11th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2007, Hammamet, Tunisia, 05-09 September, 2007.

THE EFFECT OF THE WELDING PARAMETERS ON RESISTANCE OF WELDED JOINTS IN MULTI-CHAMBER TANKS TO CRACK PROPAGATION

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ABSTRACT
In this paper is presented the effect of the welding procedure, i.e. of selection of technology in the process of plate welding, on resistance of welded joints of structural and constructional steel intended for manufacture and reconstruction of the single-chamber into multi-chamber tanks to crack propagation has been assessed by determination of critical-limit stress intensity factor of the components of welded joint and critical-limit crack length.
Key words: Č.0361 steel, multi/chamber tanks, welded joint, fracture toughness, critical crack length.

1. INTRODUCTION
In construction of vertical, cylindrical flat-bottom tanks, i.e. low-pressure vessels, a relatively high degree of safety is applied. However, inadequate knowledge of all operating conditions, low level of quality control during manufacture and variation of operating conditions as well may significantly reduce the designed degree of safety. One of the most important variations in operating conditions is modification of a single-chamber tank into multi-chamber tank, by fitting up corresponding vertical partitions-barriers. The multi-chamber tanks for liquid fuel are the result of the increasing demand of the fuel distributors who want to store different fuels in one place [1].
Considering the heterogeneity of structural, mechanical and exploitation properties of individual regions of welded joints, the behaviour of a vessel of large dimensions as a whole cannot be easily predicted and interpreted-explained. A welded joint, as a complex and heterogeneus structure, is a critical point in a welded structure. Therefore, the safety of a welded structure is most frequently assessed based on the properties of a welded joint as a whole, as well as on the properties of its integral parts, i.e. HAZ and weld metal.
The effect of the welding procedure, i.e. of selection of technology in the process of plate welding, on resistance of welded joints of structural and constructional steel intended for manufacture and reconstruction of the single-chamber into multi-chamber tanks to crack propagation has been assessed by determination of critical-limit stress intensity factor of the components of welded joint and critical-limit crack length. In general, these investigations should provide an answer to the question whether the existing tanks could be reconstructed or not, as well as to provide sufficient data for

standardisation of modification of the single-chamber tanks into multi-chamber tanks and for construction and manufacture of multi-chamber tanks.

2. MATERIAL

Basic material for manufacture of vertical, cylindrical flat-bottom tanks is steel of Č.0361 designation. For the analysis of the effects of selection of the welding technology on mechanical and service properties, a new material was used. The supplier of the material is US STEEL SARTID. Chemical composition of the plates delivered is given in Tab. 1, while mechanical properties of supplied steel Č.0361 are given in Tab. 2 [1].

Table 1. Chemical composition of delivered plates

Charge No.	Chemical composition, mass %					
	C	Si	Mn	P	S	N
234-349	0,16	0,23	1,12	0,028	0,021	0,009

Table 2. Mechanical properties of steel Č.0361, as supplied

Charge No.	Yield stress $R_{p0,2}$, MPa	Tensile strength, R_m, MPa	Elongation A, %	Impact energy KU3, J
234-349	247	398	24	55

In welding of general structural steel, it is essential to chose proper thermal cycle of welding that will not have an extremely negative effect on the properties of steel resulting from grain refinement and extraction processes. Considering the type of the material and technical & technological regulations to be observed, and having in mind that it is structural steel designed for pressure vessels, four technologies were applied for welding of the test samples, technology A – E process with the EVB 50 electrode, without preheating, technology B – E process with the EVB 50 electrode, with preheating, technology C – MAG process with the VAC 60 wire, without preheating, and technology D – MAG process with the VAC 60 wire, with preheating [1].

3. TESTING RESULTS

The effect of structural heterogeneity and mechanical properties of a welded joint reflects in location of a fatigue-crack tip the first place, and in properties of the region where fracture develops. Testing of plane/strain fracture toughness of the specimens taken from the welded plates made of steel Č.0361 was conducted in order to determine critical stress-intensity factor, K_{Ic}, i.e. to estimate the behaviour of the basic metal and components of the welded joint, weld metal (WM) and heat-affected zone (HAZ) in presence of a crack-type defect as the most jeopardizing defect in structural materials, especially in welded joints. The tests were conducted using the three-point bend (TPB) specimens, geometry of which is defined by the ASTM E399 standard [2]. The three-point bend (TPB) specimens proved to be highly convenient in practice, so that it has been most frequently used.

The experiments were carried out using the single-specimen method with successive partial unloading, i.e. the method of single-specimen relaxation, as defined by the ASTM E1152 standard [3].

Based on the data collected from tearing machine and COD indicator, the diagrams force, F – crack mouth opening displacement (CMOD), δ, were plotted that are the foundation for plotting the diagram J – Δa, where regressive line is plotted according to ASTM E813 [4]. Critical J-integral, J_{Ic}, is obtained from the regressive line obtained. The tipical appearance of the diagrams F – δ and J – Δa for the specimen with a notch in basic metal (BM) is given in Fig. 1, for the specimen with a notch in weld metal (WM) where the EVB 50 electrode was used as a filler metal in Fig. 2, , and for the specimen with a notch in HAZ in Fig. 3 for B welding technologies that were selected.

