Journal of Energy Technology

JET Volume 6 (2013), p.p. 11 - 16

Issue 2, May 2013

http://www.fe.um.si/en/jet.html

FRACTOGRAFIC EXAMINATION OF WELDS WITH STRENGTH MISMATCHING

FRAKTOGRAFSKA RAZISKAVA TRDNOSTNO NEENAKIH ZVAROV

Zdravko Praunseis[ℜ], Jurij Avsec, Simon Marčič

Keywords: fractografic examination, welds, strength mismatching

Abstract

Many investigations of cleavage fracture have shown that the normal stresses in welds with strength mismatching have good correlation with the cleavage fracture behaviour of materials. The objective of this investigation was to find evidence for the microstructural mechanisms leading to cleavage fracture. Examinations of the centre of the macroscopic river patterns at high magnifications revealed fine river patterns. These river patterns could be traced to a single area containing one to a few cleavage facets. These areas are referred to as initiation sites of welds with strength mismatching.

Povzetek

Mnogo raziskav cepilnega krhkega loma je pokazalo, da so normalne napetosti v trdnostno neenakih zvarih v dobri korelaciji z lomnim obnašanjem krhkih cepilnih materialov. Namen raziskave je najti tiste mikrostrukturne mehanizme, ki vodijo do cepilnega krhkega loma. Raziskave centra makroskopskih rečnih strug pokažejo pri večjih povečavah drobno razvejanost rečnih strugic. Te rečne strugice lahko zajemajo eno ali več cepilnih faset in predstavljajo iniciacijske točke krhkega loma trdnostno neenakih zvarov.

ℜ Corresponding author: Zdravko Praunseis, PhD, Faculty of Energy Technology, University of Maribor, Tel.: +386 31 743 753, Fax: +386 7 620 2222, Mailing address: Hočevarjev trg 1, SI-8270 Krško, Slovenia, E-mail address: zdravko.praunseis@uni-mb.si

----

1 INTRODUCTION

The development of the microstructure in the weld metal and especially in the heat-affected zone (HAZ) of multi-pass joints is strongly influenced by the welding thermal cycle and base material properties. Metallographically examined microstructures in under-matched joints with homogeneous and heterogeneous welds were, in particular, expected to have extremely low fracture toughness. Therefore, microstructures developed in weld metal and the HAZ of a multi-pass under-matched joint with homogeneous and heterogeneous weld metals were analysed using optical microscopy.

High strength low-alloyed (HSLA) steels are often used as new materials for the construction of multi-pass welded joints. The welding of HSLA steels to produce under-matched weld joints is a technological challenge for the current production of welded structures.

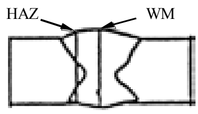
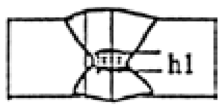
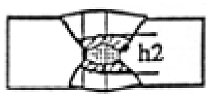
Therefore, the aim of this paper is to analyse the fracture behaviour of HSLA under-matched welded joints, and to determine the brittle fracture initiation points and crack path deviation in testing specimens, [1].

2 EXPERIMENTAL PROCEDURE

The fracture toughness of homogeneous and heterogeneous under-matched weld joints was evaluated using a standard static Crack Tip Opening Displacement (CTOD) test at the Geesthacht Research Center [5]. All CTOD tests were conducted using Zwick (20t) and Schenk (100t) testing machines. Specimen loading was carried out with constant crosshead speed v = 0.5 mm/min. The test temperature was -10 °C according to the recommendation of the OMAE (Offshore Mechanics and Artic Engineering) association. For CTOD testing, the single specimen method was used. To evaluate the fracture toughness of under-matched welded joints, standard bending specimens, [2-4] with deep (a/W = 0.5) and shallow (a/W = 0.25 - 0.4) notches in the weld metal and HAZ were used, [1]. For all specimens, fatigue pre-cracking was carried out with the Step-Wise High R ratio method (SHR) procedure, [5]. During the CTOD tests the potential drop technique was used for monitoring stable crack growth, [1]. The load line displacement (LLD) was also measured with a reference bar to minimize the effects of possible indentations of the rollers. The CTOD values were calculated in accordance with BS 5762, [2], and also directly measured using a clip gauge on the specimen side surfaces at the fatigue crack tip over a gauge length of 5 mm, [5].

For fracture mechanics, standards for the treatment of welded joints suitable are not yet available, but different procedures exist, [1, 6-8], recommending different ways of fatigue crack positioning in weld joints. Having this in mind, different positions and depths (a/W) of fatigue cracks in homogeneous and heterogeneous welds were chosen, as shown in Table 1.

