate bolting/welding, are its better corrosion characteristics and its fatigue performance. Additionally, adhesively bonded composite patches are more structurally efficient than traditional repairs. For this purpose, a review of the composite patch technique is addressed, and many related research works are presented.

Keywords: Pipeline, Fiber reinforced polymer FRP Patch, Stress Intensity Factor (SIF), Cracked plate, Adhesive Bonding, Rehabilitation, Reinforcement, Finite Element Analysis.

1. Introduction

It is well known that during the manufacturing process of a pipe, numerous local defects and inclusions can be produced. In service, the combination of these factors under loading condition, particularly internal pressure, and the environmental effect (humidity, temperature, and time) can reduce significantly the lifetime of these components. Fortunately, Prevention of a catastrophic failure and fatigue life extension of such cracked pipes is possible using a proper repair technique [1].

Because of their valuable properties and behavior, fiber composites have found applications in repairing cracks in structural components such as steel members, panels, beams, pipelines and pressure vessels, through patching process. The potential of this technique was firstly examined by researchers of the Aeronautical and Maritime Research Laboratories (AMRL) for the Royal Australian Force (RAAF) in early 1970's [2]. The repair and upgrade of pipelines using Fiber Reinforced Polymer materials (FRP) has primarily been utilized for water pipelines which cannot be taken out of service in order to extend their service life. Subsequently, its use has been extended to different industries [3]. Generally, the composite patch is adhesively bonded to the cracked area of the pipeline. Adhesive bonding has numerous advantages than mechanical one, which include installation cost, corrosion resistance, effective crack propagation delay, and lightweight. Our scope in the next section, is on different research works done in relation with composite patch repair.

2. Literature review

Composite patch repair reduces the stress intensity factor near the crack-tip, thus delays the crack propagation, it can also stop the crack in some cases [4]. In recent years, many authors have studied numerous aspects of the rehabilitation of pipes by composite patch. [5] Provided a comprehensive review on the use of FRP composites for in-air, underground and underwater pipeline repairs. It has been cited that FRP composites are an effective repair option. However, they need complex preparation, also they are not the best choice for underwater scenario. [6] presented an experimental analysis of thin-walled metallic pipelines with corrosion crack reinforced with polymer based composite repair systems. Several tests were carried out to estimate the failure pressure of the cracked pipeline. Additionally, it was found that the methodology can be used to define the suitable patch thickness for an adequate repair.[1] have studied fatigue crack propagation of an offshore steel pipe repaired by glass/epoxy composite patch, which has many advantages compared to other composites (graphite/epoxy; boron/epoxy…etc.): cost, availability, and compatible thermal coefficient with the material pipe (steel).

Analyses were performed using Linear Elastic Fracture Mechanics (LEFM) assumptions, also it was supposed that the growth of the crack is only in the pipe, with complete absence of any de-bonding process between the pipe and the patch. The fracture analyses were done based on the calculation of the strain energy release rates using in addition a modified virtual crack closure technique in order to obtain the local SERR in the crack-front. It was shown that the mode-I SIF at the crack-tip of the repaired pipe is the prevailing one related to the modes II and III. Mode-I stress intensity factor of the repaired pipe was considerably reduced. Moreover, a parametric study was performed to find the effects of patch thickness on crack growth life extension of the repaired pipes. It was clear that K_I is decreased with the increase of the number of patch layers. However, it was concluded that using more than 16 layers of patch may not provide significant fatigue lifespan improvement.

[7] Have studied the effect of mechanical and geometric properties of patch on fracture parameters. The results showed that there is significant decrease in SIF near crack-tip. It was concluded that the effect of a double symmetric patch is higher than the single one. [8] Have studied the effect of the composite patch on the stress field. The model investigated is a cylindrical pressure vessel, and it was found that the increase of layers leads to an important stress reduction up to 56% near the crack-front. However, the results obtained were presented in terms of Von Mises Stress, thus they may not be relevant enough. [9] have conducted experimental and numerical investigations on reinforcing damaged pipelines with (FRP). It was suggested that (FRP) materials can be used for a wide variety of pipe diameters and length for both quasi-static and cyclically loaded pipeline sections and pipelines. [10] noted that the stiffness of the composite material plays a major role in determining the strain level at which the load transfer will take place. Experience has shown that elastic modulus (of at least 6.89 GPa) is a good benchmark for predicting the in situ performance of a composite repair.

