PIPELINES RESISTANCE ESTIMATION ON UNSTABLE CRACK PROPAGATION

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ABSTRACT

This paper presents the design-experimental method of the gas pressure pipeline resistance estimation on unstable crack propagation. The theoretical model of pipeline fracture behaviour is described. Fracture design practices for certain gas pipeline are given. The method of the arresting crack pipe length calculation is also described.

KEYWORDS

Fracture, crack propagation and arrest, gas pressure, pipelines, crack rate, plastic crack opening, toughness, gas decompression wave, cylindrical vessel

INTRODUCTION

One of the important classes of structures to which knowledge of fracture mechanics concepts can be applied is that of pressure vessels and piping. The gas pipeline resistance estimation on unstable crack propagation is still the problem of great importance.The full-scale testing of the pipe sizes, steels and pressures employed in natural gas transmission lines (Duffy et al., 1969) shows that 100% shear cracks propagate at speeds 120-370 mps that sometimes means less than gas decompression rate (400 mps for natural gas). Kanninen et al.(1976) have developed the theoretical model of gas pipeline fracture behaviour which includes effects of gas dynamics, bulging behined the crack tip and dynamic inertia forces. Crack tip plasticity and underground effects in this model are not taken into account.

BASIC CONCEPTIONS

Crack rate of pipeline supposed fracturing V_f^0 is adopted as a criterion of pressure pipeline resistance on unstable crack propagation (Makarov et al.,1976; Makarov,1982; Makarov et al.,1986; Makarov,1988). When this crack rate V_f^0 is lower then pipeline resistance on unstable crack propagation is higher. The critical value of crack rate pipeline supposed fracturing is adopted as: $[V_f]$=70-100 mps. Hence the condition of pipeline crack non-propagation and arrest is:

$$V_f^0 \leq [V_f] \qquad (1)$$

The value of $[V_f]$ was estimated by experimental data in full-scale testing (safety factor: k_v=1.4-1.6).

DEVELOPMENT OF THE THEORETICAL MODEL

The theoretical model of gas pipeline fracture behaviour (Makarov,1988) includes effects of gas dynamics, bulging behind the crack tip, dynamic inertia forces, crack tip plasticity and underground effects. The axial gas decompression wave in pipeline at collapse has been theoretically investigated (Makarov et al.,1976), where it was pointed out that the internal gas pressure at crack tip depends on the crack rate by the following relationship:

$$p^* = \begin{cases} p_0[1-(1-V_f/V_g)(\gamma-1)/(\gamma+1)]^{2\gamma/(\gamma-1)}, & V_f \leq V_g \\ p_0, & V_f > V_g \end{cases} \qquad (2)$$

where p_0 is the initial pipeline internal pressure, V_g is the gas decompression rate and γ is the gas adiabatic exponent.

The radial-axial gas decompression wave and bulging behind the crack tip in pipeline at collapse have been also theoretically investigated (Makarov et al.,1986) and it was shown that the crack opening displacement behind the crack tip can be calculated as:

$$\vartheta_A = Cx^2 \qquad (3)$$

where x is the coordinate behind the crack tip and C is the parameter of bulging computing by special program as a function of crack rate, pressure value, pipe diameter and wall thickness, covered ground depth.

The final theoretical model of cylindrical pressure vessel with longitudinal propagating crack is developed (Makarov,1988) using the elasto-plastic Dugdale conception. The solution of this boundary problem was obtained by variational Rayleigh-Ritz method. The calculated value of plastic crack opening δ is equal to double value of transversal displacement at crack tip. The special computer program PIPE using the theoretical model developed by Makarov et al.(1976,1986,1988) calculates values of curve $\delta(V_f)$ for

certain gas pipeline with fixed parameters: pipe diamater and wall thickness, nominal pressure value, covered ground depth, yield strength and ultimate strength values.

PRACTICES IN DESIGN AND CONSTRUCTION

Fig.1 shows the example of pipeline resistance estimation on unstable crack propagation for gas pipeline 530 mm diameter, 5.7 mm wall thickness and nominal pressure value 55 atm.

