FRACTURE BEHAVIOUR OF A WELDED TUBULAR JOINT - Call for Interest: "Round Robin on Failure Assessment Methods"

U. Zerbst, J. Heerens and K.-H. Schwalbe*

Experimental work was carried out to determine the fracture behaviour of welded tubular T-joints made of a high strength TMCP-steel. Besides the load parameters needed for a fracture save design the crack profiles along the crack front were determined for the T-joints as well as for small SENB-specimens at different applied loads. This enables a direct information on the crack driving force. The aim of this work is an evaluation of various analytical failure assessment methods by carefully controlled experiments on a typical component.

INTRODUCTION

Welded tubular joints are widely used design elements in engineering structures and components. As shown in many practical cases those joints carry the potential risk that surface cracks may nucleate and propagate in the highly stressed regime near the weld. These surface cracks can severely influence the load carrying capacity of the joint. Reliable failure assessment methods are needed in order to quantify the risk caused by the flaw.

To address this problem, the fracture behaviour of welded tubular T-joints made from a high strength TMCP-steel is currently under investigation at GKSS.

* Institute of Materials Research,
Forschungszentrum Geesthacht GmbH, Geesthacht, Germany

THE TUBULAR T-JOINTS

The geometry and the dimensions of the T-joints are presented in Figure 1. The tubes carry surface cracks near their saddle points. They are loaded in tension. The starter notch for the cracks was introduced in the saddle region of the joint with a distance of 2 mm from the weld. The angle between the notch plane and the loading direction was chosen as 66° to ensure a straight extension of the fatigue crack. The dimensions of the final crack were: length at surface ≈ 45 mm, depth ≈ 10 mm.

EXPERIMENTAL DATA

Material data

The material. The steel used in this investigation was a cold deformed 450 YS TMCP steel. After manufacturing the T-joints and the plates for test specimens were subjected to a post weld heat treatment. To simulate the different properties across the wall thickness which originate from the bending of the plates during the manufacturing process some of the plates for the test specimens were cold deformed.

Engineering stress strain curves. Figure 2 shows the influence of a 5% cold deformation on the stress-strain-curve. In the T-joint the condition of 5% cold deformation corresponds to the outer surface of the chord wall whereas no cold deformation corresponds to the centre line of the cord wall. Near and beyond the maximum of the stress-strain-curve an anisotropic deformation of the tensile specimens was observed and quantified.

Fracture resistance. The fracture resistance was determined following a fitness for purpose philosophy. From the plates SENB-specimens were machined with L-S notch orientation (in terms of ASTM E 616-82 (1)). So the crack orientation of the specimens was in accordance with the crack orientation in the T-joints.

A multiple specimen R-curve was obtained using different fracture parameters such as the J-integral and the CTOD based on different testing standards. Additionally a sectioning technique was applied to obtain the crack tip profile at the centre line of the SENB-specimen. The crack tip opening displacement in this case was defined as the crack opening at the initial crack tip after fatigue. An illustration is given below (Figure 6). The stable crack growth was determined on the fracture surfaces using a scanning electron microscope.

Applied side data

Strain concentration at the hot spot. At different loading steps in the elastic range local strains were measured by strain gages in the hot spot region. The measurements were carried out on two T-joints to get an impression on the influence of the scatter between the individual weldments. An example is shown in Figure 3. The data allow the determination of a stress concentration factor.

Residual stresses*. The residual stresses were determined at different points at the surface by a hole drilling method. The results are shown in Figure 4. The drop of the tensile residual stresses at the surface line (Figure 4a) is a consequence of the specimen preparation (grinding). So the plateau value beyond ca. 0.3 mm in depth is taken as the maximum value at surface. This value is shown as a function of different locations with regard to the subsequent surface crack in Figure 4b.

Load-v_{LL}-curves. Figure 5 shows the load-load line displacement (v_{LL})-curve of a specific T-joint. In addition, CMOD was also measured with a δ_5-clip. The T-joints were loaded to different amounts of deformation to permit the determination of a multiple specimen R-curve. The results shown were derived at room temperature. Within the frame of the present project it is also planned to generate a data set in the ductile-to-brittle transition regime.

*This investigations were carried out at the MPA Stuttgart with the help of Mr. Schwarz and Dr. Kockelmann.

