UDK 621.791.05
Izvirni znanstveni članek

ISSN 1580-2949
MTAEC9, 39(1–2)29(2005)

DEJAVNIKI, KI OVIRAJO TEČENJE ZVARJENIH KOMPONENT Z RAZPOKO

FACTORS INFLUENCING THE YIELDING CONSTRAINT FOR CRACKED WELDED COMPONENTS

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Prejem rokopisa – received: 2004-10-04; sprejem za objavo – accepted for publication: 2005-03-15

Z uporabo metode končnih elementov je raziskan vpliv različne trdnosti materiala in različne geometrije zvarnih spojev na omejitev tečenja zavarjene konstrukcijske komponente. Kot konstrukcijska komponenta je uporabljen upogibno (tritočkovno) obremenjen lomnomehanski preizkušanec. V prispevku je analiziran vpliv geometrijskih faktorjev na omejitev tečenja in s tem mejno obremenitev preizkušanca z razpoko v sredini zvarnega spoja. Analiza je pokazala, da imata dva parametra najbolj izrazit vpliv na omejitev tečenja, in sicer globina razpoke a/W in širine zvara $(W–a)/H$. Globina razpoke a/W in širina zvara sta bili sistematično spreminjani kot: a/W = 0,1; 0,2; 0,3; 0,4; 0,5 in W = 2H, 4H, 8H, 16H, 24H za določitev mejne obremenitve pod pogoji ravninskega deformacijskega stanja.

Namen članka je določiti mejno obremenitev tečenja v globalno heterogenem zvarnem spoju, ki je v prvi polovici zavarjen z nizkotrdnostnim in v drugi polovici z visokotrdnostnim dodajnim materialom, kar se navadno uporablja pri popravljanju zvarnih spojev. Trdnostno razmerje M, ki je razmerje med napetostjo tečenja zvara in osnovnega materiala, je bilo pri zvaru z višjo trdnostjo M = 1,19, med tem ko je pri zvaru z nižjo trdnostjo M = 0,86. Analiziran je vpliv različne dolžine razpoke in s tem različne razdalje med konico razpoke in linijo zlitja z nizkotrdnostnim zvarom. Vpliv ključnih parametrov na omejitev tečenja je bil analiziran. Rezultati za mejo tečenja za preizkušance z različno širino zvarnega spoja kažejo največje odmike pri globini razpoke a/W = 0,5. Iz rezultatov je razvidno, da napetostno in deformacijsko stanje na konici razpoke v visokotrdnostnem zvarnem spoju ob naraščanju širine zvara povzroča prehod iz rešitve za visokotrdnostni zvar k nizkotrdnostnem zvaru. Rezultati tudi kažejo, da širina zvara ima majhen vpliv na preizkušanec s površinsko kratko razpoko in konico razpoke v visokotrdnostnem zvaru. Vsi omenjeni vplivi so predstavljeni v prostorski upodobitvi nad ravnino, ki jo prikazujeta parameter širine zvara in globine razpoke.

Prav tako parameter triosnega napetostnega stanja h je bil določen na osnovi 2D- in 3D-analiz, ki so bile opravljene po metodi končnih elementov. Na osnovi izračunanih parametrov triosnega napetostnega stanja je podan pogled v omejitev tečenja v posameznih področjih. Ugotovljeno je, da je 3D rešitev za mejo tečenja zelo blizo rešitvam za ravninsko deformacijsko stanje. Prav tako učinek a/W na omejitev tečenja je večji, kot sta trdnostna neenakost M in globina razpoke $(W–a)/H$.

Ključne besede: SE(B) vzorec, zvarjeni spoj, razpoka, sila tečenja, parametri omejitve tečenja

The effect of strength mismatch for welded joints performed with different geometries on the yielding constraint has been investigated in the context of single-edged fracture-toughness specimens subjected to bending SE(B) using the finite-element method. The crack was located in the centre of the weld. Two geometrical parameters have been identified as being the most important: the crack-length ratio a/W and the slenderness of the welded joint $(W–a)/H$. They were systematically varied as follows: a/W = 0.1; 0.2; 0.3; 0.4; 0.5 and W = 2H, 4H, 8H, 16H, 24H. Basic equations and plane-strain finite-element solutions for the overmatched SE(B) specimen with all configuration combinations are given. The results are in good agreement with those in literature.

This paper aims to establish yield-load solutions for the same weldment configurations, but with materials dissimilarity present within the weld. This situation is usually encountered during repair welding. For this purpose, a practical combination of filler materials, with the same portion of overmatched part with M = 1.19 and undermatched part with M = 0.86, has been selected. Plane-strain solutions for the heterogeneous weld with the crack located in the overmatched half were obtained. The influence of the yielding-constraint key parameters has also been evaluated. Yield-load results for the specimens performed with different weld widths have the greatest scattering for the a/W = 0.5. The transition from the overmatched to the undermatched solution with increasing H is evident. On the other hand, the behaviour of the specimen with a shallow crack is dictated by the overmatch region ahead of the crack tip and depends very little on the weld slenderness. An approximated 3-D area of the yield-load solutions depending on a/W and $(W–a)/H$ has been proposed.

