SOME PROBLEMS OF THE COLD CRACKING IN WELD JOINTS IN ASPECT OF FRACTURE MECHANICS

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After characteristic the real conditions of the cold cracking in weld joints shows the possibilities of used the threshold stress intensity factor K_{Ith} to evaluate the cold cracking resistance. There also was established a modified van Leeuwen - Lancaster equation and determined the relation K_{Ith} / K_{IC}. In this relation K_{Ith} / K_{IC} was considered the influence of the constraint effect in mismatched weld joints on cold cracking resistance. Lastly was made some analytical examples.

INTRODUCTION

In general, the presence of hydrogen in steel causes a reduction of strain to failure and of the energy of fracture. Hydrogen cracking represents the most common problem encountered when welding steel structures. Of much greater importance in welding is the temporary form of hydrogen embritllement, since this may cause hydrogen - induced cold cracking. The cracks are sited either in the heat - affected zone (HAZ) of the parent material or in the weld metal itself. The cracking in HAZ or weld metal occurs when the conditions outlined below occur simultancously {1}:
- hydrogen is present to a sufficient degree,
- tensile stresses act on the weld which are a result of the weld thermal cycle,
- a susceptible HAZ microstructure is present which was expressed by fracture toughness.

These factors interact in a complex manner so that a quantitative treatment of the subject is difficult. Cracks in the HAZ are usually sited either at the weld toe, the weld root or in the underbead position. Fracture occurs when a critical hydrogen content has accumulated in the strained region at the root of the notch or defects.

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COLD CRACKING IN ASPECT OF FRACTURE MECHANICS.

The presence of hydrogen in weld joint cause a reduction of the energy of fracture. This is reflected in the fracture morphology. In this situation the application of well know fracture criterion: $K_I = K_{IC}$ it is impossible. There has been much speculation as to the mechanism of hydrogen embrittlement. The basis of further consideration in this paper is supported on the van Leeuwen conception {3} which was adopted by Lancaster to weld joints {1}. At first it was suggested by Oriani {2} that the cohesive force between atoms in the metal lattice is reduced in proportion to hydrogen concentration and takes account of the increase of hydrogen solubility in the strained region at the tip of a crack. Van Leeuwen {3} improved Oriani's treatment and suppose that the reduction of fracture stress $\sigma_o = \sigma_H$ is a function of hydrogen concentration C at the root of a pre - existing crack:

$$\sigma_o - \sigma_H = \beta C^{\gamma} \tag{1}$$

where β and γ are constants.
If the solubility C / C_n of hydrogen at the crack tip with the radius ρ:

$$\rho = \frac{K_I^2}{2E\sigma_{ys}} \tag{2}$$

is augmented in accordance with equation:

$$\frac{C}{C_n} = \exp\left(A\sigma_{ys}^{1/2} - B\sigma_{ys}\right) \tag{3}$$

where:

$$A = \frac{2(1+\nu)\overline{V}}{3RT}\left(\frac{2E}{\pi}\right)^{1/2} \quad ; \quad \left(MNm^{-2}\right)^{1/2} \tag{4}$$

$$B = \frac{2(1+\nu)\overline{V}}{RT}\left(\frac{2}{\pi}\right) \quad ; \quad \left(MNm^{-2}\right)^{-1} \tag{5}$$

we finally received:

$$\frac{K_{Ith}}{K_{IC}} = \frac{1}{1 + \left(\frac{p}{p_o}\right)^{\gamma/2} \left(b\left(\sigma_{ys}\right)^{1/2}\right)^{-1} \exp\left(A\sigma_{ys}^{1/2} - B\sigma_{ys}\right)} \tag{6}$$

where: $b = (8E / \beta 2\pi)^{1/2}$
Then the subcritical hydrogen - assisted crack growth doesn't take place when:

$$K_I \leq K_{Ith} \tag{7}$$

INFLUENCE OF CONSTRAINT EFFECT ON COLD CRACKING.

Some groups of weld joints are often highly inhomogeneous. The heterogeneous nature of the weld joints are characterized by macroscopic dissimilarity in mechanical properties. The essential physical phenomena affecting the mechanical properties of the mismatched weld joints occur at the interfaces of different zones. This mis - match causes constraints and stress concentrations which are enhanced by geometric and physical parameters of the mismatched weld joints and state of loading. The general theory of constrained materials in classical mechanics of deformable media is characterized by a restriction on the class of possible motions. The level of constraint of heterogeneous system depends upon:

- the body configuration,
- type and magnitude of applied load,
- physical phenomena at the interface of zones with different mechanical properties and their geometric configuration.