[11] have studied the effect of mechanical and geometrical properties of the patch on the reduction of the mode-I stress intensity factor near the crack-front in the case of a plate with an edge crack. It was stated that fracture parameters are influenced by the stiffness of the patch, the bonding region, and the strength of the adhesive. The effect of the orientation of fibers has been investigated, and it was found that we can get a maximal SIF reduction when fibers are perpendicular to the direction of the crack. Moreover, a patch with fibers parallel to the crack direction is less efficient than the perpendicular configuration. Particularly, the effect of the adhesive layer thickness was also investigated. It was concluded that the thickness of the adhesive plays an integral role on the stability of reinforced structures. For example, it was found that the value of the mode-I stress intensity factor decreases with the reduction of the adhesive layer thickness. An important adhesive thickness improves the adherence of the patch, but it reduces the load transfer from the internal to the external of the pipe. That is to say, a small adhesive layer thickness is recommended for the repair option.

Similarly, the effect of the adhesive shear modulus was inspected. Indeed, it was shown the reduction of the stress intensity factor is inversely proportional to the increase of the adhesive shear modulus. However, when the shear modulus soars indefinitely, the reduction of the SIF is insignificant.

In the spirit of discussions associated with the composite repair patch, one must consider load transfer between the main material of the pipeline and the composite one during internal pressurization of the pipe. [12] examined the interfacial stress transfer behavior. In this research work, two kinds of nonlinear interfacial constitutive laws describing the micro-de-bonding behavior are introduced to solve the nonlinear interfacial stress transfer and fracture problems for different kinds of adhesive joints. Expressions for the maximum transferable load, interfacial shear stress distribution, and initiation and propagation of interfacial cracks were derived analytically.

Additionally, numerical simulations based on the finite element analysis were performed to discuss the factors influencing the interfacial behavior and the theoretical derivations. The derived solutions can be extended to predict the de-bonding behavior of composite patch.

Most of the studies about composite repair systems are concerned with the materials (matrix, fibers, adhesive) as well as their properties (mechanical, geometric), and application procedures. Only a few studies dealt with the mechanical analysis of the repair system. [13] proposed a new methodology to define the minimum thickness of composite material to assure the safety of the repair and the lifetime extension under operation conditions. The definition of the repair thickness is based on analytical expressions for the stress, strain, and displacement field. In order to verify a given criterion, the minimum thickness is obtained. The expressions were formulated for pipe without localized damage (crack, corrosion defect…etc.), and the authors proposed a procedure to extend them for the localized damage case, taking into account the applied pressure, and the contact pressure. For this purpose, the basic idea was to suppose that the maximum hoop stress σ_θ close to a localized imperfection can be approximated considering the tangential stress for an undamaged cylinder $\sigma_{\theta\ (undamaged)}$ corrected by a factor η which is a function of the geometry. It was concluded that the methodology can be helpful to define the pressure of application of the composite repair as well as its thickness necessary to assure safer and more reliable repair option. Also, a procedure of epoxy resin application was proposed to preclude eventual leak problems.

Discussion

In recent years, several researches covered the applicability of the composite patch repair technique. Most of studies focused on the analysis of simple structures, particularly thin plates, and only a few studies have dealt with circular or spherical shell structures. Likewise, there was limited investigations on the mechanical behavior of the interface between the structure and the composite patch material. Many authors discussed the impact of numerous properties (patch material, thickness, number of layers, fibers orientation…etc.) on the reliability of the repair system.
In the spirit of the bibliographical research, it was found that there is insufficient number of research studies on the analysis of the patch repair technique in the case of pipelines, and pressure vessels. For this purpose, the aim of our research study is to provide more grounding ideas about the applicability of the technique, similarly, the subsequent scope will be on the modelling of the mechanical behavior of the composite patch repair as well as the research for innovative design optimization criteria of the composite patch.

Conclusions

The purpose of this paper was to provide an overview on the composite patch as a cracked pipeline repair technique. Primarily, repairing with composite patch is utilized in aeronautical field to rehabilitate cracked structures. After that, Studies have been conducted in order to extend the use of the patch to different disciplines, such as petrochemical industry, oil and gas transmission processes. These studies proven that composite patches are a powerful and effective for many applications. Indeed, the majority of publications has covered only structural plates. Our goal is to enhance the comprehension of the employment of composite patches in the case of pipelines.

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