Furthermore, the stress triaxility parameter h has been calculated using 2-D and 3-D finite-element analysis, and given as a field in the specimen to get an insight into yielding-constraint regions. It was found that the 3-D yield-load solutions are very close to the plane-strain solutions. Also, the effect of a/W on the yielding constraint is more significant than the effect of M and $(W–a)/H$.

Key words: SE(B) specimen, welded joint, crack, yielding load, yielding-constraint parameters

1 INTRODUCTION

Welded components are an unavoidable part of any power plant, petrochemical facility or bridge. For this reason, an integrity assessment of such structures, where cracks may appear during production or exploitation, is very important. It is well known that a welded joint is a critical part of any welded component with respect to defects, geometry, misalignments and mechanical anisotropy. The safe use of welded structures depends not only on the joint's fracture toughness, but also on the material's capacity to yield and harden in the vicinity of a flaw. There are many methods and procedures that assess the significance of crack-like defects in welded joints with a mechanical and geometrical mismatch[1,2]; these were mainly involved in the recently developed SINTAP procedure[3]. With this procedure, instantaneous failure, i.e., end-of-life conditions, can be assessed in terms of crack size, applied force or applied strain. Due to the fact that many parameters influence the fracture behaviour of the component, some solutions for plastic yield load remain open. The most influential factors are preconditioned by the geometry of the fracture-toughness specimen [weld configuration (I-, V-, X- or K-groove), the width of the welded joint in root $2H$, the thickness B, the weld slenderness $\Psi = (W-a)/H)$, the crack-length ratio $\xi = a/W$, the crack location within the weld and the type of loading (tension, bending)]. Besides the geometry, a very important factor with respect to the yielding of the specimen is the dissimilarity of the materials in the weldment. This yield-strength mismatch between the base metal and the weld metal(s) is usually described by the mismatch factor M.

Several experimental and numerical studies in the past few years were devoted to an analysis of possible plastic deformation patterns which, in turn, depend on the value of the mismatch factor M, as well as on the geometry of the weldment[4,5]. They include a number of yield-load solutions for homogeneous materials, F_Y, and mismatch yield-load solutions, F_{YM}, for a few characteristic configurations as well[6]. In order to evaluate the complete fracture behaviour it is also necessary to analyse the stress-strain fields in the neighbourhood of a crack[7]. Thus, the stress triaxility effects have to be introduced into the estimation of the plastic collapse of the defective component of interest.

This paper gives yield-load solutions for a single-edged fracture-toughness specimen subjected to bending SE (B) with an I-shaped weld groove geometry and materials dissimilarity. Finite-element (FE) studies were performed for the characteristic case, when a weld-joint centre-located crack propagates from the overmatch (OM) region to the undermatch (UM) region. The corresponding fully plastic yield-load solutions were obtained directly from the 2-D and 3-D FE analyses for the case of the homogeneous and heterogeneous welded joints as well.

2 OVERVIEW OF THE PROBLEM

The SE (B) configuration most extensively investigated is shown in **Figure 1**, with all the geometrical parameters that are important for the analysis defined.

When assessing the effect of mechanical mismatch on the fracture behaviour of a component, the behaviour of the all-base plate component is taken as the starting point. The base-material properties are kept constant, while the weld-metal properties vary. This variation is described by the mismatch factor:

$$M = \frac{\sigma_{YW}}{\sigma_{YB}} \tag{1}$$

where σ_{YW} and σ_{YB} represent the yield strength of the weld metal and the yield strength of base metal, respectively. The weld metal is commonly produced with a yield strength greater than that of the base plate; this case is designated as **overmatching** (OM), with the mismatch factor $M > 1$. However, the increasing use of high-strength steels forces the producer to select a consumable with lower strength in order to comply with the toughness requirements. In this case **undermatching** (UM), where $M < 1$, is obtained.

The mismatch yield-load solutions for the SE(B) specimen are given in Ref.[6] for all possible crack lengths and locations within the weld metal and for both plane-strain and plane-stress conditions. The basic equations used in this work for the crack in the centre line of the homogeneous OM or UM weld metal, assuming the plane-strain state, are given for the yield load for all-base plates and for the cases of pure OM and UM[6]:

Yield load for all-base-metal plate:

$$F_{YB} = \beta \cdot \frac{\sigma_{YB}}{\sqrt{3}} \cdot \frac{B(W-a)^2}{S/2} \tag{2}$$

where $\beta = \begin{cases} 1{,}125 + 0{,}892 \cdot \xi - 2{,}238 \cdot \xi^2 \\ \quad \text{for } 0 < \xi = a/W < 0{,}172 \\ 1{,}199 + 0{,}096 \cdot \xi \\ \quad \text{for } 0{,}172 \le \xi < 1 \end{cases}$ and $S = 4\,W$.

