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NUMERIČKA ANALIZA LOMA ZATEZNE EPRUVETE SA PRSLINOM U ZUT

NUMERICAL ANALYSIS OF TENSILE SPECIMEN FRACTURE WITH CRACK IN HAZ

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Ključne reči
- overmečing zavareni spoj
- finozrna zona-uticaja-toplote
- grubozrna zona-uticaja-toplote
- rast prsline
- metoda konačnih elemenata

Izvod

Numeričkim rešenjima se omogućava istraživanje složenijih problema, uključujući analizu pojedinačnih uticaja, posebno u slučajevima kada izostaju odgovarajući eksperimenti i matematička rešenja usled visoke cene, složenosti problema, itd. U ovom radu se razmatra numeričko modeliranje i analiza ponašanja loma zavarenih zateznih epruveta sa prslinom u ZUT, na primer, uticaj heterogenosti zavarenog spoja na raspodelu napona i deformacija ispred vrha prsline, kao i uzroci pojave loma. Analizirana su dva slučaja: vrh prsline lociran u finozrnom ZUT i vrh prsline lociran u grubozrnom ZUT.

Eksperimentalna istraživanja, u oba slučaja, su pokazala dejstvo prepreke mismečinga zavarenog spoja, nakon inicijalnog širenja prsline u finozrnom ili u grubozrnom ZT, što je prouzrokovalo skretanje rasta prsline u oblasti duktilnijeg osnovnog materijala, čime se smanjila i brzina rasta prsline. U ovom članku su opisana razmatranja ovakvog ponašanja uz primenu numeričke simulacije eksperimenta.

Keywords
- overmatched welded joint
- fine-grained heat-affected-zone
- coarse-grained heat-affected-zone
- crack propagation
- finite element method

Abstract

Numerical solutions enable investigation of complex problems, including analysis of various influences, especially in cases when experimental research and mathematical solutions are not appropriate, such as high price, problem complexity, etc. In this article, numerical modelling and analysis is presented, concerning fracture behaviour of HAZ cracked welded tensile specimens i.e. the influence of welded joint heterogeneity on the distribution of stress and strain in front of the crack tip and the reasons causing failure. Two cases are analysed: crack tip located in fine-grained HAZ and crack tip located in coarse-grained HAZ.

Experimental research in both cases exhibited that the barrier act of welded joint mismatch, after the initial propagation of crack in fine-grained or coarse-grained HAZ, has brought to a turn of crack propagation into more ductile base metal, thus decreasing the crack propagating speed. The article brings some observations regarding such behaviour by applying numerical simulations to the experiment.

UVOD

Zavareni spoj, kao konstrukcijsko rešenje za spajanje komponenata i sklopova, predstavlja najčešći oblik procesa u izradi konstrukcija i instalacija, a ogroman broj zavarenih spojeva se izvodi u uređajima pod pritiskom, na železničkim i drumskim vozilima, kilometarskim zavarenim spojevima cevovoda, brodova, itd. Najbitniji zahtev u svim ovim slučajevima jeste njihov vek bez otkaza sa prisustvom greške ili, koji su to oblici otkaza mogući, koja je razlika u ponašanju loma između osnovnog materijala, metala šava i ZUT, ili čak, koji su krajnji uslovi pod kojima će zavareni spoj sa prslinom biti u eksploataciji, itd. Površinske prsline su često fenomen kod metalnih konstrukcija, a predviđanje njihovog rasta i otpornost konstrukcije na lom zahteva određivanje mnoštva podataka osobina materijala i precizna istraživanja stanja napona-deformacija. U mnogim slučajevima nisu poznata egzaktna rešenja, stoga se koriste numeričke, približne analitičke i eksperimentalne metode mehanike loma da bi sa njihovom kombinacijom postigli bliži prilaz krajnjem rešenju.

