MODELING OF THE GAS - CONTROLLED INTERFACE CRACK GROWTH: NON-IDEAL VS. IDEAL SINK

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ABSTRACT

We consider delamination crack growth controlled by gas diffusion into crack. In case of small pressure, the crack can be considered as an ideal sink. However, as crack is growing, the pressure becomes greater, and therefore we cannot consider the crack to be an ideal sink anymore. In this research, for the conditions of a real-sink, an analytical solution for the dependence of the radius of the growing delamination on time is obtained.

Keywords: Hydrogen Induced Cracking, Interface Cracks, Internal Cracks, Non-ideal Sink.

INTRODUCTION

Hydrogen being accumulated inside the cracks in the metal creates pressure which eventually leads to the damage of the pipeline. The excessive pressure can be especially dangerous when the metal surface is coated by a protective material where small-scale delaminations occur more commonly (e.g. Figure 1). In time, these delaminations spread, damaging the coating and allowing moisture access to the metal, which results in the external corrosive fracture of the pipeline and its premature replacement. The focus of this study is modeling of how the radius of delamination grows with respect to time. The modeling requires the solution of a coupled problem involving elasticity theory, about the crack opening under gas pressure, and diffusion theory, of gas diffusion into the crack cavity.

The approximation for an ideal gas sink is first used; however, this is only accurate for low pressures. While gas accumulates inside the crack, its pressure becomes high enough that the sink can no longer be considered ideal. While the subsequent calculations are somewhat more cumbersome than for the ideal gas case, they are still straightforward that allows obtaining the close-form solution for the crack size, \(a(t)\), depending on time. Since as shown by the author in previous papers (Balueva, 2014; Germanovich and Balueva, 2011), the kinetic equations for delaminations (near surface cracks) and internal (inside the metal) cracks are identical up to the constants, the results obtained in this paper are also applicable to growth of internal cracks driven by high gas pressures.

MAIN EQUATIONS FOR INTERNAL CRACK GROWTH

If the flux density, \(q\), can be found from the boundary value problem for the diffusing parameter, \(c\) (atomic hydrogen concentration in metal). Here, we take into account that if gas pressure in the opening is high enough, gas concentration at the crack surfaces will not be 0 anymore, but accordingly to Fick’s law will be proportional to \(\sqrt{p}\) (e.g., Brouwer, 1994), where \(p\) is gas pressure inside the crack (non-ideal sink):
\[
\begin{align*}
\frac{\partial c}{\partial t} &= D \left[ \frac{\partial^2 c}{\partial z^2} + \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial c}{\partial r} \right) \right] \quad (t > 0, \, r \geq 0, \, z < 0) \\
c(r,0,t) &= c_0 - K \sqrt{p} \quad (0 \leq r \leq a(t), \, t > 0) \\
\frac{\partial c}{\partial z}(r,0,t) &= 0 \quad (r > a(t), \, t > 0)
\end{align*}
\]

where \( D \) is the diffusion coefficient. Then, \( q = -D \frac{\partial c}{\partial z} (z = 0, \, 0 \leq r < a) \) and the full flux into the delamination \( Q(t) \) can be determined from (1).

After substituting the expressions for the delamination volume and gas pressure (Balueva, 2008), and full gas flux \( Q(t) \) into the equation of state for ideal gas, the main kinetic equation for the radius of the delamination \( a(t) \) can be derived. After reducing this integral equation to differential and solving the later, a closed form solution for the delamination radius with time was obtained as follows:

\[
\frac{1}{\alpha} a - \gamma \ln(C + \alpha a) + \gamma_1 = t
\]

where \( \alpha, \gamma, C, \gamma_1 \) are the material constants. As can be seen from Figure 2, when \( a \) is big enough, the delamination where the gas sink is considered real starts growing at constant velocity, besides at exactly the same as the velocity of the gas driven delamination with ideal sink approximation.

REFERENCES