Distribution of Stresses in the Vicinity of Straight Crack Front with Present Materials Dissimilarity

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Summary

Three point bend fracture tests were performed on the *B*x2*B* specimens cracked in the middle and through the thickness with present materials and geometric mismatch. Direct measurement of the local CTOD (δ_5) displacement enables to distinct local and global mismatch. Stress and strain distribution in the vicinity of the crack front obtained by three-dimensional finite element analysis assists to better understanding of the possible causes of fracture. The aim of this paper is to determine the stress distribution at the moment of the crack initiation at the vicinity of the crack front in strength mismatch welded joints with different fracture resistances.

Introduction

The safe use of welded structures depends not only on fracture toughness of the joint but also on capacity of material to yield and harden in the vicinity of a flaw. In welded structures, flaws are generally located in several microstructures, which have different mechanical properties and different strain hardening behaviour. Therefore, the critical fracture toughness depends on an interaction between different types of microstructure in the vicinity of the crack tip. Even, if each of the microstructures independently exhibits ductile fracture behaviour, the interaction between them may lead to unstable fracture behaviour of the welded joint and the whole welded structure.

A lot of experimental and numerical studies were devoted in last 10 years to describe this fracture behaviour of welded structures with present dissimilarity [1-3]. In order to evaluate the fracture toughness and the type of fracture behaviour, the stress-strain field at cracks located in the welded joint must be understood [4]. Both, the magnitude and location of the stress peak (obtained by finite element analysis) serve to estimate the stability of the fracture behaviour. This is more important if one can expect the crack path deviation from its original direction.

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Fracture toughness tests

In this investigation a high strength low allowed steel (HSLA) with 700 MPa strength class was used as a base material (BM). The root of X-welded joint was produced with two passes of overmatched metal with strength mismatch factor M=1,13 and filler was produced with M=1,22. Single edge notch bend (SENB) Bx2B test specimens (thickness B=36 mm) were extracted from the plate with butt welded joint (Figure 1). The crack through the thickness is located in the middle of the specimen, with average value of a_0 = 35,822 mm (ratio a_0/W = 0,5). Approximately straight crack front crosses over strength overmatch welded materials. After fatigue pre-cracking, the CTOD (δ_5) parameter of fracture toughness was directly measured for each load up to the load at which stable crack growth occurred [5].

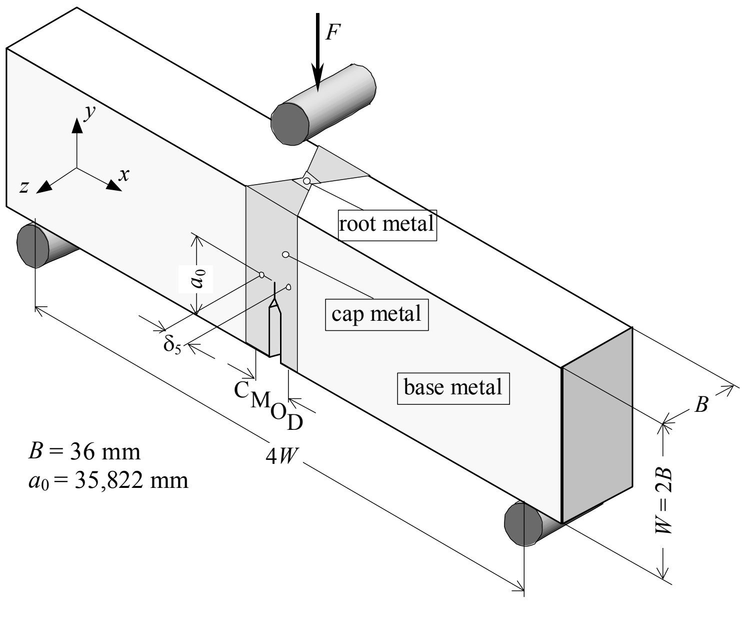

Fig. 1 SENB fracture toughness specimen

Finite element modeling

Regarding the symmetry of the specimen, only 1/4 of the specimen has been considered for 3-D finite element (FE) modeling [6]. Note from the Fig. 2 that any section plane of the solid model for eventually 2-D FE modeling consists from different percent of the base metal. Therefore, 2-D FE modeling is not appropriate in this case.

