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Estimation of failure strain of EH36 high strength marine structural steel using average stress triaxiality

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ABSTRACT

We describe the theoretical background of fracture phenomena in marine structural steels and provide a failure strain criterion for EH36, one of the most popular polar class steels, based on experimental and numerical investigations. Various fracture criteria are theoretically investigated including shear failure criteria such as constant/variable failure strain and forming limit diagram failure strain, porosity failure criterion, and damage failure criterion. Based on our theoretical evaluation, we suggest that stress triaxiality is a key index that can be used to determine fracture phenomena for ductile metals. A new criterion to predict ductile fracture is proposed based on tensile tests of notched specimens and numerical simulations for EH36 high strength marine structural steel. We prove that stress triaxiality is one of the important factors governing material failure. Instead of using local stress triaxiality, this paper introduces critical strain energy concept and corresponding average failure stress triaxiality. It is proved that EH36 high strength steel well obeys a failure strain curve with 100% critical energy in a limited average failure stress triaxiality zone from 0.5 to 1.0.

1. Introduction

The accidental limit state (ALS) in marine structures is usually classified as ship-to-ship or ship-to-platform collision, ship grounding, falling or swinging impact of handling objects, and explosion/fire of a leak gas cloud. However, it is difficult in practice to design marine structures, such as large vessels and

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Nomenclature

a	Radius of curvature at necked or notched section.
A	Material constant for rate of void nucleation.
A_d	Damaged area.
A_0	Initial (undamaged) area.
D	Damage.
$\dot{D}$	Rate of damage evolution.
D_c	Critical damage (damage to fracture).
d_1, d_2, d_3	Material constants of Johnson–Cook failure strain criterion.
e	Engineering strain.
E_d	Damaged elastic modulus.
E_f	Critical energy (energy to fracture).
E_0	Initial (undamaged) elastic modulus.
f	Porosity.
f^*	Effective porosity.
f_c	Critical porosity.
f_f	Failure porosity.
$\dot{f}_g$	Rate of void growth.
f_n	Porosity.
$\dot{f}_n$	Rate of void nucleation.
$f(\eta)$	Stress triaxiality function for CDM.
J_2	Second invariant of deviatoric stress tensor.
K	Strength coefficient.
m_1, m_2, m_3	Material constants of GTN yield potential.
n	Plastic hardening exponent.
p	Hydrostatic stress.
q	Von Mises equivalent stress.
R_a^2	Adjusted coefficient of multiple determination.
$r_{\varepsilon s}$	Strain ratio of ε_1 to ε_2.
S	Engineering stress.
s_{ij}	Deviatoric stress tensor.
s_n	Standard deviation of void nucleation strain distribution.
S_u	Engineering tensile stress.
S_0	Material constant for CDM.
R	Necking or notch radius of curvature.
t_f	Time to fracture.
α	Material constant for CDM.
δ	Element edge length.
δ_{ij}	Kronecker delta.
ε_f	Failure strain.
ε_{ij}	Cauchy strain tensor.
ε'_{ij}	Deviatoric strain tensor.
ε_m	Volumetric strain or hydrostatic strain.
ε_n	Mean of void nucleation strain distribution.
ε_p	Plastic strain.
$\varepsilon_{p,eq}$	Von Mises equivalent plastic strain.
$\varepsilon_{p,un}$	Uniform true plastic strain.