Overmatching (OM):

$$\frac{F_{YM}}{F_{YB}} = \begin{cases} M & \text{for } 0 \le \Psi \le \Psi_1 \\ A + B \cdot \dfrac{\Psi_1}{\Psi} + C \cdot \left(\dfrac{\Psi_1}{\Psi}\right)^M & \text{for } \Psi_1 \le \Psi \end{cases} \tag{3}$$

where $\Psi = \dfrac{W-a}{H}$, $\Psi_1 = 2e^{-(M-1)/8}$, $A = \dfrac{M+49}{50}$,

$$B = \frac{49(M-1)}{50} - C,\; C = 0{,}3(M-1)\sqrt{M-1}$$

Equation (3) is the solution for the case when the yielding zone spreads through the cracked section of the weld metal.

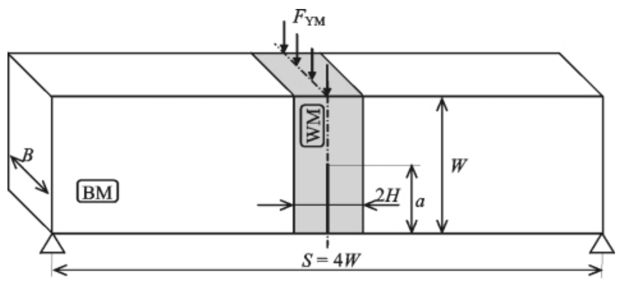

Figure 1: Configuration of the single-edged fracture-toughness specimen subjected to bending SE (B)
Slika 1: Oblika upogibnega SE (B) lomnomehanskega preizkušanca

Undermatching (UM):

$$\frac{F_{YM}}{F_{YB}} = \begin{cases} M & \text{for } 0 \le \Psi \le 2 \\ M\left[\begin{array}{l} \beta + (5{,}384 - 3\beta)\chi^2 + \\ +(2\beta - 3{,}384)\chi^3 \end{array}\right] / \beta & \text{for } 2 \le \Psi \le 12 \\ M\left[0{,}616\chi + 1{,}384\right] / \beta & \text{for } 12 \le \Psi \end{cases} \quad (4)$$

where $\chi = \dfrac{\Psi - 2}{10}$.

Equation (4) is the solution for the case when the plastic deformation is fully confined to the weaker weld metal, determined from the slip-line field analysis[6].

3 FINITE-ELEMENT MODELLING OF THE SE(B) FRACTURE-TOUGHNESS SPECIMEN WITH A HOMOGENEOUS WELD

In order to evaluate the yielding-load variation using an SE(B) fracture specimen with a **heterogeneous** structure in the weld, it is first necessary to validate the results for an SE(B) specimen with a **homogeneous** weld joint. In that case, the weld joint is made entirely of either overmatched or undermatched metal. The analysis here is focused on the plane-strain finite-element analysis of the SE(B) specimen with the crack located in the centre of the overmatched weld. Plastic yield-load solutions normalised by an all-base-metal yield load are found for the systematically varied widths of the weld as $H = W/2$, $W/4$, $W/8$, $W/16$, $W/24$ and for the specimen consisting of all-base plate. The crack-length ratio was varied as $a/W = 0.1$; 0.2; 0.3; 0.4 and 0.5. All the combinations are given in **Figure 2**, where each key-point is related to a suitable FE model.