INTRODUCTION

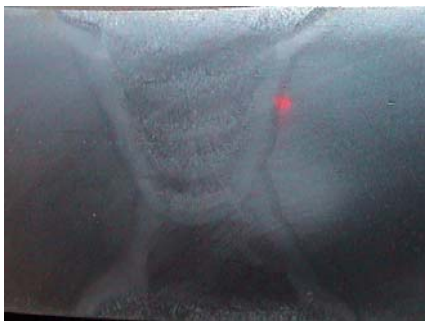
The welded joint as a structural solution for joining components and assemblies is the most frequently used form in producing structures and installations, and welded joints are performed massively in pressurized equipment, railway and road vehicles, kilometres of weldments in pipelines, ships, etc. The essential demand in all these cases is their life without failure in the presence of a defect, or, what failure modes are possible, what is the difference in fracture behaviour between the base- and weld metal, and HAZ, or even, what are ultimate conditions under which the cracked welded joint may remain in service, etc. Surface cracks are often a phenomenon in metal structures, and predicting their propagation and structural resistance to fracture requires the necessity for determining plenty of data for material properties and accurate research of the stress-strain state. In numerous cases, exact solutions are unknown, thus, numerical, approximate analytical, and experimental methods of fracture mechanics are used combined for a closer approach to the ultimate solution.

U ovom članku urađena je elastoplastična 2D i 3D numerička analiza u okviru složenog istraživanja integriteta i ponašanja loma sferne posude pod pritiskom sa prslinom u ZUT zavarenog spoja. Analizirano je ponašanje uzorka sa prolaznom prslinom, opterećenim jednoosnim zatezanjem, kao eksperimentalni model velike posude pod pritiskom sa dvoosnim naponskim stanjem. Dva slučaja su uzeta u obzir u istraživanju: vrh prsline lociran u finozrnom (FZ) ZUT i vrh prsline lociran u grubozrnom (GZ) ZUT.

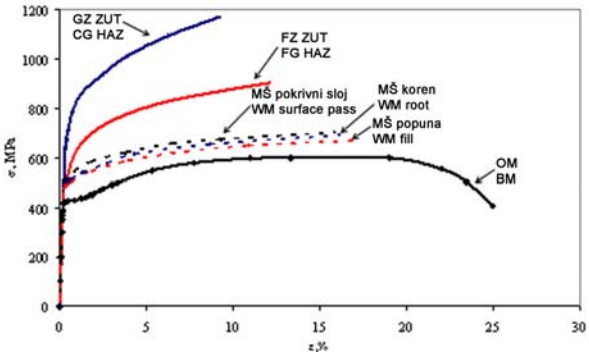
Osnovni materijal je mikrolegirani čelik klase St.E 420, prema DIN (sa $R_{p0,2}$ = 420 MPa, R_m = 604 MPa i A_5 = 25%). Zavareni spoj oblika X izveden je ručnim elektrolučnim postupkom zavarivanja, upotrebom obložene elektrode bazičnog sastava, E 7018-1, prema AWS (E 46 5 B42 H5, u skladu sa EN 499), u više prolaza, čime je formiran veći broj slojeva.

An elastic-plastic 2D and 3D numerical analysis is carried out within complex research of the integrity and fracture behaviour of a spherical pressure vessel with a crack in HAZ of the welded joint. The behaviour of a through-thickness crack is analysed in a specimen, loaded by uniaxial tension, as an experimental model of a large spherical vessel in bi-axial stress state. Two cases are taken into account: crack tips located in the fine-grained (FG) HAZ and in the coarse-grained (CG) HAZ.

The base material is microalloyed steel, DIN class St.E 420 ($R_{p0.2}$ = 420 MPa, R_m = 604 MPa, A_5 = 25%). The X-shaped welded joint is performed by manual metal arc welding with basic coated electrode E 7018-1, AWS (E 46 5 B42 H5 in acc. with EN 499), in a multipass technique, thus resulting in a large number of deposited layers.



Slika 1. Presek zavarenog spoja
Figure 1. Weld cross section.



Slika 2. Krive napon-deformacija u oblastima zavarenog spoja
Figure 2. Determined stress-strain curves of the welded joint regions.