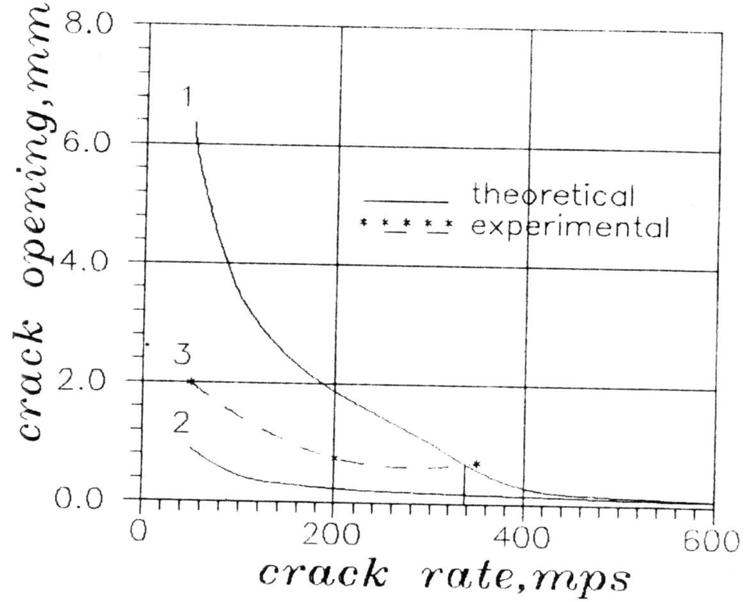

Fig.1. Illustration of pipeline resistance estimation on unstable crack propagation:
1 - 0 m; 2 - 1 m; 3 - $\delta_c(V_f)$

The material is a carbon steel X-65 with a yield strength level 490 MPa and a ultimate strength level 630 MPa. The calculated curves $\delta(V_f)$ are given for two values of underground depth: zero and 1 metre. The experimental curve $\delta_c(V_f)$ was obtained by full-scale testing of the pipe 5 m length at the temperature -20°C. The value of the crack rate supposed fracturing V_f^0 is obtained as an abscissa of the point of intersection of two curves: $\delta(V_f)$ and $\delta_c(V_f)$. For two cases (0 and 1 m underground depth) the value of the crack rate supposed fracturing V_f^0 can be obtained only for the overground pipeline: V_f^0=330 mps, that means much higher then the critical value: $[V_f]$=70-100 mps. Hence the underground gas pipeline for 1 m depth has a high resistance on unstable crack propagation, but the overground gas pipeline with the same parameters has no resistance on unstable crack propagation. It means that a sudden fracturing of this overground pipeline can lead to unstable crack propagation and a great collapse. In this case the gas pipeline must be protected by the crack arresting pipe of the material with high toughness.

The computer program PIPE can also calculate the length of the crack arresting pipe l_a and the level of its material toughness. Fig.2 shows the calculating curve $l_a(V_f^0)$ for the overground gas pipeline 530 mm diameter and 5.7 mm wall thickness with nominal pressure value 55 atm. The crack arresting pipe reduces a crack rate level to value 50 mps. The crack arresting pipe metal toughness level must be equal: δ_c=6.37 mm, the length of the arresting pipe is: l_a=640 mm.

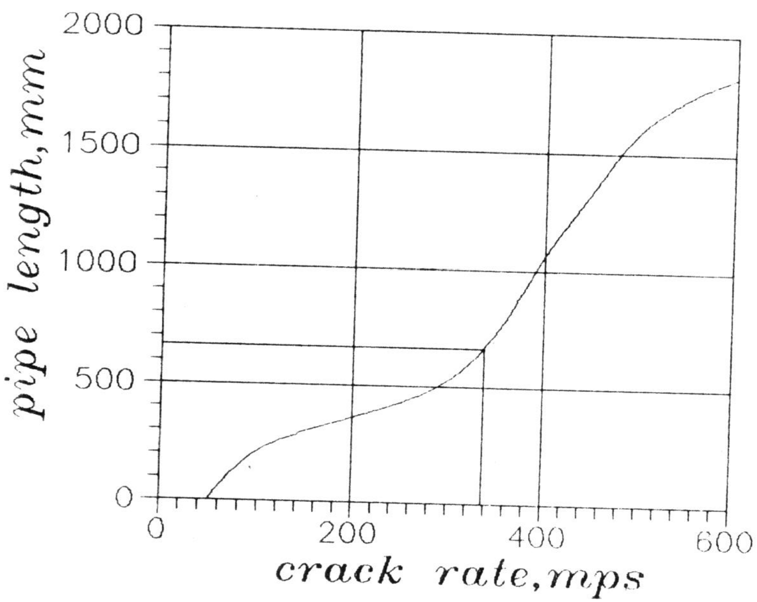

Fig.2. Crack arresting pipe length l_a as a function of crack rate supposed fracturing V_f^0

SUMMARY

The research discussed in this paper has demonstrated the design-experimental method of gas pressure pipeline resistance estimation on unstable crack propagation. It was pointed out that material toughness and underground depth are the main factors of pipeline resistance on unstable crack propagation.

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