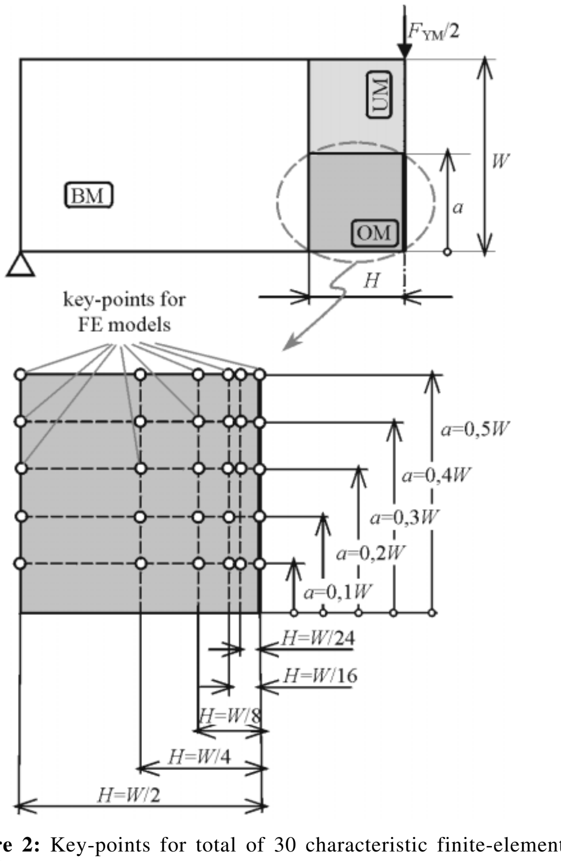

Figure 2: Key-points for total of 30 characteristic finite-element models

Slika 2: Ključne točke za 30 karakterističnih modelov končnih elementov

The typical finite-element mesh employed in the present investigation, using the commercial FEM programme ANSYS, is shown in **Figure 3**. Due to the symmetry, only one half of the specimen was modelled. The number of elements and nodes is equal to 1847 and 5690, where the first fan of elements was sized to about 100 μm. The materials were considered to be elastically and plastically isotropic, with a small hardening after the yielding point.[8] The magnitude of the applied pressure was large enough to bring the specimen to its limiting load state. For mismatched specimens, the plastic deformation patterns are very complex, due to the influence of the $(W–a)/H$ parameter and the value of the mismatch factor M. The characteristic equivalent stress distribution in the weld metal caused by force, which induced yielding through the ligament of the specimen, is presented in **Figure 4** ($W = 2H$, $a = 0.5W$, $M = 1.5$). For a given set of parameters of the weld slenderness, and keeping the constant a/W equal to 0.5, two characteristic overmatch yield-load solutions are presented in **Figure 5** in the form of diagrams ($M = 1.5$ and $M = 2$). The results are in good agreement with Eq. (3) and the results given in Ref. [6].

4 YIELD-LOAD SOLUTIONS FOR THE SE(B) FRACTURE-TOUGHNESS SPECIMEN WITH A HETEROGENEOUS WELD

In practice, an inhomogeneous multipass weld joint with half OM and half UM weld metal is usually used for the repair welding of weld joints where a cold hydrogen-assisted cracking could appear[9,10]. Also, the undermatched weld part satisfies high toughness

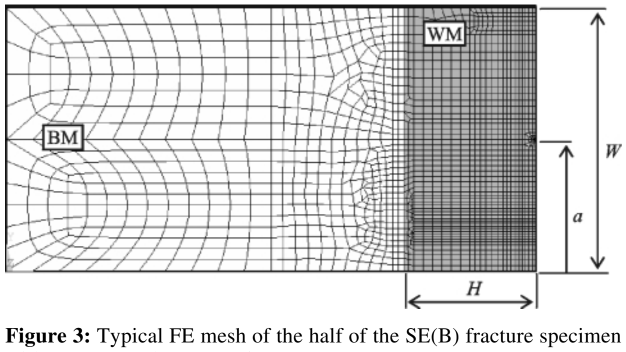

Figure 3: Typical FE mesh of the half of the SE(B) fracture specimen with $2H = W$ and $a/W = 0{,}5$

Slika 3: Tipična MKE mreža za eno polovico SE(B) upogibnega preizkušanca z $2H = W$ in $a/W = 0{,}5$

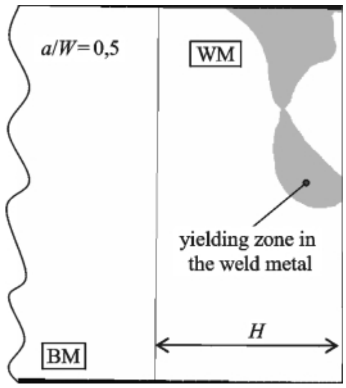

Figure 4: Characteristic yielding spread through the ligament of the specimen ($2H = W$, $a/W = 0,5$ and $M = 1,5$)
Slika 4: Karakteristično širjenje tečenja skozi ligament preizkušanca ($2H = W$, $a/W = 0,5$ in $M = 1,5$)

requirements, while the overmatched weld halves have a crack-shielding effect. It is questionable as to how accurately the yield-load solutions given earlier can be employed for the case of a homogeneous weld and for a heterogeneous weld. The conservative approach is to calculate the yield-load solution assuming the weld is made entirely from UM. This approach is near reality for the specimen with $a/W = 0.5$, where the region ahead the crack is undermatched, but considering the shallow crack, it can underestimate the yield-load value. Such an approach becomes more incorrect when the weld width $2H$ decreases, i.e., as the weld is narrower, its influence on the overall fracture behaviour decreases. Therefore, the yield-load values converge to those obtained for all-base metal.