From the very appearance of the diagrams, the effect of structural heterogeneity on toughness of basic metal and welded-joint components is obvious. The value of critical stress-intensity factor or plane-strain fracture toughness, K_{Ic}, can be computed when the values of critical J_{Ic} integral are known, using the dependences

$$K_{Ic} = \sqrt{\frac{J_{Ic} \cdot E}{1 - \nu^2}} \qquad 1$$

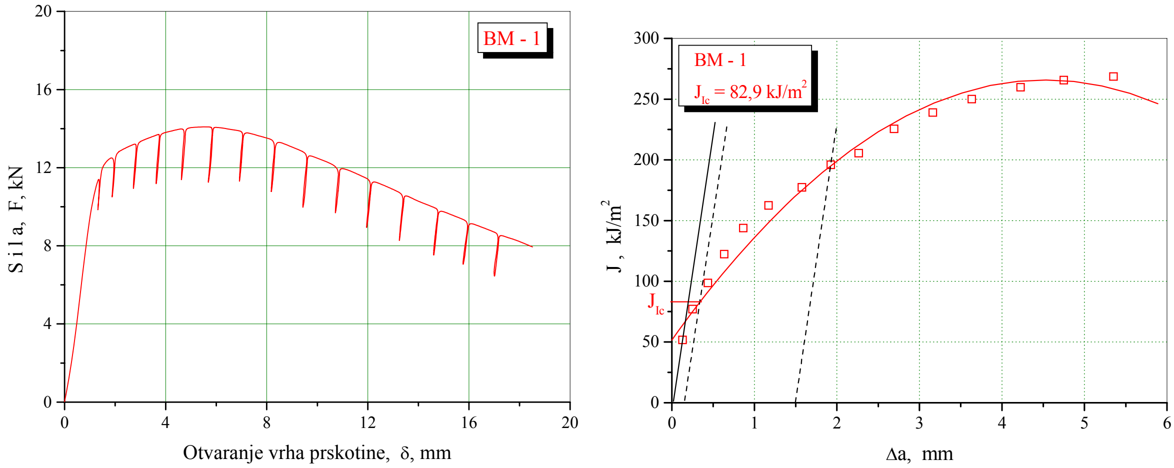

Figure 1. Diagrams $F - \delta$ and $J - \Delta a$ for the specimen with a notch in BM [1]

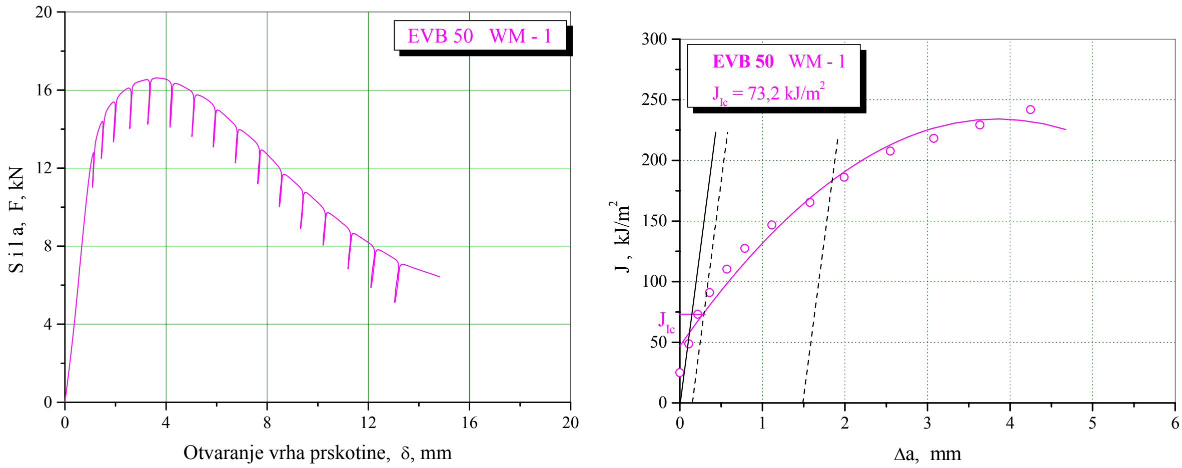

Figure 2. Diagrams $F - \delta$ and $J - \Delta a$ for the specimen with a notch in WM - EVB 50 [1]

