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Fracture mechanics-based design and reliability assessment of fillet welded cylindrical joints under tension and torsion loading

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ABSTRACT

Cylindrical fillet-welded joints under tensile and torsion loads are analyzed to investigate the sensitivities of weld geometry-related parameters, such as size of lack of penetration, weld shape and weld root radius, on the fracture response of the joint. SIFs decrease with decreasing lack of penetration size and that having a convex weld shape yields better fracture response. The longer the penetration edge on the shaft the better the fracture response. Weld root radius does not have significant effect on the fracture response of LOP crack. Lower convexity radius resulted in lower mode-I and mode-III SIFs due to more material around the crack tip region in the fillet weld throat.

1. Introduction

Welded joints are widely used in engineering applications to connect structural elements with different sizes and geometries and to transmit loads from one structural member to another. The mechanical strength of a welded joint is extremely important for the integrity of the structure in which the joint exists [1–4]. Although the quality of the welding has improved over the past decades, welding discontinuities are still unavoidable [5]. There are many factors affecting the mechanical strength of a welded joint, such as weld quality, cleanliness of the part surfaces before welding and thermal control of the environment before and after welding, geometrical discontinuities such as weld toe radius, weld root and lack of penetration (LOP). These factors directly affect the strength of the weld and its immediate vicinity. They make these regions the points from which fatigue cracks may initiate [5,6]. These geometrical discontinuities formed on the welded joint tend to intensify the local stress field and hence reduce the load carrying capacity, which consequently represent an important limitation to the safety and reliability of welded structures [4].

Fatigue failure is probably the most common type of failure in welded constructions. Weld geometry is one of the primary factors that control the fatigue life. Fatigue cracking can occur in welded joints evolving from severe imperfections, which are actually an inherent part of the joint [7]. Fracture mechanics can be used to characterize the fatigue crack growth behavior of welded joints. The improvement of fatigue life by means of weld geometry control can be obtained by reducing stress concentration at welds since geometric weld parameters have direct influence on the stress intensity factor of an existing inherent crack in the welded joint. To calculate the fatigue life of welded structures and to analyze the progress of these cracks using fracture mechanics require accurate calculation of the stress intensity factor, SIF [8]. For example, in the case

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Nomenclature

a	radius of crack underneath the thinner shaft
a/r	non-dimensional lack of penetration size
$2a$	effective crack length/diameter
E	modulus of elasticity
FEA	finite element analysis
FEM	finite element method
h	height of the base fillet weld leg
h/r	non-dimensional weld height
L	length of the thicker cylindrical shaft
L/r	non-dimensional length of thicker shaft
LEFM	linear elastic fracture mechanics
LOP	lack of penetration
r	radius of the thinner cylindrical shaft
r_0	radius of the thicker cylindrical shaft
r_0/r	non-dimensional diameter of the thicker shaft
SIF	stress intensity factor
w	width of the base fillet weld leg
w/r	non-dimensional weld width
ρ	concavity/convexity radius of the fillet weld
ρ_0	concavity radius of fillet weld leg edges
ρ/r	non-dimensional concavity/convexity radius of the fillet weld
σ_0	nominal normal stress
τ_0	nominal shear stress
v	poisson's ratio

of fillet welds, there is a surface of limited-size between the welded parts, which is called "lack of penetration". Because, the parts are brought together back-to-back before welding and they are welded from the joint corners on which the weld material forms a fillet. Thus, the surface underneath the thinner welded member is not connected to the other member (Fig. 1). The lack of connection, i.e., penetration of the weld, over this surface, essentially, acts as a crack of size equal to the thickness of the thinner member (Fig. 1a). On the other hand, if there is a diagonal cut on the side corners of the thinner member, the region of lack of penetration (LOP) and, therefore, the resulting crack size gets smaller (Fig. 1b). Hence, thoroughly

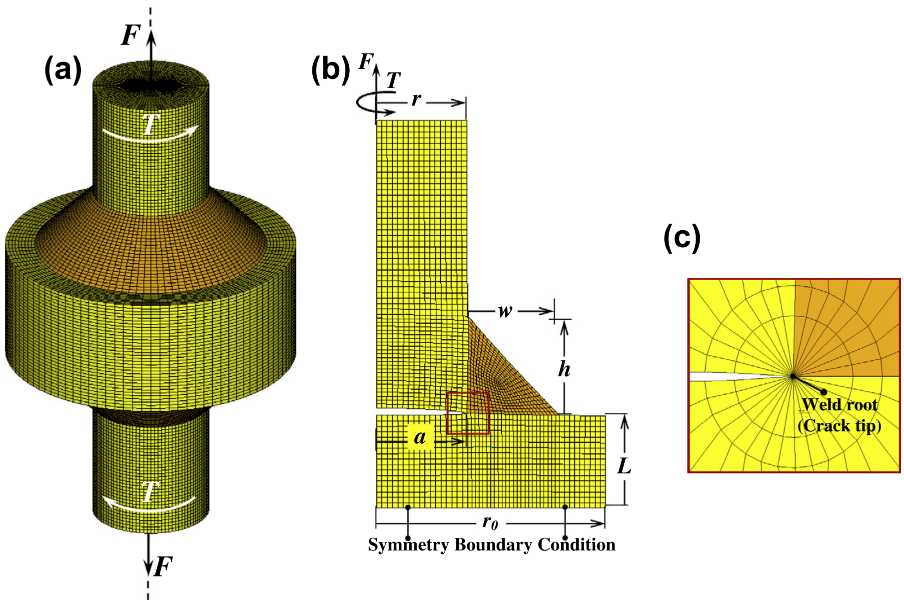

Fig. 1. Fillet-welded cylindrical shafts: (a) structures are under axial and torsional loads, (b) parametric representation and quarter part of the axisymmetric finite element model and (c) crack tip of the lack of penetration.