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FATIGUE LIFE PREDICTION FOR WELDED JOINTS WITH KNOWN INITIAL CRACK

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ABSTRACT

The inspection of various structures often detects a fatigue cracks developed during long service life. These fatigue cracks significantly reduce remaining fatigue life and fatigue strength. Influence of the initial fatigue cracks size in non-load-carrying fillet-welded one-sided transverse attachment joints on the remaining fatigue life and fatigue strength is considered in this paper. A computer simulation of fatigue crack growth was used in this analysis. Obtained results could be very useful to determine optimal inspection intervals.

Keywords: welded joint, prediction of fatigue crack propagation, low carbon steel

1. INTRODUCTION

Fatigue is one of the most frequent form of the failures of the welded structures. According to ref. [1,2,3] 50 -90 percent of all mechanical failures are fatigue failures. Many experiments show that the fatigue crack mostly initiates at the weld toe because of the severity of the stress concentration at that location and propagates through the main plate (Fig.1.) to a final fracture. The objective was to determine how well one can predict the crack propagation life of a weldment under cyclic loads. The fracture mechanics approach was utilized, average material properties were assumed. The objective was pursued by analysing crack propagation at non-load-carrying fillet-welded one-sided transverse attachment joints (Fig.1). Specimens were fabricated from low-carbon structural steel S355JO conformed to MEST EN 10025 2003 standard specification.

2. ANALYSIS OF CRACK PROPAGATION

2.1. Crack propagation model

The crack propagation lives were calculated with the Paris equation [4]:

$$\frac{da}{dN} = C(\Delta K)^m \tag{1}$$

where

da/dN = crack growth rate,
ΔK = range of stress intensity factor,
C and m = material constants.

2.2. Stress intensity factor

The stress intensity factor was calculated by using Eq.(2) in which Newman's solution [5] for plate with surface semi-elliptical crack is multiplied by the geometry correction factor M_k calculated by using Albrecht's solution [6] given in Eq.(3):

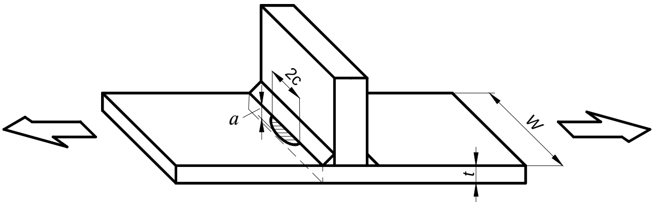

Figure 1. Welded joint

$$K = M_k F\left(\frac{a}{c},\frac{a}{t},W,\varphi\right)\sigma\sqrt{\frac{\pi a}{Q}} \tag{2}$$

where:

$$F = \left[M_1 + M_2\left(\frac{a}{t}\right)^2 + M_3\left(\frac{a}{t}\right)^4\right] f_\varphi f_W g\,;\; M_1 = 1.13 - 0.09\left(\frac{a}{c}\right);\; M_2 = -0.54 + \frac{0.89}{0.2 + \frac{a}{c}}$$

$$M_3 = 0.5 - \frac{1.0}{0.65 + \frac{a}{c}} + 14\left(1 - \frac{a}{c}\right)^{24};\; f_\varphi = \left[\left(\frac{a}{c}\right)^2 \cos^2\varphi + \sin^2\varphi\right]^{\frac{1}{4}};\; f_W = \left[\sec\left(\frac{\pi c}{W}\sqrt{\frac{a}{t}}\right)\right]^{\frac{1}{2}}$$

$$g = 1 + \left[0.1 + 0.35\left(\frac{a}{t}\right)^2\right](1 - \sin\varphi)^2;\; Q = 1 + 1.464\left(\frac{a}{c}\right)^{1.65};$$

$$M_k = \frac{2}{\pi}\sum_{i=1}^{n}\frac{\sigma_{bi}}{\sigma}\left(\arcsin\frac{b_{i+1}}{a} - \arcsin\frac{b_i}{a}\right) \tag{3}$$

