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Original Research Article

Investigation on fatigue behaviour of load-carrying fillet welded joints based on mix-mode crack propagation analysis

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ABSTRACT

The fatigue behaviour of the load-carrying fillet welded joints was investigated by experimental and numerical approach in this paper. 26 load-carrying cruciform fillet welded joints involving 8 stress levels were tested and the S–*N* curves of 95% survival probability in terms of toe failure and root failure were established separately. The test results also demonstrate that the design curves of Eurocode3 are not suitable for this batch of specimens. In the following numerical simulations, three types of initial crack assumption were analysed by 3D mix-mode fatigue crack propagation analysis according to experimental observation. All the possible crack growth routes were simulated well. However, the single crack assumptions cannot form satisfactory simulations on fatigue lives with enough safety stock. Therefore, multi-crack analysis was conducted based on the combined data in terms of both toe failure and root failure. It is found that multi-crack analysis with 0.5 mm weld toe initial line crack and 0.1 mm weld root initial line crack can provide appropriate prediction. The findings can be beneficial for the fatigue assessment of load-carrying fillet welded joints fabricated by the normal welding technique in China and offer some references for the fatigue assessment of structural details with different possible failure modes.

1. Introduction

Load-carrying fillet welded joint (LCFWJ) is one of the most typical fatigue prone structural details. Many efforts have been made to investigate its fatigue behaviour [1]. The most direct approach is the experimental observations and extensive fatigue tests on LCFWJ have been conducted [2,3]. On the basis of the numerous test data, reliable S–*N* curves were established and adopted in many design codes, such as BS5400 [4], Eurocode3 [5] and AASHTO [6]. Meanwhile, more and more refined fatigue assessment approaches have been developed,

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which can be classified into two types. One is the 'stress-life' approach, including the hot spot stress (HSS) approach [7,8] and effective notch stress approach [9,10], the other one is the Fracture Mechanics based approach [11,12]. All the 'stress-life' approaches depend on appropriate design curves, which can only be established by fatigue tests. For structural details made by new materials, new welding techniques or even new weld shapes, the applicability of the existing design curves is limited and fatigue tests have to be conducted in most cases, which are quite time and money consuming. From the view of Fracture Mechanics, fatigue failure is the process of the fatigue crack initiation and propagation. Due to the inevitable defects in fillet welds, the propagation life can be regarded as the total fatigue life. This approach only requires appropriate fatigue crack growth model of the corresponding materials [13,14], which costs much less than the fatigue tests on different types of structural details. Many researches based on Fracture Mechanics have been conducted on the LCFWJ [15]. Nevertheless, the existing work was mainly carried out on the basis of planar model and mode I type crack assumption, which has relevant analytical solutions for stress intensity factor (SIF) of the crack front. However, fatigue cracks in practical structures usually belong to mix-mode cracks due to the complexity of loading and local geometry. Even the initial cracks belongs to mode I type, they will probably become mix-mode cracks after a period of propagation. Therefore, the mix-mode crack propagation analysis is of great importance to reveal the more actual fatigue behaviour of key structural details.

In this paper, the fatigue behaviour of LCFWJ was investigated based on both fatigue tests and 3D mix-mode fatigue crack propagation analysis. The experimental *S–N* curve of 95% survival probability was established, which can replenish the public fatigue database in China. Three initial crack assumptions were analysed and the corresponding fatigue performance was discussed in details. According to the comparison between the predicted and the experimental fatigue lives, the most suitable initial crack assumption was recommended for LCFWJ in terms of the steel materials and the normal welding technique in China.

2. Experimental investigation

2.1. Specimen preparation

Cruciform specimens of LCFWJ were adopted in the fatigue test. Fig. 1 shows the geometric scheme of the specimens. The fillet weld foot was designed to be 8 mm. The steel plates were welded by MCAW with 240 ± 20 A welding current and 30 ± 2 V welding voltage. Two panels were fabricated in ZiJingGuan Bridge Plant, which is a typical bridge construction company and could represent the mean level of bridge construction technique in China. Each panel was cut up into 13 specimens by mechanical processing, each 50 mm wide. All the steel plates belong to Q345qD grade, which are in the exactly same batch with that in Ref. [14] for fatigue crack growth rate tests. Therefore, the coupon test result and fatigue crack growth rate test data in [14] can be applied in the following numerical analysis of this paper.

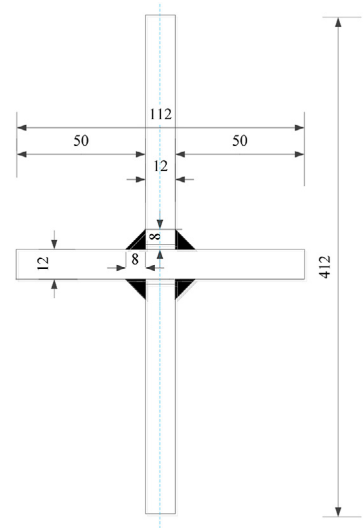

Fig. 1 – Geometric scheme of test specimens.

2.2. Experimental programme

Constant amplitude fatigue tests were implemented by PLG-200C fatigue test machine of ±10 t loading capacity. The loading frequency depends on the stiffness of the specimens. It would decrease if the stiffness of the specimen decreases, which represents certain extent fatigue damage occurred in the specimen. The maximum fatigue life was settled as 5 million cycles. The test would stop when the loading frequency had a 10 Hz drop or the loading cycles reached up to 5 million cycles.

The stress ratio for the test was 0.1. According to Eurocode3 [5], the cruciform joints with fillet welds are classified as FAT63 and FAT36 with respect to weld toe failure and weld root failure, respectively. The nominal stress range for weld toe is just the stress range in the vertical plate, $\Delta\sigma$, as shown in Fig. 2. The nominal stress range for weld root failure is the stress range in the fillet welds and the related calculation approach is specified in Eurocode3. The minimum $\Delta\sigma$ was determined to be 54 MPa (the corresponding nominal stress range at the weld root is about 48 MPa), which is between FAT63 and FAT36. The maximum tensile stress kept increasing at a 10 MPa interval in the following tests until eight stress levels were involved in the whole test. Therefore, the maximum stress was taken from 60 MPa to 130 MPa. The loading cases were numbered by NFW1 to NFW8, accordingly. The geometric profile of the specimens would be measured as shown in Fig. 2, which can provide modelling data for the following numerical simulation.

3. Experimental observations

3.1. Geometric measurement

To obtain the accurate geometric profile of the joints, the thickness of the main plates was measured in the first step. The average value of t_1 and t_2 is 11.85 mm and 11.83 mm, respectively. Based on the thickness of the steel plates, the