In this situation expression characterizing constraint need to developed and match the constraint parameters with the appropriate crack - driving parameters such as K_I , K_{Ith} etc. Analytical assessment of the constraint factors K_W^{un} , K_W^{ov} of the under- and overmatched weld joints in accordance to reference {4} yields:

$$K_W^{un} = \frac{2}{\sqrt{3}}\left[\frac{1}{4(1-q)}\left[\frac{\pi}{2} + 2(1-2q)\sqrt{q(1-q)} - a\sin(2q-1)\right] + (1-q)\frac{1}{4\kappa}\right] \qquad (8)$$

$$K_W^{ov} = \frac{2}{\sqrt{3}}\left[\frac{1}{4(1-q)}\left[-\frac{\pi}{2} - 2(1-2q)\sqrt{q(1-q)} - a\sin(2q-1)\right] + (1-q)\frac{1}{4\kappa}\right] \qquad (9)$$

and it will be able to transform the equation (6) as follows:

- undermatched weld joints

$$\frac{K_{Ith}}{K_{IC}} = \frac{1}{1 + \left(\frac{p}{p_o}\right)^{\gamma/2}\left[b\left(\sigma_{ys} \cdot K_W^{un}\right)^{1/2}\right]^{-1} \exp\left[A\left(\sigma_{ys} \cdot K_W^{un}\right)^{1/2} - B\left(\sigma_{ys} \cdot K_W^{un}\right)\right]} \qquad (10)$$

- overmatched weld joints

$$\frac{K_{Ith}}{K_{IC}} = \frac{1}{1 + \left(\frac{p}{p_o}\right)^{\gamma/2}\left[b\left(\sigma_{ys} \cdot K_W^{ov}\right)^{1/2}\right]^{-1} \exp\left[A\left(\sigma_{ys} \cdot K_W^{ov}\right)^{1/2} - B\left(\sigma_{ys} \cdot K_W^{ov}\right)\right]} \qquad (11)$$

In relation K_{Ith} / K_{IC} in agreement with equation (10), (11) was considered generally the influence of constraint effect in mismatched weld joints on cold cracking resistance. Finally, by used the quantitative values of constraint factors K_W^{un} and K_W^{ov} we received the relation K_{Ith} / K_{IC} as follows:

$$\frac{K_{Ith}}{K_{IC}} = \frac{1}{\left[1+\left(\frac{p}{p_o}\right)^{\gamma/2}\left[b\left[R_e\left[\frac{2}{\sqrt{3}}\left[\frac{1}{4(1-q)}\left[\frac{\pi}{2}+2(1-2q)\sqrt{q(1-q)}-a\sin(2q-1)\right]+(1-q)\frac{1}{4k}\right]\right]\right]^{\frac{1}{2}}\right]^{-1}}$$

$$\overline{\cdot\exp\left[A\left[R_e\left[\frac{2}{\sqrt{3}}\left[\frac{1}{4(1-q)}\left[\frac{\pi}{2}+2(1-2q)\sqrt{q(1-q)}-a\sin(2q-1)\right]+(1-q)\frac{1}{4\kappa}\right]\right]\right]^{\frac{1}{2}}-\right.}$$

$$\overline{\left.-B\left[R_e\left[\frac{2}{\sqrt{3}}\left[\frac{1}{4(1-q)}\left[\frac{\pi}{2}+2(1-2q)\sqrt{q(1-q)}-a\sin(2q-1)\right]+(1-q)\frac{1}{4\kappa}\right]\right]\right]\right]} \qquad (12)$$

$$\frac{K_{Ith}}{K_{IC}} = \frac{1}{\left[1+\left(\frac{p}{p_o}\right)^{\gamma/2}\left[b\left[R_e\left[\frac{2}{\sqrt{3}}\left[\frac{1}{4(1-q)}\left[-\frac{\pi}{2}-2(1-2q)\sqrt{q(1-q)}-a\sin(2q-1)\right]+(1-q)\frac{1}{4k}\right]\right]\right]^{\frac{1}{2}}\right]^{-1}}$$

$$\overline{\cdot\exp\left[A\left[R_e\left[\frac{2}{\sqrt{3}}\left[\frac{1}{4(1-q)}\left[-\frac{p}{2}-2(1-2q)\sqrt{q(1-q)}-a\sin(2q-1)\right]+(1-q)\frac{1}{4\kappa}\right]\right]\right]^{\frac{1}{2}}-\right.}$$

$$\overline{\left.-B\left[R_e\left[\frac{2}{\sqrt{3}}\left[\frac{1}{4(1-q)}\left[-\frac{\pi}{2}-2(1-2q)\sqrt{q(1-q)}-a\sin(2q-1)\right]+(1-q)\frac{1}{4\kappa}\right]\right]\right]\right]} \qquad (13)$$

The results of this study of mismatched weld joints after used to calculation the date:

$$A = 6{,}926 \cdot 10^{-5} \left(\frac{N}{m^2}\right)^{-\frac{1}{2}} \quad ; \quad B = 3{,}242 \cdot 10^{-10} \left(\frac{N}{m^2}\right)^{-1}$$

$$b = 4{,}7895 \cdot 10^{-5} \left(\frac{N}{m^2}\right)^{-\frac{1}{2}} \quad ; \quad \gamma = 0{,}26375 \quad ; \quad \sigma_{ys} = 9{,}038 \cdot 10^{8} \left(\frac{N}{m^2}\right)$$

reveals high dependence of fracture parameters K_{Ith} / K_{IC} on the constraint factors K_W^{un}, K_W^{ov} at different hydrogen concentration C, as presented on figure 1 and 2.

