Marine Structures 46 (2016) 102–126

Contents lists available at ScienceDirect

Marine Structures

journal homepage: www.elsevier.com/locate/marstruc

Analysis of fatigue failure mode transition in load-carrying fillet-welded connections

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ARTICLE INFO

Article history:
Received 2 February 2015
Received in revised form 15 December 2015
Accepted 23 January 2016
Available online 11 February 2016

Keywords:
Load-carrying fillet welds
Traction stresses
Finite element
Weld root cracking
Weld toe cracking
Fatigue failure

ABSTRACT

In load-carrying fillet welded connections, two distinct fatigue failure modes are possible depending upon fillet weld leg size and loading conditions. One is weld toe cracking through base plate thickness and the other is through weld metal, often referred to as weld root cracking. Based on a recent comprehensive fatigue testing program in support of construction of lightweight ship structures, this paper examines a number of stress based fatigue parameters that can be used to formulate an effective criterion for determining failure mode transition from weld root to weld toe. A closed form solution has been developed for analytically determining the weld throat critical plane on which a traction stress based fatigue parameter attains its maximum and can be compared with that corresponding to weld toe cracking. It is found that both an effective weld throat stress based criterion by combining normal and shear traction stresses and an equivalent effective stress based criterion based on the master S-N curve formulation can be used for the determination of the minimum fillet weld leg size beyond which weld toe fatigue failure dominates. The proposed fillet weld sizing criteria are then validated using a large amount of fatigue test data on load-carrying cruciform fillet welded specimens.

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http://dx.doi.org/10.1016/j.marstruc.2016.01.001

Nomenclature

a_θ	weld throat size along a hypothetical cut angle
f	fatigue life scaling factor
$f_{x'}$	line force in x' direction
$f_{y'}$	line force in y' direction
$f_{z'}$	line force in z' direction
$m_{z'}$	line moment about z'
$m_{y'}$	line moment about y'
$f_{\theta y'}$	line force in y' direction at a hypothetical cut angle
$f_{\theta x'}$	line force in x' direction at a hypothetical cut angle
$m_{\theta z'}$	line moment about z' at a hypothetical cut angle
p	weld penetration
r	bending ratio
r^A	bending ratio corresponding to weld toe failure
r^B	bending ratio corresponding to weld root failure
s	fillet weld size (weld leg length)
t	thickness of intercostal plate
t_e	effective crack path length
t_e^A	crack path length corresponding to weld toe failure
t_e^B	crack path length corresponding to weld root failure
x_i'	local coordination of node i
$F_{x'i}$, $F_{y'i}$	nodal forces at node i in local coordinate system
T	thickness of continuous plate
$I(r)$	dimensionless life integral as a function of bending ratio r
σ_N	total normal traction stress
σ_m	membrane component of normal traction stress
σ_b	bending component of normal traction stress
$\sigma_N(\theta)$	analytical expression of total normal traction stress
$\sigma_m(\theta)$	analytical expression of membrane component of normal traction stress
$\sigma_b(\theta)$	analytical expression of bending component of normal traction stress
$\sigma_e(\theta)$	analytical expression of effective traction stress
$\Delta\sigma_e$	effective traction stress range
$\Delta\sigma_b$	bending component of normal traction stress range
$\Delta\sigma_m$	membrane component of normal traction stress range
$\Delta\sigma_e^A$	effective traction stress range corresponding to weld toe failure
$\Delta\sigma_e^B$	effective traction stress range corresponding to weld throat failure
ΔS_s	equivalent traction stress range
ΔS_s^A	equivalent stress range corresponding to weld toe failure
ΔS_s^B	equivalent stress range corresponding to weld root failure
ΔS_n	nominal stress
τ_T	transverse shear traction stress
τ_L	longitudinal shear traction stress
τ_m	membrane component of transverse shear traction stress
τ_{Lm}	membrane component of longitudinal shear traction stress
τ_{Lb}	bending component of longitudinal shear traction stress
$\tau_T(\theta)$	analytical expression of transverse shear traction stress
θ	angle between a hypothetical cut and horizontal weld leg plane
θ_c	critical failure angle