In this work, a practical combination of the overmatched and undermatched weld halves with $M = 1.19$ and $M = 0.86$, and with the same portion in the butt weld joint, is considered. The weld centre crack was located in the overmatched part of the weld, although in

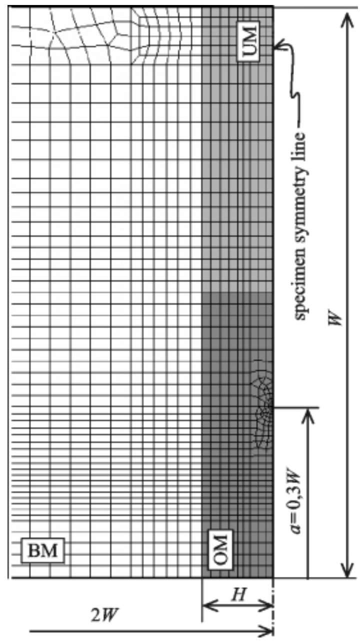

Figure 6: Detail of FE mesh with crack in overmatched part of heterogeneous weld ($a/W = 0,3$ and $W = 8H$)
Slika 6: Detajl mreže KE z razpoko v visokotrdnostnom delu heterogenega zvara ($a/W = 0,3$ in $W = 8H$)

the case of $a/W = 0.5$, the crack tip was positioned on the interface between the OM and UM parts. The a/W ratio and the weld-joint width, $2H$, are varied similarly as in the specimen with the homogeneous weld. A detail of the typical finite-element mesh, with the weld joint width of $H = W/8$, where the crack tip is located on the $0.3W$, is presented in **Figure 6**. The butt-weld joint geometry was idealised by the strip model, where the heat-affected zones are omitted.

It is evident from **Figure 7** that the yield-load results are mostly influenced by the weld half-width, H, for the crack-length ratio $a/W = 0.5$. The increasing of the

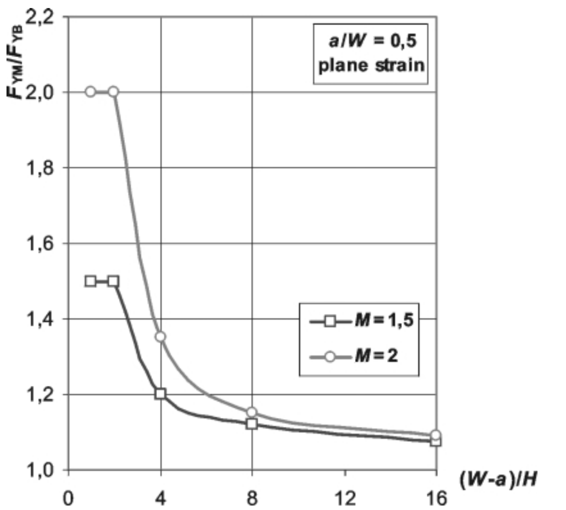

Figure 5: Overmatch yield-load solutions obtained by FE analysis
Slika 5: MKE rešitev za sile tečenja v primeru visokotrdnostnega zvara

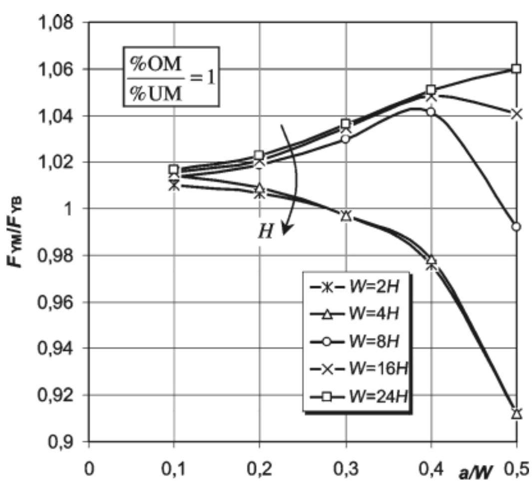

Figure 7: Mismatch yield-load solutions for a heterogeneous weld obtained by plane-strain FE analysis
Slika 7: MKE rešitev za sile tečenja v primerju heterogenenega zvara

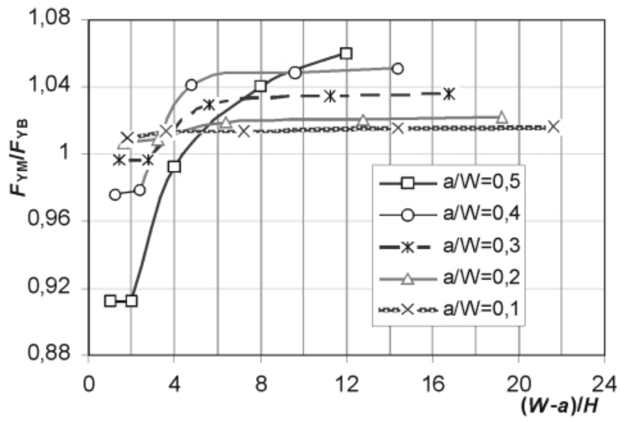

Figure 8: Mismatch yield-load variation for the heterogeneous weld with different slenderness
Slika 8: Spremembe sile tečenja za različne širine heterogenega zvarenog spoja

strength mismatched weld width by constant crack length causes lower yield loads. It is worth noting that the yield load for the component with a shallow crack is greater than the yield load for the all-base metal, regardless of the weld-width value. This fact may be of some help, shielding the welded components with shallow cracks from an unplanned failure.