CONCLUSION

The theoretical analysis form a basic to an assessment of the relation K_{Ith} / K_{IC} for mismatched weld joints.There was established a modified van Leeuwen - Lancaster equation by introduction to calculation the constraint factor $K_W^{un/ov}$. It enable the quantitative assessment of the constraint effect in mismatched weld joints of weld joints on cold cracking at different hydrogen concentration in agreement with equations (12) and (13). The cold cracking resistance described by relation K_{Ith} / K_{IC} had difference tendency for undermatched and overmatched weld joints at the same geometric characteristic.

SYMBOLS USED

κ - relative thickness of soft or hard zone,
E - modulus of elasticity, MNm^2 ,
ν - Poisson's ratio,
R - gas constant, 8.134 J $mol^{-1}K^{-1}$,
T - temperature, K,
$\overline{V}$ - partial molar volume of hydrogen in iron, m^3 mol^{-1},
σ_{ys} - yield strength, MNm^{-2},
K_{Ith} - threshold value of the stress intensity factor for initiating subcritical hydrogen - assisted crack growth, $MNm^{-1/2}$,
p/p_o - hydrogen pressure in atmospheres.
q - parameter, $0 \le q < 1$.

REFERENCES

(1) Lancaster J.F., Metallurgy of Welding. Chapman & Hall, London, UK, 1993.

(2) Oriani, R.A. and Josephic, P.H., Acta Metallurgica, Vol. 22, 1974, pp. 1065 – 1074.

(3) van Leeuwen, H.P., Corrosion, Vol. 32, No 1, 1976, pp. 34 – 37.

(4) Ranatowski, E., ECF 11, Vol. III, Published by EMAS, London, UK, 1996, pp. 2061 – 2066.

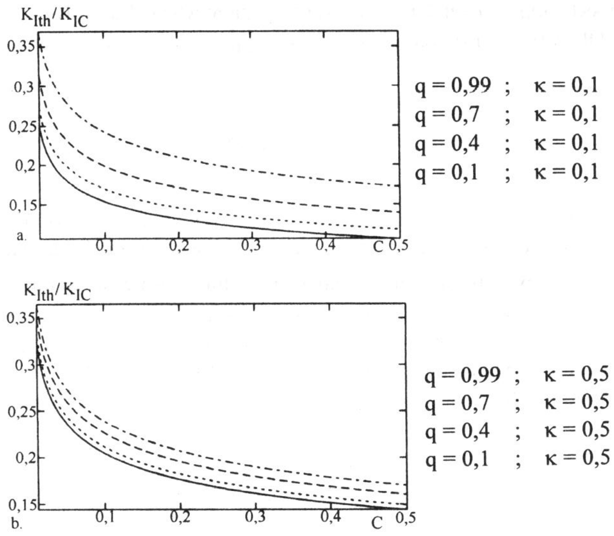

Figure 1. Characteristic of K_{Ith} / K_{IC} as a function of C for undermatched weld joints at a. κ = 0,1 ; b. κ = 0,5 and q = 0,1; 0,4; 0,7; 0,99.

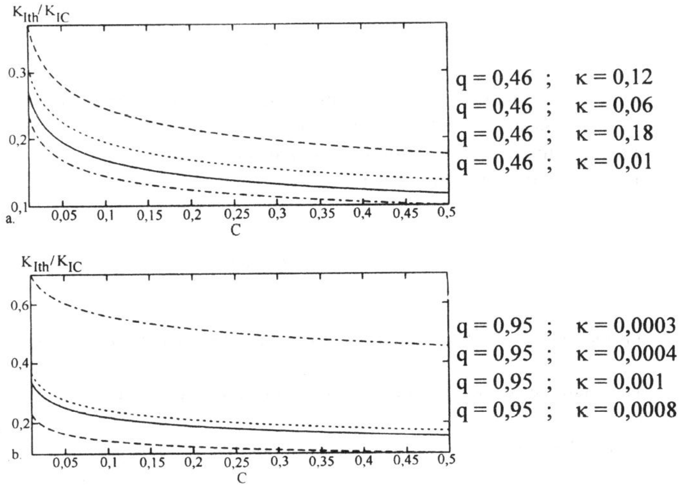

Figure 2. Characteristic of K_{Ith} / K_{IC} as a function of C for overmatched weld joints at a. κ = 0,18; 0,12; 0,06; 0,01 and q = 0,46, b. κ = 0,01; 0,0008; 0,0004; 0,0003 and q = 0,95.