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Residual harmfulness of a defect after repairing by a composite patch

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ABSTRACT

The harmfulness of a defect in a CT specimen made in an API 5L X52 steel pipe is evaluated after being repaired with a composite patch. Due to the fact that the presence of a composite patch improves the fracture resistance but also modifies the constraint, a two-parameter fracture approach is used. More precisely, the stress field at the tip of a notch-like defect repaired by a boron/epoxy bonded composite patch is evaluated by the notch stress intensity factor K_ρ and the effective *T*-stress T_{ef} as constraint parameter. An assessment point of coordinates $[T_{ef}–K_\rho]$ is reported in the Fracture Toughness–Constraint Diagram (FTCD). A line from origin O and passing through this assessment point intercepts the Failure Material Master Curve. This procedure allows us to determine a patch repairing index which is a measure of the residual harmfulness of a crack-like defect after repair. The repair with a composite patch reduces significantly the defect's severity and increases the service life.

1. Introduction

Global energy demands continue to increase with the rapid development of the global economy. The transportation of oil and gas by pipelines is the safest and most economical means for companies transporting hydrocarbons. To increase the profitability of a pipeline, the flow rate is often increased by increasing the service pressure and using larger diameter pipes. Therefore, the performance of pipes must be improved by enhancing their mechanical and chemical characteristics.

The current pipeline networks employ various grades of steel [1], with Grade B, X52 and X60 comprising about 70% of these networks. Pipeline networks are often subjected to damage inducing leak or failure. Recent studies [2] show that more than 50% of failures are caused by external interference.

For many years, the only possible solution to repair damaged pipes was complete replacement or replacement of a section with new pipes. These procedures generally cause costly production losses. Moreover, hot works are forbidden during the replacement in dangerous zones. In addition, metallurgical mismatch and residual stresses caused by welding add disadvantages to this complicated and costly solution. To avoid replacing the damaged structure, for both economic and technical reasons, a recent solution is to use a composite patch over the damaged area with an adhesive [3–5].

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In this paper, the harmfulness of a defect is evaluated after being repaired with a composite patch. Due to the fact that the presence of a composite patch improves the fracture resistance but also modifies the constraint, a two-parameter fracture approach is used. More precisely the stress field at the tip of a notch-like defect repaired by a boron/epoxy bonded composite patch is evaluated by the applied notch stress intensity factor K_ρ and the effective T-stress T_{ef} as constraint parameter. An assessment point of coordinates $[T_{ef}–K_\rho]$ is reported in the Fracture Toughness–Constraint Diagram (FTCD). A line from origin O and passing through this assessment point intercepts the Failure Material Master Curve. This procedure allows the determination of a patch repairing index which is a measure of the residual severity of a crack-like defect after repair. The notch stress intensity factor is determined by the Volumetric Method (VM) [6] and the constraint by the Stress Difference Method (SDM) [7].

This study has been made on CT specimens made in pipe steel X 52 and covered with 2 types of epoxy boron composite patch.

2. Material and specimen

Compact Tension (CT) specimens with mechanical notches of different lengths are prepared using pipe steel X52. Several relative notch lengths a/W are studied: 0.2, 0.3, 0.4, 0.5 and 0.6, where a is the notch length and W the specimen width. The CT specimens have the following dimensions: length = 63.8 mm, width = 61 mm, thickness = 5.84 mm and notch radius ρ = 0.25 mm. The width of the repair patches is 18 mm and thickness is 2 mm. Two different lengths of repair patch are used: type III: the length of patch is the same as the length of the CT specimen (63.8 mm), and type II: the length of patch is half the length of the CT specimen (32.9 mm). The thickness of the adhesive in all cases is 0.3 mm. The material is assumed to remain elastic until fracture and the elastic constants of the materials are given in Table 1. The steel and the adhesive are considered as isotropic while the composite patch is modelled as orthotropic (see Fig. 1).

3. Stress distribution at notch tip using FEM method

The stress distribution at the notch tip of specimens with and without patches is determined by the 3D Finite Element method by means of Abaqus/CAE™. The solid model is meshed using linear 8-noded hexahedral elements with a total of

Table 1
Mechanical properties (CT specimen, patch and adhesive).

Properties	API 5L X52	Boron/epoxy	Adhesive
E_1 (GPa)	210	200	2.723
E_2 (GPa)		25	
E_3 (GPa)		25	
ν_{12}	0.33	0.21	0.294
ν_{13}		0.21	
ν_{23}		0.21	
G_{12} (GPa)		7.2	
G_{13} (GPa)		5.5	
G_{23} (GPa)		5.5	

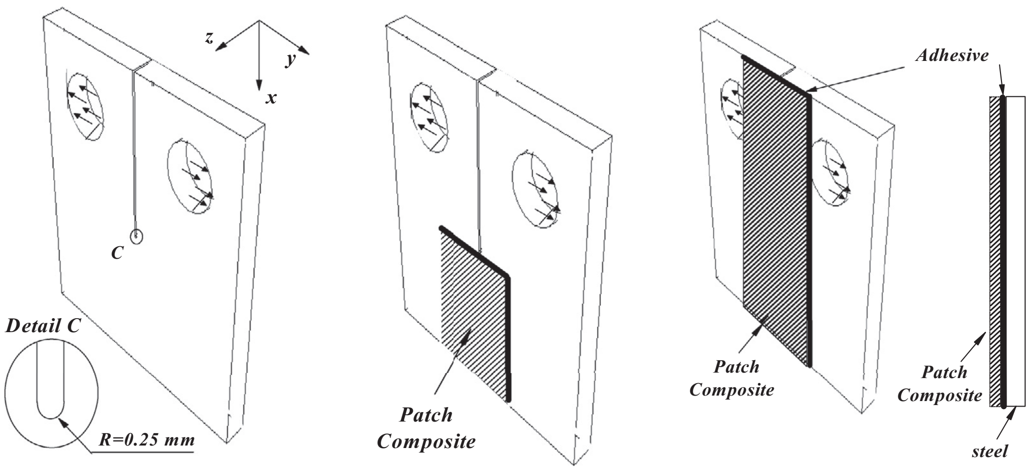

Fig. 1. Types of studied specimen.