The value of the slenderness of the weld $(W–a)/H$ is calculated for the different values of a/W and H. Its magnitude drops with increasing a/W, with H = const. It also drops with an increasing H value, with a/W = const. In this investigation the slenderness ranges from 1 (a/W = 0.5 and $H = W/2$) to 21.6 (a/W = 0.1 and $H = W/24$). **Figure 8** shows an example of the effect of $(W–a)/H$ on the weld mismatch yield-load solutions F_{YM}, for different crack lengths. The transition from the undermatch to the overmatch solution is obvious for the deep-cracked components. On the other hand, the yield solution for the components with shallow cracks is mainly dictated by the overmatch region ahead of the crack tip. The curve has a very low slope, in fact it seems almost horizontal, and it depends very little on the slenderness value.

An approximated 3-D area of the yield-load solutions over the considered range of a/W and $(W–a)/H$ parameters is depicted in **Figure 9**. Of course, this solutions field is only valid for the aforementioned combination of welded metals and for the crack located in the overmatched part of the weld.

5 STRESS TRIAXILITY QUANTIFICATION

All the yield-load solutions given earlier assume extreme out-of-plane conditions, i.e., a plane-strain (PE) state. This state limits the possibility of deformation according to the component's thickness (usually, axis z), causing a stress component in that direction, σ_z. Therefore, it is necessary to probe the property of the plane-strain state in the analysed range of the

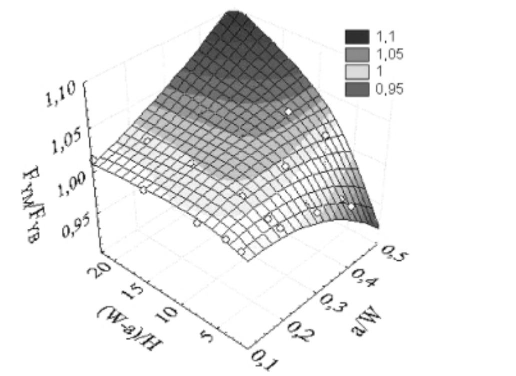

Figure 9: Overmatch yield-load solutions obtained by FE analysis
Slika 9: MKE rešitev za sile tečenja v primerju visokotrdnostnega zvara

yield-load-influenced parameters. For this purpose, 3-D finite-element models were analysed, providing, simultaneously, an insight into the effect of the component's thickness on the local stresses.

The stress triaxility is usually quantified through a calculation of the triaxility parameter, h, defined by:

$$h = \frac{|\sigma_m|}{\sigma_{eq}} = \frac{\left|\frac{\sigma_1 + \sigma_2 + \sigma_3}{3}\right|}{\frac{1}{\sqrt{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}} \tag{5}$$

where $|\sigma_m|$ and σ_{eq} denote the hydrostatic stress and the Mises equivalent stress. The values of h are extracted directly from the FE analysis. With the aim to separate the influencial geometrical parameters from that of the materials dissimilarity, first, homogeneous SE(B) specimens were analysed. The value of h should not exceed the value obtained from the so-called Prandtl field:

$$h(\text{Prandtl}) = \frac{1+\pi}{3} \cong 2{,}4 \tag{6}$$

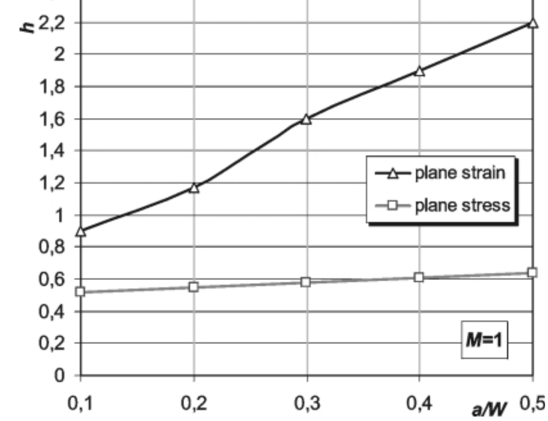

Figure 10: The variation of h with a/W for homogeneous SE(B) specimen in both PE and PS conditions
Slika 10: Sprememba h z a/W za homogeni SE(B)-vzorec, v stanju RN in RD

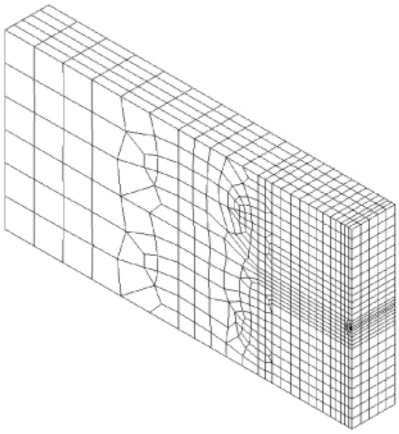

Figure 11: 3-D finite-element mesh of 1/4 of the standard homogeneous SE(B) specimen with a/W = 0.5
Slika 11: 3-D mreža končnih elementov 1/4 standardnega homogenega SE(B) vzorca z a/W = 0,5