Crack tip profiles. The crack tip profiles were determined by the sectioning technique. After the test a piece of material containing the surface crack was removed from the T-joint. It was divided into two parts. One part was used for the measurement of the amount of stable crack growth. The second part was divided into a number of pieces. From each of them a crack profile was determined which is in accordance with different positions at the crack front. From the crack profiles a CTOD was derived as described above. Figure 6 shows a comparison of the R-curves of the SENB-specimens and the T-joints whereby the preparation of the SENB-R-curve followed the ESIS test procedure P1-92 (2). The coincidence of the two curves may be surprising but it might be explained by the fact that the local loading conditions (same ligament depth, large bending components) in both cases are similar.

THE AIM: VALIDATING FAILURE ASSESSMENT METHODS

The data obtained on the T-joints are well suited for validating failure assessment methods. We are therefore inviting experts who wish to validate specific engineering assessment methods by means of an experimental data set to participate in a round robin activity; finite element analysis will also be welcome. Those interested will receive an information package from the authors upon request. We are planning to hold a workshop in 1995 for discussing the results.

REFERENCES

(1) ASTM E 616-82: Standard Terminology Relating to Fracture Testing, ASTM, 1982

(2) ESIS P1-92, ESIS Recommendations for Determining the Fracture Resistance of Ductile Materials

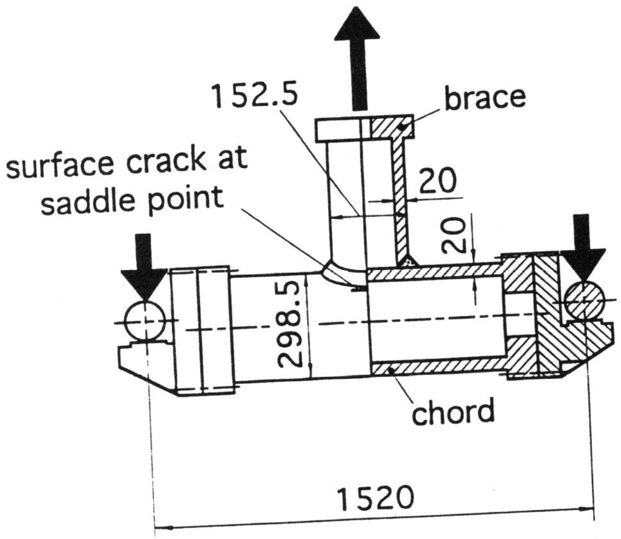

Figure 1 Geometry and dimensions of the tubular joint model specimens, dimensions in mm

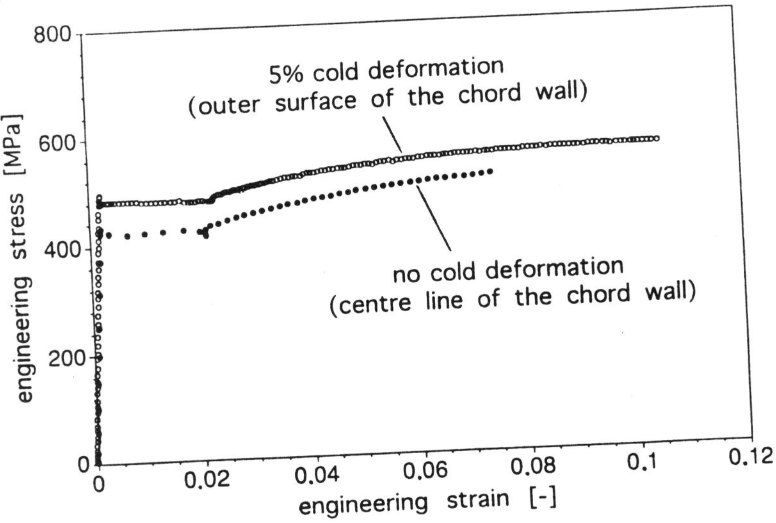

Figure 2 Engineering stress-strain-curves of the TMCP steel

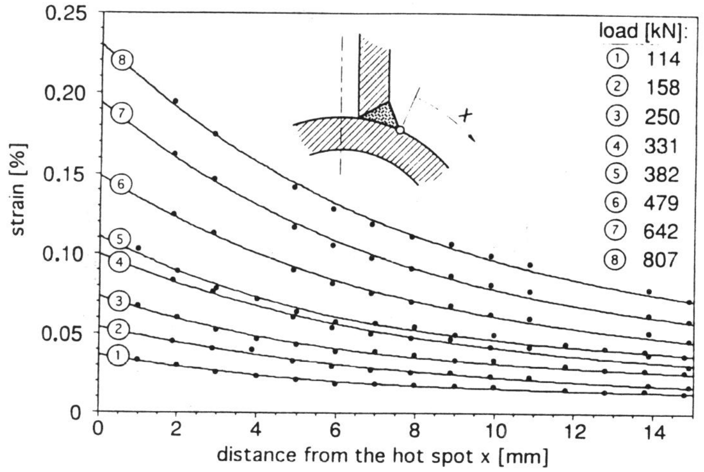

Figure 3 Local strains at different loads and positions near the saddle point of the T-joint

