Experimental and Theoretical Investigations on the Fracture Criteria for Structural Steels

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ABSTRACT

In order to verify validity and applicability of GTN model, one of the popular micromechanics yield model, for fracture simulations, punch tests are carried out for round plate specimens machined from steel of JIS G3131 SPHC. Incremental tensile coupon tests are also conducted in order to obtain plastic mechanical properties of the material. Material constants required for GTN model are identified through parametric numerical simulations for coupon tests. It is confirmed that simulated punch force vs. indentation curves using GTN model with identified material constants show good agreement with punch test results. It is also verified that fractured shapes are almost similar with experimental ones where fracture occurs along the circumferential edge of indenter.

KEY WORDS: Punch test; Shear fracture model; GTN model; Hydrostatic stress; Fracture strain.

NOMENCLATURE

Φ	Yield potential
δ_{ij}	Kronecker delta
ε_{ij}^p	Plastic strain tensor
ε_n	Mean of strain distribution for void nucleation
ε_f^p	Fracture strain
σ_0	Initial yield stress
σ_{eq}	von Mises equivalent stress
σ_Y	Yield stress
σ_H	Hydrostatic stress
σ_u	Tensile strength
λ	Normalized relative sharpness
f	Void volume fraction
f_0	Initial void volume fraction
f_u	Ultimate void volume fraction
f_c	Critical void volume fraction
f_f	Void volume fraction at failure
f_n	Volume fraction of nucleated voids
$\dot{f}$	Total rate of void volume fraction
$\dot{f}_g$	Growth rate of void volume fraction
$\dot{f}_n$	Nucleation rate of void volume fraction
f^*	Effective void volume fraction
s_n	Standard deviation of strain distribution for void nucleation
q_1, q_2, q_3	Material constants
R_{strike}	Radius of curvature of striking structure
R_{struck}	Radius of curvature of struck structure
t	Thickness of plate

INTRODUCTION

It is essential to understand plasticity and fracture behaviors of structural steels for rational design and quantitative damage estimation against ALS(Accidental Limit State) such as ship-to-ship collisions, ship-to-rock groundings or explosions in FPSOs. Reminding that fracture is the final stage of irreversible plastic deformation process, strain hardening properties as well as initial yield stress are required for large strain problem accompanying fracture of material. However, zero or single slope plastic hardening provided from mill sheets is still frequently employed in many studies which have been focused on structural re-arrangements of bow, side or bottom structures to reduce damage extents.

Most of marine structural steels such as classification steels for ship structures or API steels for offshore structures are categorized into ductile material of which plastic deformation process up to fracture typically shows three micromechanical stages : nucleation, growth and coalescence of voids. Nucleation of voids usually implies debonding of inclusions or 2nd phase particles from continuum, called steel matrix. On the other hand, growth and coalescence of voids means enlargements of nucleated voids and weakening of ligaments between enlarged voids, respectively. It is known that hydrostatic stress among Cauchy's stress tensors governs the first two stages and deviatoric stress coalescence stage. Observing stress state at the structural locations with high geometric discontinuities like crack tips or notches,