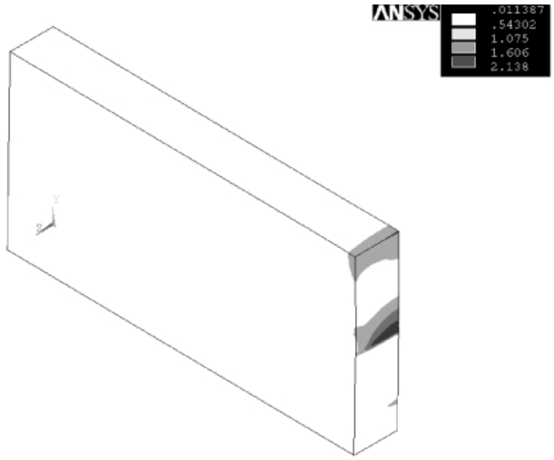

Figure 13: Stress triaxility parameter h distribution within the homogeneous SE(B) specimen (a/W = 0.5)
Slika 13: Raspodelitev parametra triosnega napetostnega stanja h v homogenem SE(B)-vzorcu (a/W = 0,5)

Figure 10 summarises the variation of h with a/W for a homogeneous SE(B) specimen obtained from FE results, supposing both plane-strain (PE) and plane-stress (PS) conditions. It is evident that the yielding of the deep-cracked specimen is more strongly constrained, especially in the case of the PE state. The magnitude of h does not exceed the value of 2.2, regardless of the PE or PS state. Both diagrams have an almost linear form. One can conclude that the crack-length ratio, a/W, plays an unimportant role on the yielding constraint by assuming the PS state. On the other hand, the assumption of a PE state strongly affects the stress triaxility value, even for the specimen with shallow cracks. This fact is more visible by employing the 3-D finite-element models. Due to the existence of two planes of symmetry, only 1/4 of the homogeneous specimen was modelled. The crack front through the thickness was imagined as straight (a/W = 0.5). The typical FE mesh of the standard homogeneous SE(B) specimen (the thickness, B, is equal to half of the width, W) consists of 2740 elements and 13200 nodes (**Figure 11**). The yield zone presented in **Figure 12a**) stands for the region where the Mises equivalent stress is greater than the yield strength of the base metal. **Figure 12b**) presents the hydrostatic pressure distribution through the elements for the same loading level, which induces the net section yielding. The dividing of these element results leads to the stress triaxility distribution depicted in **Figure 13**. It is expected that the maximum value of h = 2.138 will be found in the mid-plane of the specimen. As the yielding in this plane is constrained the most, an assumption about the PE state using 2-D modelling is very near to reality (see that the similar value of h = 2.19 was obtained using plane-strain FE analysis, **Figure 10**). Also, the value of h observed from the surface specimen plane is very close to the same value calculated from the plane-stress FE analysis. Generally, the 3-D results for the yield load are almost the same as for the 2-D results, assuming the PE state. The reason is the fact that the yielding observed with a standard deeply cracked SE(B) laboratory specimen can be characterised as highly constrained. This effect is somewhat reduced in a real component, which can be a consequence of underestimating the yield-load value.

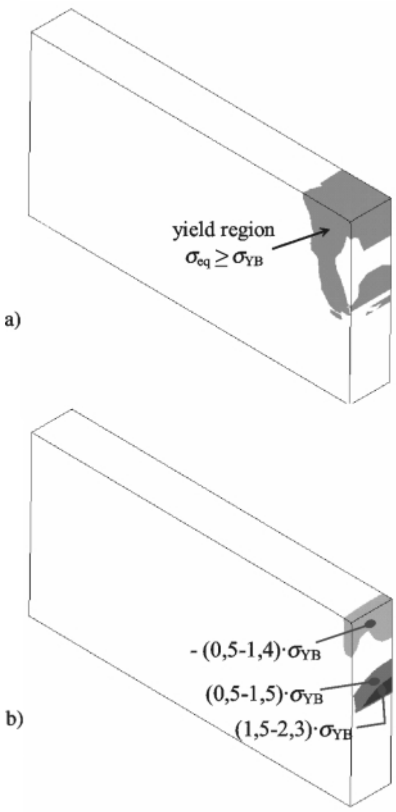

Figure 12: a) Yield zone within homogeneous SE(B) specimen and b) Hydrostatic pressure distribution
Slika 12: a) Cona tečenja v homogenem SE(B)-vzorcu in b) Raspodelitev hidrostatskega pritiska

