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Plastic deformation behavior in SEB specimens with various crack length to width ratios

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ABSTRACT

The authors have already proposed a new crack tip opening displacement (CTOD) calculation formula based on the plastic hinge model considering the unique crack tip blunting behavior due to strain hardening of the material. This formula is limited to the standard length-to-width ratio (a_0/W) range of between 0.45 and 0.55. However, CTOD calculations are necessary for various other a_0/W conditions when the critical CTOD for a specific microstructure must be evaluated in a welded joint. ISO15653, which prescribes CTOD test methods for welds, covers a wide range of a_0/W between 0.10 and 0.7 by applying a *J*-integral based CTOD derived from ASTM E1290 for a_0/W from 0.10 to 0.45 and a plastic hinge based CTOD for a_0/W from 0.45 to 0.70. This procedure leads to a discontinuity in the evaluated CTOD at $a_0/W = 0.45$. This problem results from the fact that the *J*-integral based CTOD is inconsistent with the conventional plastic hinge based CTOD, especially in low yield-to-tensile ratio materials. Thus, a single CTOD calculation method for the wide range of a_0/W is required for rational evaluation. In this study, the plastic deformation behavior of SEB specimens was analytically examined in the a_0/W range from 0.05 to 0.70, and the capacity of the plastic hinge based CTOD was discussed with the aim of establishing a unified CTOD calculation formula for SEB specimens with the wide range of a_0/W.

1. Introduction

On the basis of the CTOD concept proposed by Wells [1] in 1961, the British Standard Institution published in 1972 “Methods for crack opening displacement testing” [2] as a “Draft for Development 19,” or the so-called DD19. Since

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[1] Formerly.

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Nomenclature

a	crack length
a_0	initial crack length
B	specimen thickness
CTOD, δ	crack tip opening displacement
δ_{el}	elastic component of CTOD
δ_{pl}	plastic component of CTOD
$CTOD_{BS}$, δ_{BS}	CTOD in BS7448-1:1991
$CTOD_{JWES}$, δ_{JWES}	CTOD proposed by Japan Welding Engineering Society
$CTOD_{FEM}$, δ_{FEM}	CTOD numerically calculated from displacement between two ±45° intersection points from crack tip on crack opening profile
CMOD	crack mouth opening displacement
E	Young's modulus
f	correction factor for plastic component of $CTOD_{JWES}$
F	correction factor for thickness
J	J-integral
K	stress intensity factor
N	strain hardening exponent of Swift type stress-strain relation
P	load
r	rotational factor
rp	plastic rotational factor
R	inverse number of yield-to-tensile ratio, σ_{uts}/σ_{ys}
V_g	crack mouth opening displacement
V_p	plastic component of crack mouth opening displacement
W	specimen width
x, y	coordinates in same thickness plane
YR	yield-to-tensile ratio, σ_{ys}/σ_{uts}
z	height of knife edge
α	fitting parameter of Swift type stress-strain relation
γ	non-dimensional critical clip gage displacement
$\overline{\varepsilon_p}$	equivalent plastic strain
η	plastic eta factor for calculation of J
ν	Poisson's ratio
σ	stress
σ_{ys}	yield strength
σ_Y	effective yield strength, $(\sigma_{ys} + \sigma_{uts})/2$
σ_{uts}	ultimate tensile strength
$\overline{\sigma}$	equivalent stress

DD19, CTOD has been calculated by a hinge model of rotational deformation centered at a point in a ligament. Although the formulation in DD19 was supported by experimental measurements with various ratios of crack depth to specimen width (a_0/W), the a_0/W range from 0.45 to 0.55 had been a standardized measurement in BS5762 [3] established in 1979, in which CTOD is calculated by Eq. (1).

$$\delta_{BS} = \delta_{el} + \delta_{pl} = \frac{K^2}{2\sigma_{ys}E'} + \frac{r_p(W-a_0)}{r_p(W-a_0)+a_0+z}V_p \tag{1}$$

The same calculation by Eq. (1) was continued in BS7448 [4], which replaced BS5762 in 1991 with further modifications. CTOD calculated with a rotational hinge model has widely prevailed in the field of steel structures through the long history since DD19. The authors have already proposed the new crack tip opening displacement (CTOD) calculation formula shown in Eq. (2) based on the plastic hinge model considering the unique crack tip blunting behavior due to strain hardening of the material [5]. This formula is limited to the standard length-to-width ratio (a_0/W) range between 0.45 and 0.55.

$$\delta_{JWES} = \delta_{el} + \delta_{pl} = \frac{K^2}{m(YR)\sigma_Y E'} + f(YR,B)\frac{r_p(W-a)}{r_p(W-a)+a+z}V_p \tag{2}$$

$$m(YR) = 4.9 - 3.5YR$$
$$f(YR,B) = F(B)\cdot f(YR)_{@B=25}$$
$$F(B) = 0.8 + 0.2\{-0.019(B-25)\}$$
$$f(YR)_{@B=25} = -1.4(YR)^2 + 2.8(YR) - 0.35$$
$$r_p = 0.43$$

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