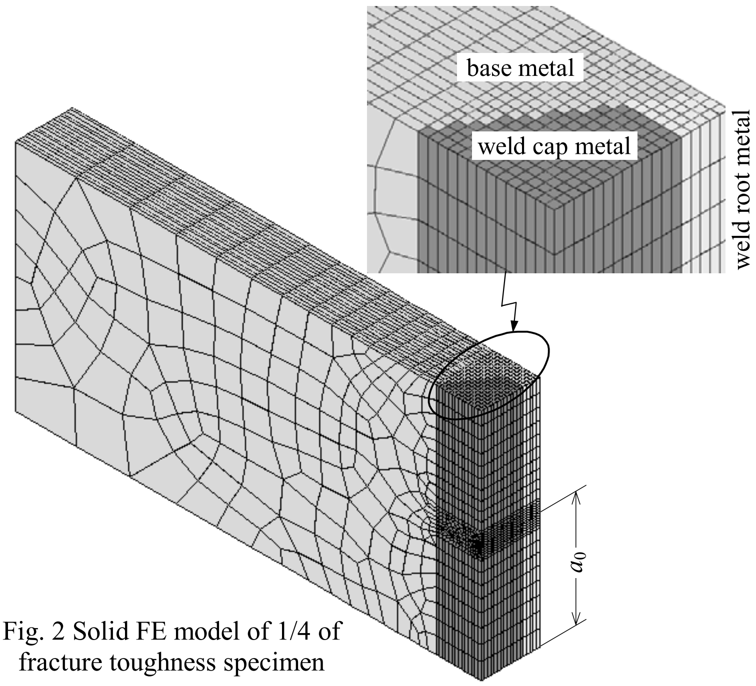

Fig. 2 Solid FE model of 1/4 of fracture toughness specimen

The mesh of one specimen's quarter consisted from 28947 nodes and 6528 of 20-node elements. The fusion line is not modeled as straight line. It is a zigzag shaped through the thickness, where each element has appropriate material properties. Heat affected zone (HAZ) as a particular material is omitted.

The comparison between experimental and numerical values of CTOD (δ_5) displacements shown good agreement [4]. Therefore, in-plane (σ_x and σ_y) and out-of-plane stress (σ_z) fields in the moment of crack initiation may be accepted as real. The aim was to obtain the in-plane stresses magnitudes as a function of the space co-ordinates x and z by $y = a_0 =$ const. This is not possible using standard FE packages, because 3D stress fields could be depicted just on visible surface of the model. In this work, stress distribution is analysed in the cylinder with radius of 2,5 mm from the crack front (Fig. 3). This cylinder was sectioned longitudinally with 5 non-equidistant YZ planes (x=0; x=0,5 mm; x=1,1 mm; x=1,765 mm and x=2,5 mm), according to mesh density. The stress changing along these paths was obtained from FE results. From five curves it is possible to define stress function over the area of rectangle with the size of 2,5 x 18 mm by multy-regression analysis. This function may be also presented as a surface of stress distribution over analysed area (Fig. 4 presents σ_y stress distribution).