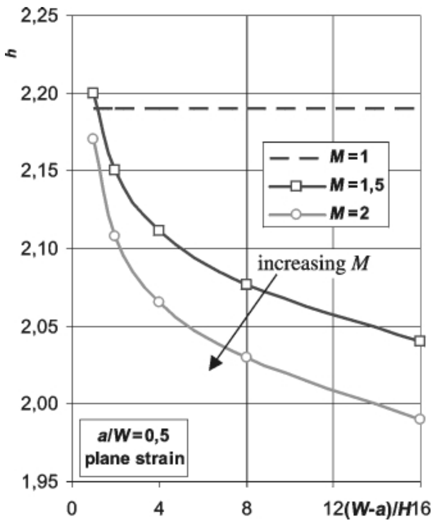

Figure 14: Variation of parameter h with $(W\text{-}a)/H$ for overmatched SE(B) specimen in PE (a/W = 0.5)

Slika 14: Sprememba parametra h z $(W\text{-}a)/H$ v visokotrdnostnem SE(B) vzorcu (a/W = 0,5) v RD stanju

For mismatched components with cracks in the weld-metal centre, the crack-tip constraint is affected by additional factors, such as M and $(W–a)/H$. The effect of M and $(W–a)/H$ on h for a plane-strain, highly constrained (a/W = 0.5), overmatched specimen (M = 1.5 and M = 2) is summarised in **Figure 14**. It is evident that higher overmatching produces a lower triaxility stress at the crack tip, similar to that reported in Ref. [11]. Such a shielding effect is even more pronounced with increasing $(W–a)/H$ values. It seems that the strength overmatch, together with the $(W–a)/H$ value, has a smaller influence on the h value than the effect of the crack-length ratio a/W.

However, a 3-D finite-element simulation of the fracture behaviour of the heterogeneous weld with the crack tip located in the overmatch zone shows that the undermatch in the front of the crack tip plays the most important role in the yielding-constraint variation. Although the yielding-constraint distribution, h, presented in this case (**Figure 15**) is similar to the h field obtained for an overmatch weld, the highest value is greater for 30 %. This confirms that the strength of the undermatch region in the joint increases the yielding constraint.

6 CONCLUDING REMARKS

This paper describes yield-load solutions for SE(B) fracture-toughness specimens, with the crack in the centre of a homogeneous weld or in the centre of a heterogeneous weld, obtained by 2-D and 3-D finite-element analysis. The most influential geometrical parameters on the yielding constraint, i.e., a/W and $(W–a)/H$, were varied systematically in a practical range of values. It was found for a homogeneous overmatched

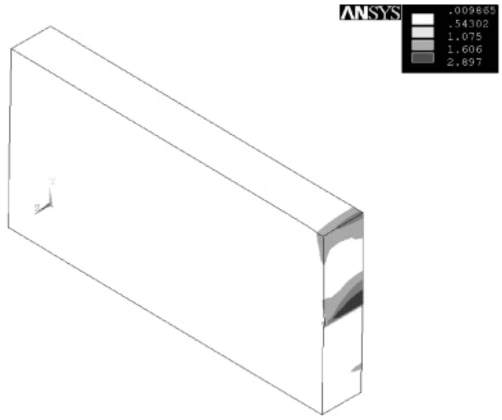

Figure 15: Stress triaxility parameter h distribution within the heterogeneous SE(B) specimen (a/W = 0.5)

Slika 15: Raspodelitev parametra triosnega napetostnega stanja h v heterogenem SE(B)-vzorcu (a/W = 0,5)

weld that the yield load F_{YM} decreases with increasing weld slenderness $(W–a)/H$ with a/W = const, due to the reduction of the weld width with higher yield-strength material. In the case of a highly constrained heterogeneous weld (a/W = 0,5) filled with M = 1.19 in the overmatched half and M = 0.86 in the undermatched half, the yield-load solutions transit from near the undermatched solutions to near the overmatched solutions with the increasing of the $(W–a)/H$ values. On the other hand, the SE(B) specimen with a shallow crack is less affected by the $(W–a)/H$ value. In order to be able to find the yield-load solution for each combination of parameters a/W and $(W–a)/H$, an approximated 3-D yield-solutions surface is given.

Furthermore, the crack-tip stress triaxility parameter h was estimated by plane-strain, plane-stress and 3-D finite-element models of a standard SE(B) specimen. It was found that the value of h by plane-strain finite-element analysis is very close to the h value in the mid-plane of the solid model. Also, the effect of a/W on the h value is more pronounced for high constraint conditions (deep crack in the plane-strain state), while it is less significant for low constraint as the plane-stress analysis of the SE(B) specimen with a shallow crack. The increase of the strength mismatch factor M leads to a lower crack-tip triaxility; moreover, how the weld slenderness increases. However, the existence of the undermatch region in front of the crack tip may increase the yielding constraint of the component.

Acknowledgement

The authors are indebted to the Ministries of Science, Education and Sport of the Republics of Croatia and Slovenia for their support of this work as part of the bilateral project 'Application of fracture mechanics by revitalisation of energetic components'.

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