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Drilling Repair Index (DRI) based on two-parameter fracture mechanics for crack arrest holes

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ABSTRACT

The most common method of preventing cracks from growing is by making a “drill stop” or crack arrest hole (CAH) at the crack tip. The objective of drilling a hole is to “blunt” the crack tip and reduce the stress concentration at the crack tip. In this paper the following situations are studied: (i) a single hole drilled at a blunt crack tip, (ii) a single hole drilled at a distance r from the crack tip with an orientation angle θ relative to the crack direction and (iii) a second hole called the “stress concentrator reducer hole” drilled symmetrically to the first near to the crack hole. A Drilling Repair Index (DRI) is proposed for evaluation of the efficiency of the CAH method. It is based on two-parameter fracture mechanics.

1. Introduction

The detection of cracks requires temporary repairs to allow continued safe operation or the design of a permanent repair. Many cracks are repaired by cutting out the crack and welding a repair patch in place or adding doublers. The most common method of preventing cracks from growing is by making a “drill stop” or crack arrest hole (CAH) at the crack tip. The objective of drilling a hole is to “blunt” the crack tip and reduce the stress concentration at the crack tip. This generally induces a retardation of crack growth and, rarely, crack arrest. The drill-stop method is often not effective because the size of the CAH based on the material properties can be too large to access practically. In this case, cracks are reinitiated on the other side of the drill CAH. An improved drill stop method for effectively arresting crack growth is generally carried out by additional hole expansion which induces residual stresses. These methods are widely used in maintenance of aeronautics, bridges [1], railways and ships [2]. Therefore this method can be considered as a temporary reparation method before crack reinitiation, but no tool is actually available to evaluate the efficiency of this method.

In this paper, a numerical simulation of a Compact Tension (CT) specimen is performed with three hole configurations:

i) A single hole is drilled at the blunt crack tip. A range of hole radii of $0.25 < \rho < 4$ mm is investigated in order to evaluate the value of the associated stress concentrator k_t. The influence of the crack aspect ratio a/W is also studied (Fig. 1a).
ii) In the case of a crack tip that is impractical to access, a single hole is drilled at a distance r from the crack tip at an orientation angle θ relative to the crack direction in the range of $0 < \theta < \pi$. The optimal orientation θ* is obtained with the criterion of the

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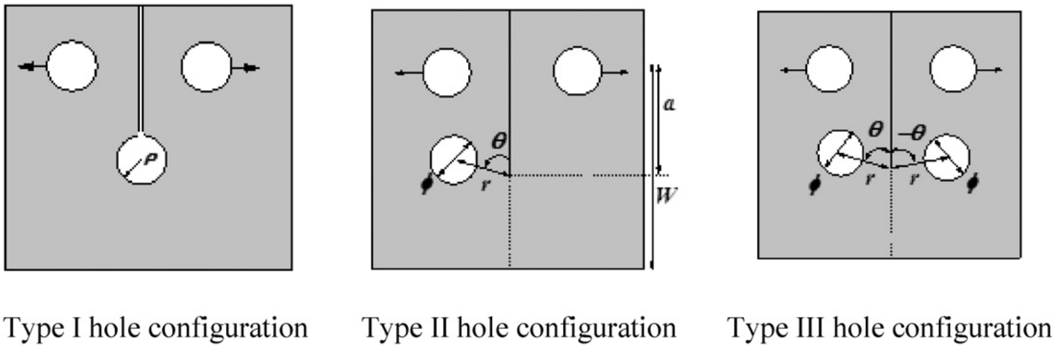

Fig. 1. Different types of hole configurations.

minimum of (maximum) crack tip stress $\sigma_{max.}$ In order to take into account the ease of access for drilling, a larger hole diameter is investigated in the range of $1 < \rho < 5$ mm (Fig. 1b). The distance from the drilling was kept constant and equal to 8 mm.

iii) In order to obtain a better design to reduce the stress concentration due to the drilled hole, it is recommended that a second hole called a "stress concentrator reducer hole" be drilled. Therefore a second hole is drilled symmetrically to the first hole near to the crack hole. The orientation of the two holes is chosen as θ^*, which depends on the relative defect length. This hole configuration has been studied for the following parameters: distance, $r = 8$ mm and a single hole diameter, $\rho = 5$ mm (Fig. 1c).

In order to evaluate the efficiency of the CAH method, a Drilling Repair Index (RDI) is proposed. It is based on the two-parameter fracture mechanics approach in which the Material Failure Master Curve (MFMC) is represented in the plane $[K_{\rho,c} - T_{ef,c}]$, where $K_{\rho,c}$ is the notch fracture toughness and $T_{ef,c}$ is the effective T-stress at fracture. After drilling one or two holes, the stress state of a cracked component is represented by an assessment point A of coordinates $[K_\rho - T_{ef}]$, where K_ρ is the notch stress intensity factor and T_{ef} is the effective T-stress of the new stress situation which is less severe than the critical one. Examination of RDI values confirms that the best practice is to drill a large diameter hole at the crack tip. If this operation is not possible due to access difficulty, it is preferable to drill two holes near the crack tip rather than a single one.

2. Material and specimens

The material used in this study is an X52 steel meeting the requirements of the API 5L standard. In Table 1, the mechanical properties of API X52 steel are presented. E,σ_y, σ_u, A%, n, k, and K_{Ic} are Young's modulus, yield stress, ultimate stress, elongation at fracture, strain hardening exponent and hardening coefficient of Ludwik's law, and fracture toughness, respectively.

CT specimens with mechanical notches of different lengths are prepared. 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 $L = 63.8$ mm, width $W = 61$ mm, and thickness $B = 5.84$ mm. The specimen is assumed to exhibit a blunt crack of radius $\rho = 0.25$ mm in order to simulate an open and visible crack as is frequently observed in this problem. The hole configurations of these CT specimens have been described in the Introduction section along with the ranges of the studied parameters: the hole radius, orientation angle, and distance.

The stress distributions at the blunt crack tip have been computed by the finite element method under critical load, from the static rupture tests, which varies with non-dimensional crack length a/W according to Table 2 [6]. The load is modelled by a pressure, which is defined on the inner surfaces of the holes of the CT specimens.

The load (F) can be applied by different methods. The simplest method would be to apply a single concentrated force to the node at the top of the pin hole; however, this will create very high stresses (which is unrealistic) in the vicinity of the force. An alternative method is to apply a pressure along the bearing surface (Fig. 2). This produces a much more realistic type of loading and minimizes the error caused by the concentrated force near the point of load application.

We will apply a uniform pressure along the surface of an upper bearing surface. The magnitude of the pressure is based on the projected area of the bearing:

$$P = \frac{F}{D \cdot B}$$

Table 1
Mechanical properties of API 5L X52.

E (GPa)	σ_Y (MPa)	σ_u (MPa)	A%	n	K (MPa)	K_{Ic} (MPa $\sqrt{m}$)
210	410	528	32	5 0.164	518	116.6