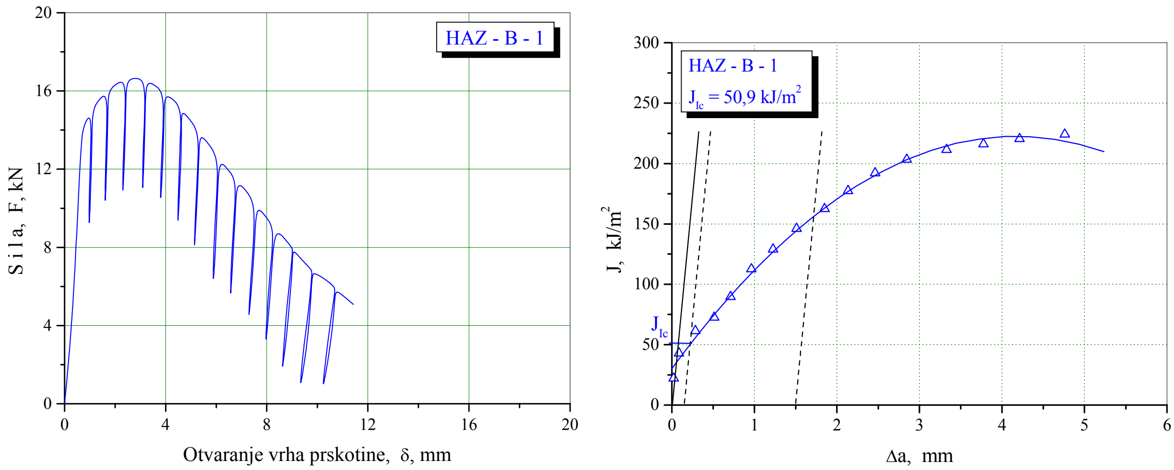

Figure 3. Diagrams $F - \delta$ and $J - \Delta a$ for the specimen with a notch in WM – Tehnology B [1]

4. RESULTS ANALYSIS

Heterogeneity of mechanical properties of a welded joint, i.e. the welded-joint components, is obvious from the obtained value of plane-strain fracture toughness, K_{Ic}, determined indirectly through critical

J_{Ic} integral. The specimens with a notch in PM have the largest measured value of K_{Ic}. Average K_{Ic} values of 136.6 MPa $m^{1/2}$ that were obtained are within the limits of the values in literature for this group of general structural steels [5]. Somewhat lower K_{Ic} values were obtained for the specimens with a notch in WM, where the filler metal EVB 50 (mean value of K_{Ic} was 126.9 MPa $m^{1/2}$)shows higher resistance to fracture than the filler metal VAC 60 (mean value of K_{Ic} was 114.5 MPa $m^{1/2}$). However, in this particular case the differences are relatively small, ranging from 10 to 15 MPa $m^{1/2}$ in terms of minimum and maximum value. The lowest values are that for HAZ, which anyway a critical spot in a welded joint is. However, heat input in parent metal, i.e. preheating, favourably affects the resistance to fracture. Technology B (mean value of 111.0 MPa $m^{1/2}$), where the EVB 50 electrode was used as a filler metal and preheating was applied, shows best resistance to fracture, i.e. in this particular case the best values of K_{Ic} were obtained.

Here, it should be mentioned that, from the structural point of view, the properties of the materials may be better estimated through the individual values of the K_{Ic} and $R_{p0.2}$ quantities and their relationship (which is a relevant quantity in the ASTM E399 and BS 7448 standards), than when estimated based on one of them only. By applying the fundamental formula of fracture mechanics

$$K_{Ic} = \sigma \cdot \sqrt{\pi \cdot a_c} \qquad 2$$

and introducing the value of conventional yield stress, $R_{p0.2} = \sigma$, assuming that the shape factor equals to one, approximate values of critical crack length, a_{cr}, can be computed.

It is obvious that allowable stress, which is lower than conventional yield stress, will provide higher values of critical crack length. It means that tested welded joint, i.e. the welded joint components, in service may have a crack up to the length specified, with no risk of brittle fracture. Therefore, for reliable detection of a crack before it reaches the critical length, convenient non-destructive test procedures should be applied. It should be mentioned that computed values of critical crack length, a_{cr}, relate to the plane-strain conditions, and that they should be corrected in terms of actual structural-material thickness for every particular case.

5. CONCLUSION

Based on the test results obtained, one can conclude that structural and mechanical heterogeneities of a welded joint significantly affect the resistance to crack propagation, both in elastic and in plastic region. The heterogeneity of the mechanical properties of the welded joints, i.e. welded-joint components, is obvious from the values obtained for plane-strain fracture toughness, K_{Ic}, determined indirectly through the critical J_{Ic} integral.

- The specimens with a notch in parent metal have the highest measured K_{Ic}. Filler metal EVB 50 shows higher fracture resistance than filler metal VAC 60. HAZ, as a critical spot in a welded joint, has the lowest values. However, technology B that was chosen shows the best resistance to fracture, i.e. in this case the best values of K_{Ic} were obtained.

In general, the results obtained by testing the parameters of fracture mechanics (K_{Ic}, J_{Ic} and a_c) point to that selected welding technology by applying the E process with preheating gave best results, i.e. that the highest values of the fracture-mechanics were obtained.

6. REFERENCES

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