***Table 1:** Fatigue crack positioning in SENB specimens (B x 2B) at weld joints*

SENB specimen	Specimen	Fatigue crack position	Crack depth a/W
B×2B	M		0.5
	D		0.5
	E		0.5

3 RESULTS AND DISCUSSION

As it can be seen from Table 1, the fatigue crack was positioned in the HAZ and the weld metal of the homogeneous and heterogeneous under-matched weld joints. By positioning the fatigue crack in the HAZ, a so-called "composite" fatigue crack front crosses the filler passes - HAZ - base material - HAZ - filler passes**.** The distance between the fatigue crack front and the fusion line in the weld root region was approximately 3.5 mm in all specimens B × 2B (Fig. 1 - Cross-section A-A). The basic aim of the fractographical investigation was to determine the location of brittle fracture initiation on the fracture surface of specimens B × 2B, and to identify the brittle fracture initiation point by using Energy-Dispersive X-ray (EDX) analysis. The microstructure at the brittle fracture initiation point and around it, as well as the nature of the crack path deviation was evaluated using the fracture surface cross-section through the brittle fracture initiation point. After the metallographic specimen was made, a detailed analysis of the welded joint region at the crack tip and along deviated crack path was performed with an optical microscope and a Scanning Electron Microscope (SEM). In this manner, a critical microstructure in the fatigue crack tip surroundings, where the brittle fracture initiated, and the microstructure where it propagated and later arrested was identified. For fractographical and metallographical analysis, the most representative fracture of specimens B × 2B were chosen, which also appeared in other specimens in an appropriate shape (Fig. 1).

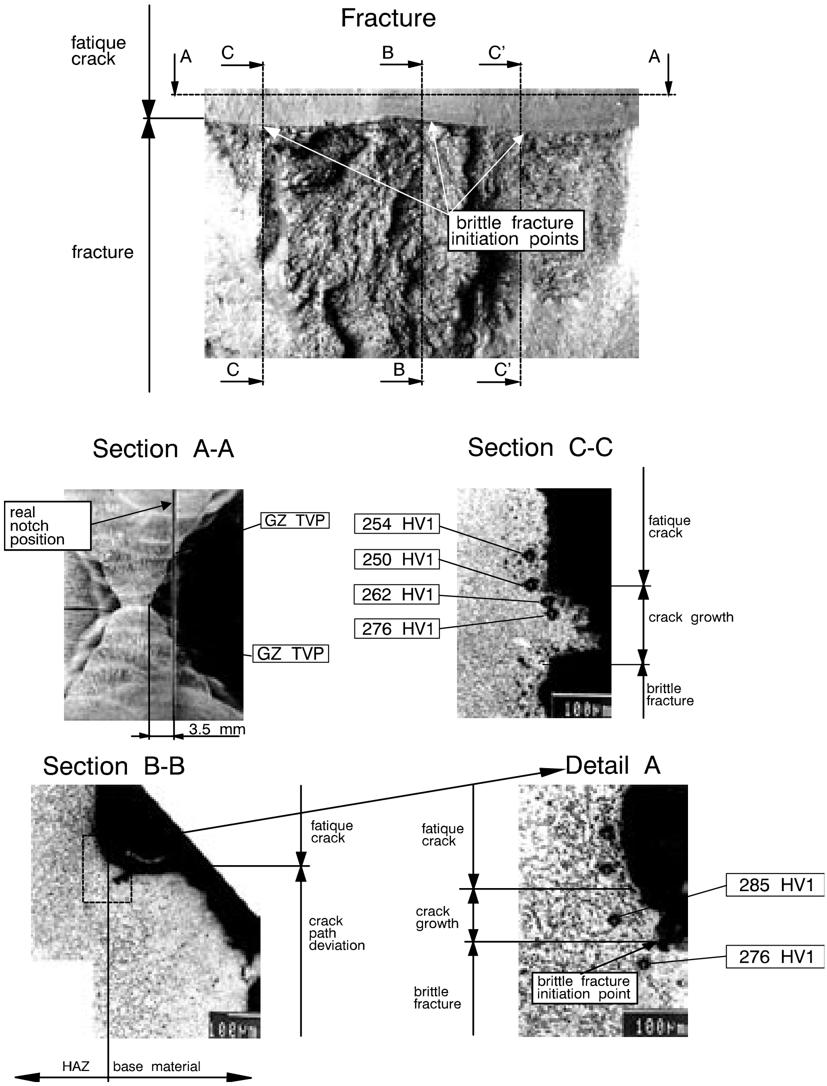


Figure 1: *Brittle fracture initiation points and crack path deviation on fractured specimen B × 2B with deep crack in HAZ of the heterogeneous under-matched weld joint*

Directly measured (δ_5) and calculated CTOD values (δ_{BS}) of fracture toughness for homogeneous and heterogeneous under-matched weld joints are summarized in Figure 2 for Single Edge Notch Bend (SENB) specimens, B × 2B. Different values of rotational factor were used at the determination of calculated CTOD values (δ_{BS}) for surface cracks introduced in specimens in accordance with different ratio a/W. Rotational factor values r_p, [1], to determine the calculated CTOD - (δ_{BS}) were depended on crack depths (a/W) as following:

- for crack depths a/W = 0.25 - 0.37 » r_p = 0.25
- for crack depths a/W = 0.43 - 0.48 »r_p = 0.44

Direct measurement (δ_5 method) and the calculation (BS - 5762) of CTOD values from the measured Crack Mouth Opening Displacement (CMOD) values and the estimation of δ values (δ_c, δ_u in δ_m) are described in [1, 6-8]. Evaluation of pop-in appearance using curves (F - CMOD, δ_5) is described in more detail in [1]. The CTOD testing was done at a temperature at -10 °C.

