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Numerical prediction of ductile fracture resistance of welded joint zones

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Abstract

This study deals with the numerical prediction of ductile fracture initiation and development in welded joints of a high strength low alloyed steel. Having in mind the material heterogeneity in the joint zone, a combined experimental-numerical procedure is applied for determination of properties of the weld metal and heat affected zone - HAZ (both coarse-grained and fine-grained portion). Single smooth tensile specimen is tested, and the surface strains are determined during this test using stereometric measurement. Combined with numerical analysis, this enabled determination of stress-strain curves, which are subsequently used in numerical analysis of fracture of pre-cracked specimens. Two different geometries are considered: standard single-edge notched bend (SENB) specimens and surface-cracked tensile specimens. In each of them, the crack is positioned either in weld metal or between the coarse-grained and fine-grained HAZ. Micromechanical model (complete Gurson model, by Z.L. Zhang) is applied in numerical analysis. Higher resistance to ductile fracture initiation and crack growth in HAZ is successfully predicted, as well as constraint effect caused by different crack shapes.

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Keywords: welded joint; heat affected zone; ductile fracture; numerical analysis; micromechanical model

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1. Introduction

Ductile fracture is conventionally characterized by fracture mechanics parameters and crack growth resistance curves, obtained from the standard fracture mechanics tests. However, testing of different specimens often reveals considerable differences, due to the constraint effects, as shown by Schwalbe et al. (1997), Kocak (1998), Clausmeyer et al. (1991), Hacket et al. (1993), Kirk and Bakker (1995), Pluvinage et al. (2014). The constraint influences the fracture resistance even in macroscopically homogeneous structures (e.g. dependence on structure/crack geometry and loading type). It is a reason why fracture parameters (such as J integral, stress intensity factor, etc.) cannot always be successfully transferred from one geometry to another, for example from laboratory specimens to real machine or structure components.

In welded joints, the problem becomes more complex, having in mind the heterogeneity of the joint zones, in addition to the other constraints. The safety of welded structures in exploitation depends on integrity of their welded joints. Therefore, the fracture resistance of the joint is a very important factor for understanding the fracture and failure of such structures under different exploitation conditions, Kocak (1998), Ravi et al. (2004), Kozak et al. (2009), Chibber et al. (2011), Rakin et al. (2008), Younise et al. (2011), Rakin et al. (2013). In case the crack is located in the middle of weld metal (WM), the joint is often considered as bimaterial - consisting of base metal and weld metal. However, there are situations when it is very important to take into account the fracture behavior of heat affected zone (HAZ), Gubeljak (1999), Wilsius et al. (2006). Its toughness may influence the overall fracture behavior of a welded joint, if the initial defect is positioned in HAZ, or if the crack reaches this zone during the crack growth.

Nomenclature

a_0	initial crack length
Δa	crack length increment
f	current void volume fraction
f^*	modified void volume fraction (damage function)
f_0	initial void volume fraction
f_c	critical void volume fraction
f_u^*	ultimate void volume fraction
f_F	void volume fraction at final failure
f_N	volume fraction of void nucleating particles
f_v	volume fraction of non-metallic inclusions
J	J-integral
J_i	J-integral at crack initiation
$J_{0.2/BL}$	J-integral at 0.2 mm crack growth offset to the blunting line
n	strain hardening exponent
q_1, q_2	fitting parameters of the Gurson-Tvergaard-Needleman yield criterion
r	void space ratio
S_N	standard deviation in the Gaussian distribution of nucleation rate
Greek symbols	
α, β	parameters in CGM
ε_1, ε_2, ε_3	principal strains
ε_N	mean nucleating strain
ϕ	yield function of the Gurson-Tvergaard-Needleman model
Φ	position of the point along the front of the surface crack
λ	mean free path between non-metallic inclusions
σ_1	maximum principal stress
σ_m	mean stress
σ	current flow stress of the matrix material