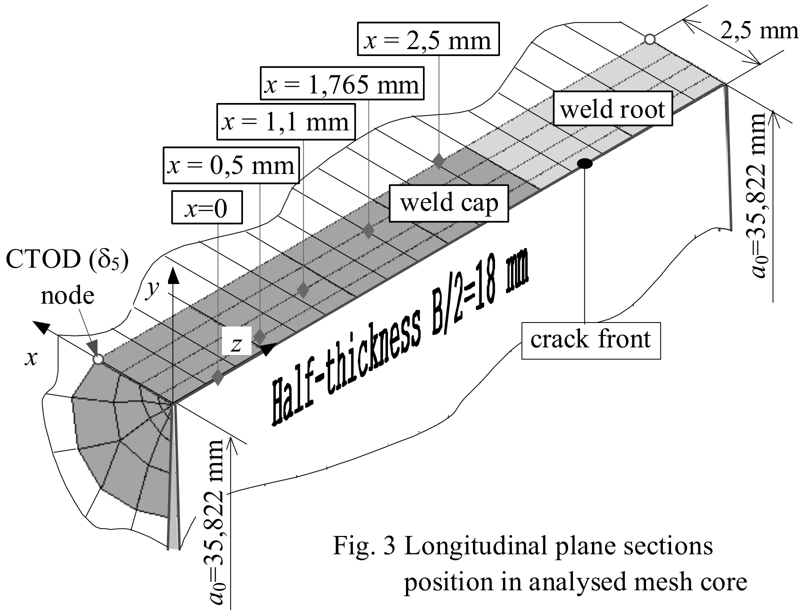

Fig. 3 Longitudinal plane sections position in analysed mesh core

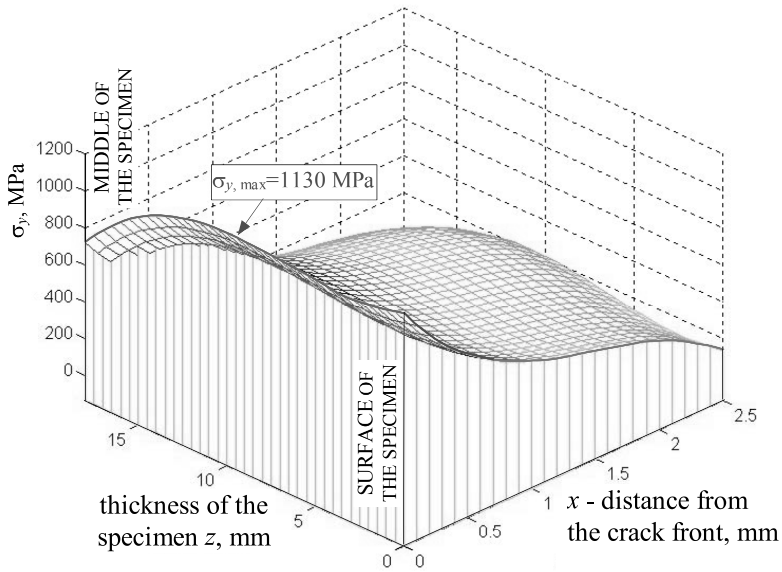

Figure 4 Distribution of the σ_y stress in the vicinity of the crack front

In the Fig. 5 is depicted crack opening stress field (σ_x in this case) in the moment of the crack initiation. Its peak value is shifted from the crack front for the little bit greater value than twice local CTOD in

x-direction. This is influenced by size of finite elements, neglecting of heat affected zone, idealising of crack front as a straight-line etc., but also with the fact that maximal principal stress is located in front of crack tip in the direction of the crack propagation (y-axis here), what is not here analysed.

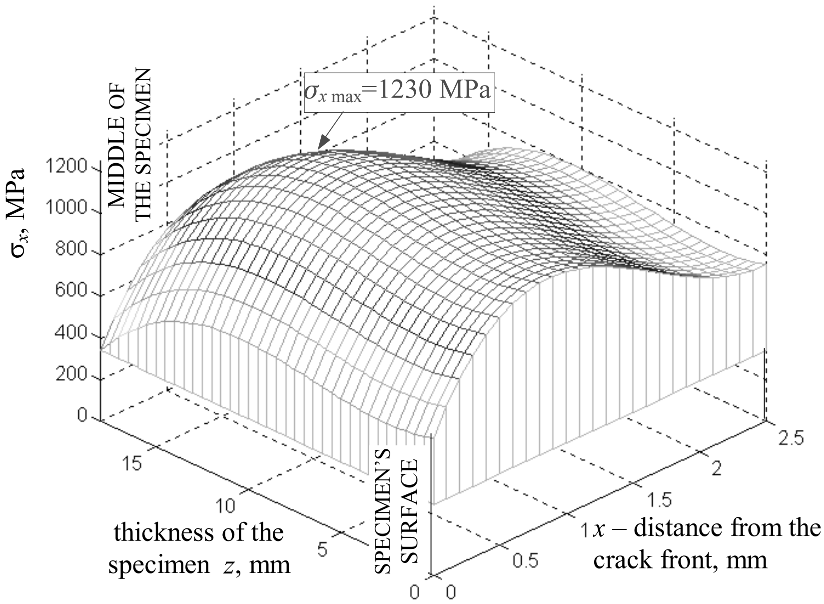

Figure 5 Crack opening stress field σ_x

Figures 4 and 5 show distribution of σ_y-stress and σ_x-principal opening stress along crack front, respectively. As was mentioned, fracture behaviour depends on material ability to yielding and hardening. Therefore, in the case of small scale yielding and hardening the brittle fracture governed by σ_y stresses can occur. The ductile fracture behaviour occurs in case of large scale yielding governed by both stresses σ_y and σ_x. This is obvious at specimen for material where crack growth just below surface under the angle of 45° to mean crack growth direction.

Conclusions

In the paper was analyses fracture behaviour of specimen in the ductile-to-brittle temperature region. FE analysis shows that by increasing load the stress state at the vicinity of crack tip makes condition for ductile and brittle fracture depends on properties of material (yielding and hardening). The achieved "critical" stress distribution at same temperature can cause neither brittle nor ductile fracture behaviour. The resulted behaviour depends on constraint. For instance, in the case of higher constraint (yielding and hardening is smaller) the brittle fracture occurs. Usually, this effect exhibits higher scatter of fracture toughness values in the ductile-to-brittle temperature region.

In-plane stress distributions (σ_x and σ_y) around the crack front may assist to estimate possible crack path deviation or the possibility of the unstable fracture after crack initiation. Stress field imagined as the surface over the crack front cannot be viewed using usually finite element postprocessing options as isostress presentation or as mapping stresses onto path. Such a 3-D stress field presentation is also good educational example of a real stress distribution around the crack front.

Acknowledgement

This paper is supported by the project 0152-018 financed from the Ministry of Science and Technology of Republic of Croatia.

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