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Fracture from Fatigue Cracks Installed at Weld Toes of Plate to Plate T-joints

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ABSTRACT

This paper concerns the assessment of the effects of weld defects on crack growth and fracture behavior of welded T-joints. Each welded T-joint specimen was composed of a main plate and a rib plate. These specimens were installed with fatigue cracks at the weld toes. Two different loading methods were adopted to test T-joints. Welded T-joints showed large-scale yielding around the weld defect, and sustained brittle fracture and/or ductile tear after showing significant ductile crack growth. Test and numerical results were evaluated on the basis of the failure assessment diagram (FAD) according to BSI PD 6493.

INTRODUCTION

Tubular joints are subjected to severe stress concentrations at points along the weld toes. The gap region of a tubular K-joint is typical of such examples. Ductile cracks are frequently observed along the weld toes during laboratory testing. A few K-joints sustained a premature failure due to an unstable extension of these ductile cracks (Kurobane et al., 1997a). Although Cheaitani et al. (1994) studied tubular K-joints with machined through-thickness cracks in the gap regions, the K-joints failed as soon as surface cracks along the weld toes grew to through-thickness cracks according to the past tests. Thus, Cheaitani's models are not necessarily reflecting the actual behavior of K-joints observed during testing. Brittle fracture may start from the tips of the ductile cracks. However, no laboratory evidence exists that tubular K-joints failed by brittle fracture, presumably because plate thicknesses of specimens tested in the past were not large enough to provoke brittle fracture.

During the 1994 Northridge and 1995 Kobe Earthquakes, however, many of the welded connections of modern steel building frames sustained brittle fractures. Some started from the toes of groove welds at the beam ends. Post-earthquake investigation (AIJ Kinki, 1997) revealed that brittle fracture could have started from the tips of ductile cracks or from weld defects due to slag inclusions at the weld toes or to incomplete fusion.

The crack growth from weld toes and its change to brittle failure are the subject of this study (Kurobane et al., 1997b). Welded T-joint configuration was selected because it had the simplest possible form and yet was considered to reproduce brittle fracture as observed during the earthquakes. Namely, each specimen had a main plate, with a rib plate groove welded at its center. Fatigue cracks were installed along the weld toes to simulate weld defects. Details of specimens are shown below. Tensile loads were applied to the ends of the main plate as well as to the rib plate. Ductile cracks extended stably in the through-thickness direction. Finally, these specimens failed by ductile tear or brittle fracture.

Test results for cracked T-joints are evaluated on the basis of the failure assessment diagram (FAD) according to BSI PD 6493 (1991). Several crude assumptions have to be introduced to apply the FAD to welded T-joints. Specimens are simulated numerically using nonlinear FE analysis. Failure assessment is also conducted on numerical models.

TESTING OF WELDED T-JOINTS UNDER 2 LOADING METHODS

Loading Procedures

Fig. 1 shows 2 different loading methods. The loading sequences are as follows:

Loading Method I. Step 1: A tensile load P_0 was applied up to a predetermined percentage a of the axial tensile strength of the main plate, i.e. $P_0 = \alpha \cdot B \cdot t \cdot \sigma_u$, in which B, t and σ_u denote the breadth, thickness and tensile strength of the main plate, respectively. The cross-section of the main plate reached the plastic region under P_0.

Step 2: While P_0 was kept at a constant load, a horizontal load was applied to the rib plate until complete failure, as shown in Fig. 1a.

Loading Method II. A horizontal load was applied to the rib plate until complete failure, while both ends of the main plate were fixed to a strong reaction frame (Fig. 1b).

The horizontal static load was applied to the rib plate by a 1000–kN hydraulic ram. The horizontal load H versus deflection data were converted to H–$\sin\theta$ data to compare the rotation of the main plate because span l_0 in Fig. 1a, b was different between the 2 test setups.

Specimens

Eleven specimens were tested under Method I loading. Each specimen was composed of a main plate and a rib plate. The main plates, in grade SS400 steel, were either 22 mm or 26 mm thick, 80 mm wide and 880 mm long as shown in Fig. 2a. Five speci-

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KEY WORDS: Welded T-joints, fatigue crack, ductile tear, brittle fracture, J-integral, failure assessment diagram.