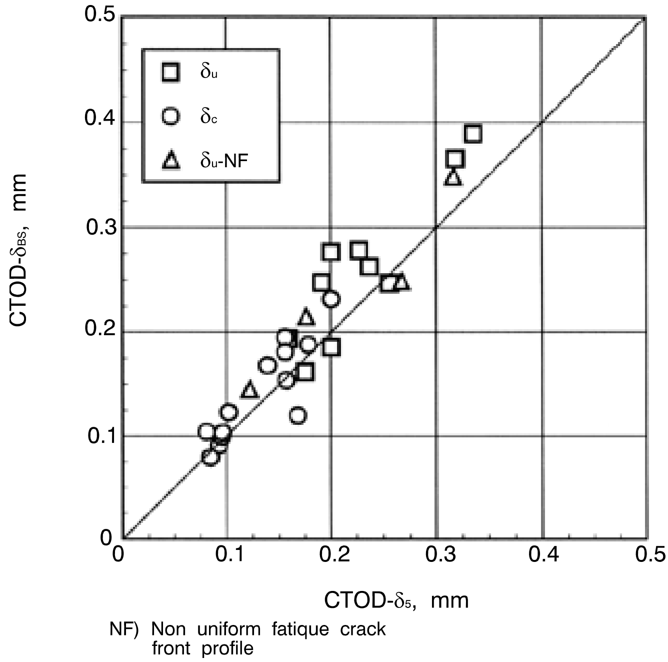


Figure 2: *Comparison of directly measured (δ_5) and calculated (δ_{BS}) CTOD fracture toughness values of specimens B × 2B with a deep crack (a/W = 0.5) in homogeneous and heterogeneous under-matched weld joints*

From Fig. 2, it is clear that measured (δ_5) and calculated (δ_{BS}) CTOD fracture toughness values match approximately. More detailed analysis indicates that the direct measured method δ_5 gives more conservative CTOD values [1].

4 CONCLUSIONS

Good agreement between calculated (δ_{BS}) and measured (δ_5) CTOD values is obvious from the comparison of CTOD results, verifying the method of direct measurement of CTOD, for which the material property data (e.g. yield strength) is not necessary, in contrast to the calculated CTOD values according to the BS 5762 standard. This argument favours using direct measurement δ_5 at the crack tip in welded joints with local and global strength mismatching, and precludes the application of the BS 5762 standard for welded joints, which is valid for base material.

The brittle fracture initiation points of the root layer were indicated by EDX analysis as a Mn-Al-Si inclusion or TiCN carbide, and are found just below the blunting line, which is in agreement with the brittle fracture model theory. It should be noted that for correct identification of a brittle fracture initiation point it is of utmost importance to apply EDX analysis to both fracture

----

surfaces. In the opposite case, it could happen that the EDX analysis detects a false brittle fracture initiation point.

Acknowledgements

The authors wish to acknowledge the financial support of the Slovenian Foundation of Science and Technology and the Japanese Promotion of Science

References

[1] **Z. Praunseis:** *The influence of Strength Under-matched Weld Metal containing Heterogeneous Regions on Fracture Properties of HSLA Steel Weld Joint* (Dissertation in English). Faculty of Mechanical Engineering, University of Maribor, Slovenia, 1998

[2] BS 5762, *Methods for crack opening displacement (COD) testing*, The British Standards Institution, London 1979.

[3] ASTM E 1152-87, *Standard test method for determining J-R curves*, Annual Book of ASTM Standards, Vol. 03.01, American Society for Testing and Materials, Philadelphia, 1990.

[4] ASTM E 1290-91, *Standard test method for crack-tip opening displacement* (CTOD) fracture toughness measurement, American Society for Testing and Materials, Philadelphia, 1991.

[5] GKSS Forschungszentrum Geesthacht GMBH, *GKSS-Displacement Gauge Systems for Applications in Fracture Mechanic*.

[6] **Z. Praunseis, M. Toyoda, T. Sundararajan**: *Fracture behaviours of fracture toughness testing specimens with metallurgical heterogeneity along crack front*. Steel res., Sep. 2000, 71, no 9,

[7] **Z**. **Praunseis**, **T. Sundararajan, M. Toyoda, M. Ohata:** *The influence of soft root on fracture behaviors of high-strength, low-alloyed (HSLA) steel weldments*. Mater. manuf. process., 2001, vol. 16, 2

[8] **T. Sundararajan, Z. Praunseis**: *The effect of nitrogen-ion implantation on the corrosion resistance of titanium in comparison with oxygen- and argon-ion implantations*. Mater. tehnol., 2004, vol. 38, no. 1/2.