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Fatigue assessment of welded joints using critical distance and other methods

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Abstract

This paper describes an investigation into four different methods for predicting high-cycle fatigue behaviour in welded joints. Two of these methods (the crack modelling method and the notch stress intensity factor) are based on modifications of linear elastic fracture mechanics. The other two are methods to which we give the general name critical distance methods (CDM). The direct CDM approach uses stress values at critical distances from the weld, taken from finite element analysis. Another method (the stress averaging approach) achieves the same effect using a fictitious radius concept. When tested against a large body of experimental data from the literature, all four methods were found to give reasonable predictions of endurance limits for a range of weld types in both aluminium alloys and steels. The explicit use of CDM with FEA was found to give the best combination of high accuracy and ease of use. The methods were also applied to a specific case – fatigue in a T-shaped joint containing a drilled hole – which allowed us to study a typical industrial design problem involving competition between two different features.

Keywords: Fatigue; Fracture mechanics; Weld fatigue; Stress concentrations

1. Introduction

The assessment of welded joints is a major industrial problem for two reasons. First, welds tend to be regions of weakness in a structure due to stress concentration effects and poor material properties. Second, it is difficult to predict their behaviour accurately due to the difficulty of defining precisely the weld geometry and material properties. Methods for predicting the fatigue behaviour of welded joints can be di-

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Nomenclature

α_d	drilling angle
K_t	elastic stress concentration factor
$K_{t,w}$	elastic stress concentration factor of the weld
a_0	ElHaddad length parameter
b	ellipse semiaxis orthogonal to the applied load
K_f	fatigue strength reduction factor
$K_{f,w}$	fatigue strength reduction factor of the weld
ρ_f	fictitious notch radius
α	flank angle of the weld
$2a$	gap length of butt weld
k_1, k_2	geometrical coefficients for notch stress intensity factors
F	geometrical factor in the stress intensity factor K_I
$\Delta\sigma_{0,w}$	ground butt weld endurance limit
t	main plate thickness
L	material characteristic length parameter
σ_{max}	maximum stress
ρ^*	microstructural length
σ_n	nominal stress
ψ	notch opening angle
D	notch or crack length
ρ	notch radius
ΔK_1^N	notch stress intensity factor
$\Delta\sigma_{0n,w}$	notched butt weld endurance limit
$\Delta\sigma_{0n}$	notched-specimen endurance limit
$1-\lambda_1$	order of singularity
$\Delta\sigma_0$	plain-specimen endurance limit
r, θ	radial and angular polar coordinates
ρ_c	radius of curvature
R_d	radius of the drill
K_1	stress intensity factor
R	stress ratio
ΔK_{th}	threshold value of stress intensity factor range for crack propagation

vided into two types: those which are specifically aimed at the problem of welds and those which treat welds as just one example of the more general problem of failure from stress concentrations.

Methods which are designed specifically for welds include the following two. First, the traditional approach, accepted by major industries and encapsulated in the current British Standard [1], classifies the welded structures in different classes based on joint geometry and loading mode. For each class, the *S–N* curve is experimentally evaluated. Fatigue life is estimated by the nominal stress applied to the joint and by the *S–N* curve of class chosen. Second, the hot spot stress approach uses the concept of a "hot spot stress", defined as at weld toe location taking all geometrical influences into consideration except for the local weld geometry. The hot spot stress or structural stress has been defined in various ways: the mean stress value evaluated at certain distance away from the weld toe [2] or multiplying the nominal stress range by an appropriate stress concentration factor. These two approaches have some important limitations [2,3]: the