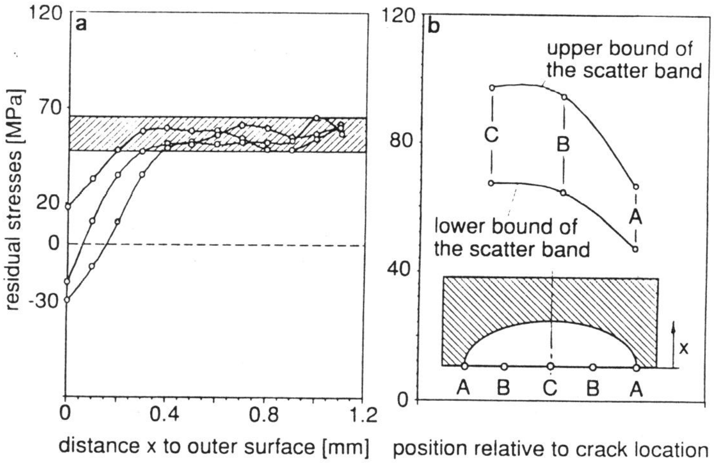

Figure 4 Residual stress measurements near the weld; a) Example; b) Maximum values at different positions

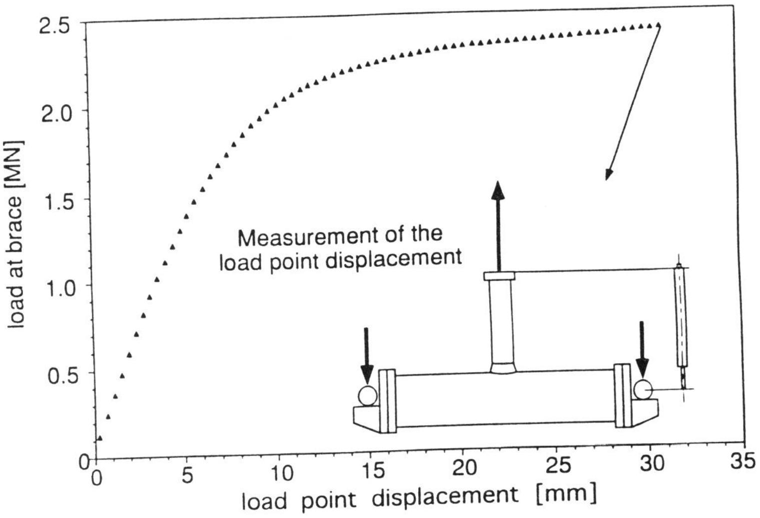

Figure 5 Load-v_{LL}-record of a T-joint

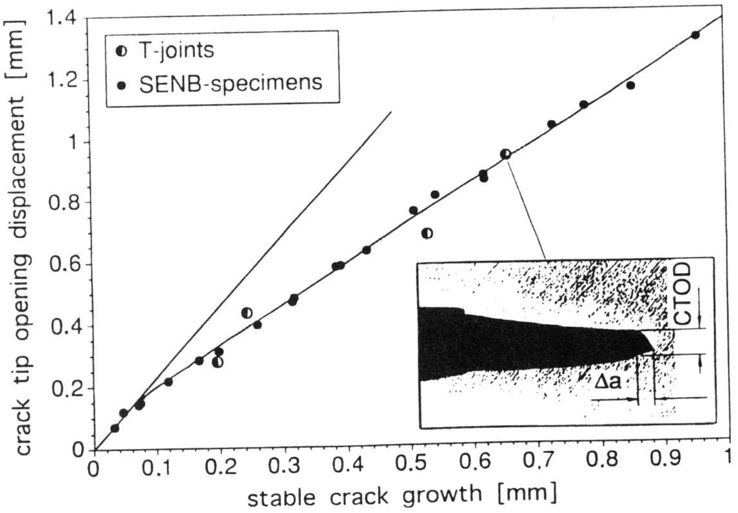

Figure 6 Comparison of the R-curves of the SENB specimens and the T-joints