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Fracture assessment of damaged square hollow section (SHS) K-joint using BS7910:2005

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ABSTRACT

A pre-cracked square hollow section K-joint was tested under static loads up to failure. It is found that the load–displacement curves are in good agreement with the finite element results. Ductile tearing was observed to initiate from the crack front parallel to the chord side wall where fracture toughness is smaller. Using plastic collapse load obtained via twice elastic compliance technique and fracture toughness obtained from crack tip opening displacement, the two fracture parameters K_r and L_r are plotted on the standard failure assessment diagram. It shows a conservative assessment for the cracked K-joint subjected to brace end axial loads.

1. Introduction

In practice, the safety and integrity of a welded structure relies heavily on periodic non-destructive inspection carried out to detect crack before it develops to a critical size. This vital piece of information is then used to decide whether a structural repair or a structural replacement should be carried out before catastrophic failure is likely to occur. In order to determine the critical crack size, the structure should be assessed according to the knowledge of the service stresses and the knowledge of the fracture properties of the material.

API 579-1/ASME FFS-1 [1], BS7910 [2] and CEGB R6 procedure [3] give a quantitative engineering assessment to determine the acceptability of defects found in welded structures. Essentially, this approach is based on the failure assessment diagram (FAD) method, originally derived from the original two-criterion approach [4]. This approach states that a structure can fail by either of two mechanisms, brittle fracture or plastic collapse, and that these two mechanisms are connected by an interpolation curve based on the strip yield model [5]. If the service (assessment) point falls within the assessment curve, the structure is still safe, otherwise, the structure is considered unsafe. The usage of the FAD for assessment showing the loading path of a flawed structure is illustrated in Fig. 1. This method enables an engineer to go directly from linear elastic fracture mechanics (LEFM) calculations to plastic instability calculations [6].

In the BS7910 [2], different assessment curves are presented for different materials and geometries. In the codes of practice, lower bound curves are used to assess all types of structures. They are intended for general applications and do not always give a save solution for all types of structures including cracked welded rectangular hollow section (RHS) and circular hollow section (CHS) tubular joints. Therefore, the standard curves should be applied with care, and they should be validated before they are used to assess the integrity of any cracked tubular joint.

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Nomenclature

a	crack depth of surface crack
b_0	chord width
b_1	brace width
d_1, d_2	displacements at LVDT points 1 and 2
d_{IC}	inclined crack depth
C_V	Charpy V-notch impact energy (in Joules)
E	Young's modulus
h	vertical distance of LVDT 3
h_0	chord height, original vertical distance
h_1	brace height
J_e	value of J determined using an elastic analysis
J_{ep}	value of J determined using an elastic-plastic analysis
K_I	Mode-I stress intensity factor
K_{IC}	material toughness measured by stress intensity factor
K_r	fracture ratio of the applied elastic K_I value to K_{IC}
L	distance at LVDT point 3
l_{c1}	crack length along the longitudinal direction
l_{c2}	crack length along the transverse direction
l'	horizontal displacement
L_1, L_2, L_3	distances from LVDTs 1,2,3
L_r	ratio of applied load P to plastic collapse load P_u
P	total applied load
P_u	plastic collapse load
t	brace thickness
T	chord thickness
t_w	weld leg length
γ	rotational angle
ε_{ref}	reference strain
δ_{CTOD}	crack tip opening displacement
δ_C	critical crack tip opening displacement
δ'	crack rotation
θ	inclined angle of the crack
σ^P	stress arising from applied load
σ_{ref}	reference stress
σ_y	yield stress of the material
ρ	plastic correction factor

Because of the complexity of square hollow section (SHS) tubular joint geometries, especially at the hot spot stress location where the crack is located, the chord wall is in a state of combined bending and tension. Therefore, the crack tip material behaves in a mixed-mode of tension and shear, resulting in the crack growing in a non-planar surface, i.e. growing along a doubly curved surface. The behaviour of cracked tubular joints subjected to axial (AX), in-plane bending (IPB) and out-of-plane loading (OPB) are very complex indeed, and fracture mechanics has been used with limited success by many researchers for the past decades [7]. There are also uncertainties with respect to the fracture parameters; both experimental and numerical studies are very time-consuming and expensive.

In this paper, a full-scale pre-cracked square hollow section (SHS) K-joint subjected to brace end axial loads were tested up to failure; and a previous modelling technique is used again; and finally a finite element mesh of the cracked model is generated automatically. Based on this numerical model, the plastic collapse loads of the cracked SHS K-joint are calculated, and the stress intensity factors (SIFs) are analyzed along the crack front. The fracture toughness of the material was obtained using the standard Charpy V-notch impact and Crack Tip Opening Displacement (CTOD) tests. Based on these test results, the values of K_r and L_r are calculated, and the integrity and safety of the cracked SHS K-joint specimen is then assessed according to the BS7910 [2] Level 2A procedure.

2. Failure assessment diagrams (FADs)

According to BS7910 [2] and CEGB R6 procedure [3], any cracked structure can be assessed using the normal assessment route. The standard FAD curve has two curves, namely Level 2A and 2B as shown in Fig. 1 respectively. The Level 2A and 2B curves can be described respectively by the following equations: