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Equivalent crack approach for fatigue life assessment of welded joints

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ABSTRACT

An equivalent crack approach for estimating the fatigue strength of welded structures based on *one* experimental data point is presented. The experimental data point reflects and quantifies the stress concentration effects at the fatigue critical location. These effects are then assumed approximately equivalent to having a crack in an unwelded plate. The crack propagation from this *initial equivalent flaw* to final fracture is calculated using the Paris law. The approach has been applied to constant amplitude fatigue data. The results show good agreement between the calculated and experimental fatigue lives. Extension of the approach to variable amplitude loading is proposed.

1. Introduction

The fatigue strength of welded joints is typically determined by fatigue crack propagation from locations of high stress concentration, such as weld toes and roots. The stress concentration at the weld toe is caused by welding residual stresses and localized stress peaks due to discontinuities in geometry. Global changes in geometry depend on the joint type and possible welded attachments, whereas local changes in geometry depend on local weld toe dimensions and the existence of welding defects, such as lack of penetration and undercuts. All these effects are illustrated in Fig. 1. Variation in all these factors causes considerable scatter in fatigue endurance from specimen to specimen [1]. As a result, the fatigue endurance of a welded structure is strongly influenced by many factors. Consideration of all these factors separately may give the reliable information for fatigue design but requires a lot of experimental work. In addition, this type of detailed analysis based on extensive measurement data cannot be applied flexibly to a variety of welded joints, as the measurements need to be redone for each studied case.

Due to the high stress concentration at the weld toe, the number of cycles required to initiate a crack is decreased and the crack initiation period can most often be ignored. As a result, the fatigue life of welded joints can be estimated using linear elastic fracture mechanics (LEFM) and the Paris law. The Paris law states that the stress intensity factor (SIF) range ΔK and the crack growth rate da/dN have an exponential relationship for a stress ratio $R = \sigma_{min}/\sigma_{max} = 0$

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

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Nomenclature

a or $2a_e$	crack length
C	Paris law constant
m	Paris law exponent
f_y	yield strength
F	geometry correction factor
K_I	mode I stress intensity factor
l	crack propagation length
N	number of cycles
P_f	probability of survival
R	stress ratio ($\sigma_{min}/\sigma_{max}$)
t	main plate thickness
W	width
ΔK	stress intensity factor range
$\Delta\sigma$	applied stress range

Subscripts

0	initial equivalent value
$*$	equivalent value
c	critical value
f	failure
i	initial
ref	reference value
th	threshold value
max/min	maximum/minimum value

where C is the Paris law constant, m is the Paris law exponent and

$$\Delta K = F(a)\Delta\sigma\sqrt{\pi a}. \tag{2}$$

In Eq. (2), F is a geometry correction factor for the stress distribution, which depends on the crack length a and the configuration of the structure, and $\Delta\sigma$ is the applied stress range. As a result, the crack growth rate da/dN depends on the parameters C and m, the crack length a and the through thickness stress distribution at the anticipated crack path in terms of $F(a)\Delta\sigma$. Integration of Eq. (1) gives the fatigue crack propagation life from an initial crack to final failure.

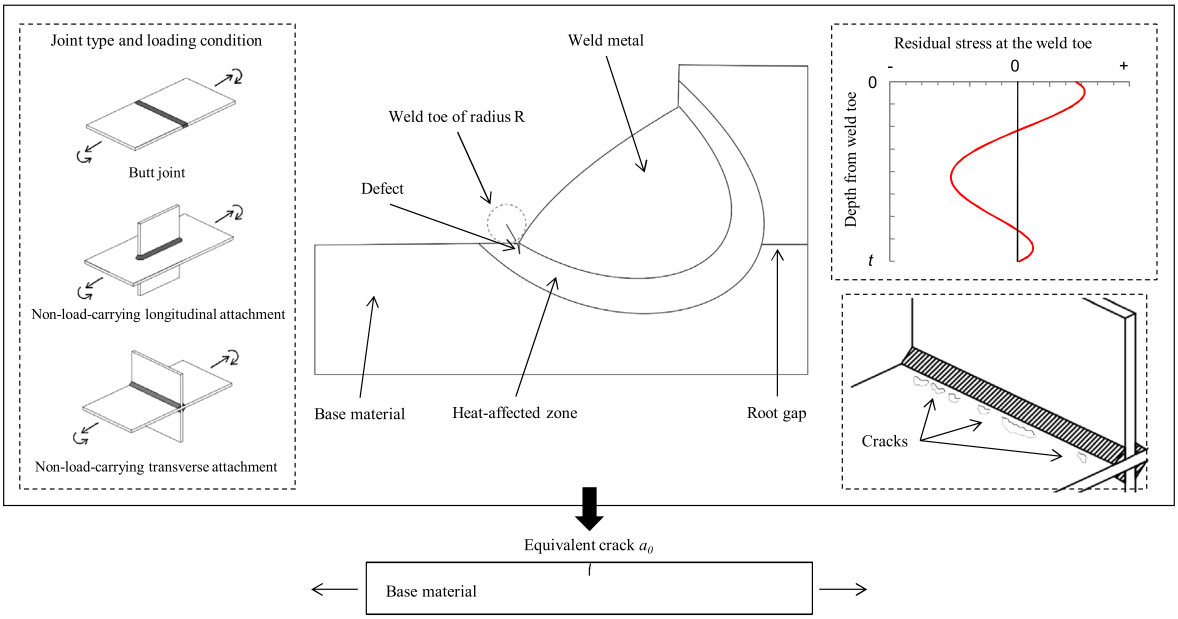

Fig. 1. Schematic view of factors affecting fatigue of welded joints and the equivalent crack concept.