where a = crack size, $2c$ = surface crack length, t = plate thickness, W = plate width, φ = parametric angle describes the location at the crack front with respect to the major axis of the ellipse, σ_{bi} = the normal stress in a finite element between the distance b_{i} and $b_{\mathrm{i+1}}$, σ = the nominal stress. Verreman *et al.* [7] used this method for determination of the stress intensity factor of a cruciform-welded joint and compared it with the accurate solution obtained by Smith [8] using high-order crack tip elements with an inverse square root singularity. They reported difference smaller than 6%, so this method can be considered accurate for engineering purposes. The advantage of Albrecht's method is that only one stress analysis needs to be made for each joint geometry, i.e. the stress analysis of an uncracked joint.

3. PREDICTION OF THE REMAINING FATIGUE LIFE

Specimens were fabricated from low-carbon structural steel S355JO. Average material properties were assumed: $m = 3$, $C = 4.9\cdot10^{-12}$, with ΔK in units of MPa$\sqrt{\mathrm{m}}$ and da/dN in units of m/cycle [9,10]. The remaing fatigue life (crack propagation life) N_{p} is obtained from the equation:

$$N_p = \int_{a_i}^{a_{\mathrm{f}}} \frac{da}{C(\Delta K)^m} \tag{4}$$

The equation (4) was solved by 32-point Gaussian quadrature method. These calculations were performed by using the computer programs based on this procedure. Numerical integration was performed for several values of $\Delta\sigma$ and a_i . The development of crack shape i.e. the change of a/c during the crack growth was taken into account [11,12]. The S-N curves were determined by the regresion analysis [13] (Fig.2). These results were compared with experimental results for welded joint according to ref. [14].

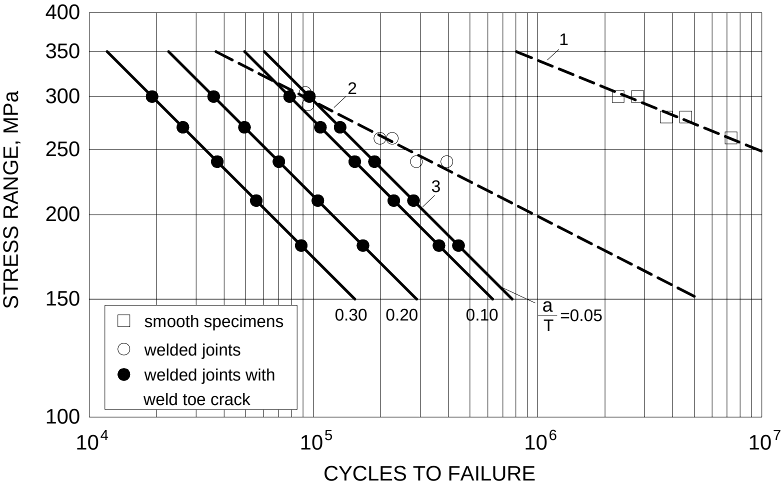

Figure 2. Experimentaly determined S-N curves; ——Predicted S-N curves for welded joints with known initial crack

It can be noticed, on Figure 2., that a small increase of fatigue crack size causes a big decrease of fatigue strength and remaining fatigue life. As the magnitude of the applied stress range decreases, the difference between total fatigue life (curve 2) and predicted crack propagation life (curve 3) increases because the crack-initiation portion of the fatigue life increases. Based on known initial crack size, determined during periodical ultrasonic or radiographic inspections, the remainig fatigue crack propagation life was obtained and shown in Figure 3.

