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Procedia Engineering 101 (2015) 177 – 184

Procedia Engineering

www.elsevier.com/locate/procedia

3rd International Conference on Material and Component Performance
under Variable Amplitude Loading, VAL2015

Total life approach for fatigue life estimation of welded structures

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Abstract

It was shown that estimation of fatigue lives of welded joints can be successfully carried out by considering the fatigue process as a fatigue crack growth from the initial intrinsic crack size of $a_0=\rho^*$ until the final crack a_f. Such an approach avoids a somewhat arbitrary division of the fatigue process into the crack initiation and propagation and concentrates on using only one methodology - the fracture mechanics theory. The stress intensity factors can be determined in such cases by the weight function method. The proposed methodology allows estimation of the fatigue life under both constant and variable amplitude loading.

Peer-review under responsibility of the Czech Society for Mechanics

Keywords: Total life; fatigue crack growth; welded joints

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1. Total life approach

An approach to estimating the entire fatigue life, from the very early stages to the final fracture, of smooth specimens subjected to constant amplitude loading histories and welded components subjected to both constant and variable amplitude loading histories is discussed in this paper. The proposed method uses only experimental strain-life and stress-strain data obtained from smooth material specimens and da/dN versus ΔK crack growth data obtained from compact tension specimens. The proposed model is based on analyzing the local stress-strain material behavior in the vicinity of a crack tip.

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Peer-review under responsibility of the Czech Society for Mechanics
doi:10.1016/j.proeng.2015.02.023

Nomenclature

ρ^*	the smallest crack size in the material being within the resolution of continuum mechanics
$K_{max,appl}$	applied maximum stress intensity factor
ΔK_{appl}	applied stress intensity range
K_R	residual stress intensity factor due to welding process
K_r	residual stress intensity factor due to reversed plastic deformations
C,γ	fatigue crack growth material constants
p	driving force parameter
W	weight function
s(x)	stress distribution in the critical cross-section
a,b	dimensions of the semi-elliptical crack

1.1. Basic assumptions of the total life approach

The Total Life approach is based on four main assumptions:

- The fatigue crack is regarded as a deep notch with a finite tip radius, ρ^*. The ρ^* parameter is a material constant.
- The size of the smallest crack which can be analyzed using classical mechanics of continuum is equal to ρ^*.
- The stress-strain material behavior can be described by the cyclic Ramberg-Osgood [1] stress-strain curve.
- The number of cycles required to break the material over the distance ρ^* can be calculated using the Manson-Coffin [2] equation and the mean stress correction proposed [3] by Smith, Watson and Topper.

The advantage of using the blunt crack model lies in the fact that notch theories can be applied and crack tip stresses and strains obtained in the analysis are more realistic than in the case of a sharp crack leading to the singular solution. Such an approach implies that while crack surfaces may get in contact away from the crack tip, the region (Fig. 1) just behind the crack tip remains open. The blunt crack tip model makes it possible to carry out elastic plastic stress-strain analysis around the crack tip using simplified methods like the multiaxial Neuber rule [4]. One of the advantages of the model is consistent treatment of the tensile and compressive parts of the stress cycle. The compressive stress effect is modeled by converting the crack into a small hole of the radius ρ^* which is a material constant.

Based on the model shown in Fig. 1 and all the assumptions above, Noroozi and Glinka [5] have analytically derived the fatigue crack growth expression in the following form:

$$\frac{da}{dN} = C\left(\Delta K_{tot}^{\;1-p} K_{\max,tot}^{\;1-p}\right)^{\gamma} = C\left[\left(\Delta K_{appl} + K_r\left(\rho^*, S\right)\right)^{1-p}\left(K_{\max,appl} + K_r\left(\rho^*, S\right) + K_R\right)^{p}\right]^{\gamma} \tag{1}$$

Parameters ‘$K_{max,appl}$‘ and ’ΔK_{appl}‘ are the applied maximum SIF and the SIF range respectively, ‘K_r‘ is the local residual SIF accounting for the effect of the crack tip residual stresses resulting from reversed plastic deformations, and K_R is the global residual SIF factor induced by the welding residual stresses. The SIF due to reversed plastic deformations is a function of the ρ^* parameter and it accounts also for the load interaction effects as discussed in reference [6]. Parameters C, γ, and p are found from the Manson-Coffin and Ramberg-Osgood material properties or from appropriate analysis [5] of fatigue crack growth data obtained at various R-ratios. Eq. (1) has been finally coded in the form of the UniGrow computer program [6] enabling fatigue crack growth analysis under a variety of loading spectra and geometrical crack configurations.