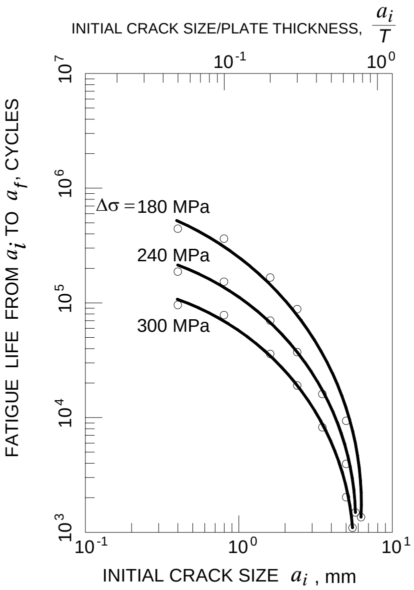

Figure 3. Predicted remaining fatigue lives for known initial crack

4. CONCLUSIONS

Most of old structures subjected to cyclic loading containes a small fatigue crack developed during long service life. It seems reasonable, at least in some cases, to perform periodical ultrasonic or radiografic inspections in order to detect potential fatigue crack. Than one can predict remainig fatigue life i.e. time until final failure and choose the best moment of time to perform the repair.

5. REFERENCES

[1] Stephens R.I., Fatemi A., Stephens R.R., Fuchs H.O.: Metal fatigue in engineering, John Wiley & Sons, USA, 2001

[2] Klikov N.A.: The calculation of the fatigue strength of welded joints (in Russian), Mashinostroenie, Moscow, Russia, 1984

[3] Toth L.: Crack growth sensitivity assessment of welded structures, Proceedings of the International Conference 'Welding 96 – Welding in Power Industry' , pp.192-195, Belgrade, Serbia, 1996

[4] Paris P.C.: The fracture mechanics approach to fatigue, Tenth Sagamore Conference, p.107, Syracuse University Press, NY, USA, 1965

[5] Newman J.C. and Raju I.S.: Stress intensity factor equation for cracks in three-dimensional finite bodies, ASTM STP 791, pp.I-238 – I-265, 1983

[6] Albrecht P. and Yamada K.: Rapid calculation of stress intensity factors, Journal of the Structural Division, Vol.103, No. ST2, pp. 377-389, 1977

[7] Verreman Y., Bailon J.P. and Masounave J.: Fatigue life prediction of welded joints – a re-assessment, Fatigue and Fracture of Engineering Materials and Structures, Vol. 10, No. 1, pp.17-36, 1987

[8] Smith I.J.: The effect of geometry changes upon the predicted fatigue strength of welded joints, Proceedings of the Third International Conference on Numerical Methods in Fracture Mechanics, Pineridge Press, Swansea, UK, pp. 561-574, 1984

[9] Albrecht P. and Yamada K.: Simulation of service fatigue loads for short-span highway bridges, Service Fatigue Loads Monitoring, Simulation and Analysis, ASTM STP 671, Eds: Potter J.M. and Abelkis P.R., American Society for Testing and Materials, pp.255-277, 1979

[10] Hobbacher A.: Fatigue design of welded joints and components – Recommedations of IIW Joint working group Doc XIII-1539-96/XV-845-96, 1996

[11] Wang Y., Tomita Y., Hashimoto K., Osawa N. and Balakrishnan B.: Simulation of fatigue crack propagation in weld joints considering coalescence of multiple surface cracks, IIW Doc XIII-2016-04, 2004

[12] Toyosada M., Gotoh K. and Niwa T.: Fatigue life assessment for welded structures without initial defects: an algotithm for predicting fatigue crack growth from a sound site, International Journal of Fatigue, Vol. 26, pp.993-1002, 2004

[13] Rustagi J.S.: Introduction to statistical methods, Rowman $& Allanheld Publishers, New Jersey, USA, 1984

[14] Perovic Z.: Fatigue strength assessment of welded joints by using notch stress approach, 13th International Research/Expert Conference 'Trends in the Development of Machinery and Associated Technology', TMT 2009, Hammamet, Tunisia, pp.509-512, 2009