Kriva σ–ε osnovnog materijala je određena standardnim ispitivanjem zatezanjem. Izmerena je i mikro tvrdoća radi određivanja zateznih osobina zavarenog spoja. Pri ispitivanju su utvrđene male razlike u vrednostima tvrdoće između metala šava ($HV1_{koren}$ = 212, $HV1_{popuna}$ = 205, $HV1_{pokrivni\ sloj}$ = 215) i osnovnog materijala ($HV1_{OM}$ = 185), čime je ustanovljen umeren overmečing u zavarenom spoju. Širina ZUT je približno 3 mm, tipična vrednost tvrdoće u blizini površine u grubozrnoj strukturi je približno HV1 = 350, a u neposrednoj blizini vrha prsline imala je vrednosti koje su se kretale oko HV1 = 280 za „kvazi“ GZ ZUT i HV1 = 220 za FZ ZUT. Mehaničke osobine i krive σ–ε heterogenog zavarenog spoja (MŠ, GZZUT i FZZUT) su određene kombinacijom vrednosti mikrotvrdoće i zakona Ramberg-Ozgud, /3, 4/. Polazne veličine su mikro tvrdoća (HV1) i simulacija ciklusa zavarivanja, radi procene $\Delta t_{8/5}$ poređenjem vrednosti HV1 u oblastima zavarenog spoja i struktura dobijenih simulacijom, što je takođe poslužilo i za određivanje eksponenta deformacionog ojačavanja, kao što je prikazano u /1/.

The base metal σ–ε curve is estimated by standard tensile test. In order to determine welded joint tensile properties, micro-hardness is measured. This test exhibited small differences in hardness between the weld metal ($HV1_{root}$ = 212, $HV1_{fill}$ = 205, $HV1_{surface\ pass}$ = 215) and base metal ($HV1_{BM}$ = 185), showing moderate overmatch in the welded joint. The width of HAZ is approximately 3 mm and typical hardness level near the surface for true CG structure is approximately HV1 = 350, and at depth near the crack tip with values around HV1 = 280 for “quasi” CG HAZ and HV1 = 220 for FG HAZ. Mechanical properties and σ–ε curves of the heterogeneous welded joint (WM, CGHAZ and FGHAZ) are assessed through a combination of micro-hardness values and the Ramberg-Osgood law, /3, 4/. Input parameters are micro-hardness (HV1) and simulated welding cycles enabling estimation of $\Delta t_{8/5}$ by comparing the HV1 values of welded joint regions and simulated structures, and has also enabled the evaluation of the strain hardening exponent, as is shown in /1/.

MODELIRANJE UZORAKA

Upotrebljen je softverski paket ANSYS za strukturalnu analizu sa pret-procesiranjem, procesiranjem i post-procesiranjem. Modeliranje zavarenog spoja obavljeno je u karakterističnim oblastima sa različitim mehaničkim osobinama, približno materijalnom sistemu sa više različitih oblasti, sačinjen iz korena, popune i pokrivnih slojeva, i iz oblasti ZUT, koja se smatra kao bimaterijalni sistem iz dve podzone sa približnim širinama 1,5 mm, i konačno, osnovni materijal, sl. 3 i 4.

SPECIMENS MODELLING

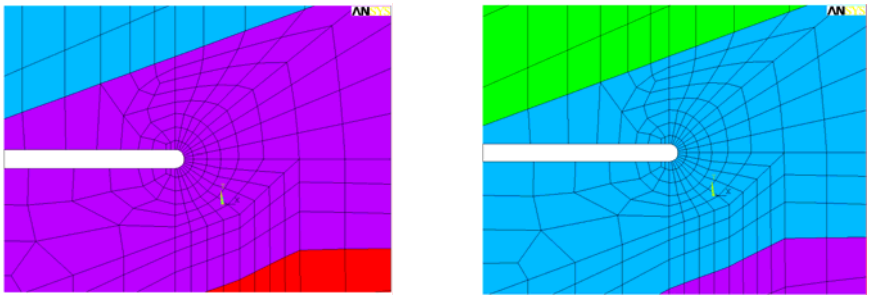
ANSYS package for FEM structural analysis is used for pre-processing, processing and post-processing. The welded joint is modelled with characteristic regions of different mechanical properties, approximated as a multi-region material system, consisting of root, fill and surface layers, and the HAZ region, determined as a bimaterial system, consisting of two subzones, 1.5 mm of approximate width each, and finally, the base metal, Figs. 3 and 4.

slučaj 1 – prslina u FZ ZUT
case 1 – crack in FG HAZ

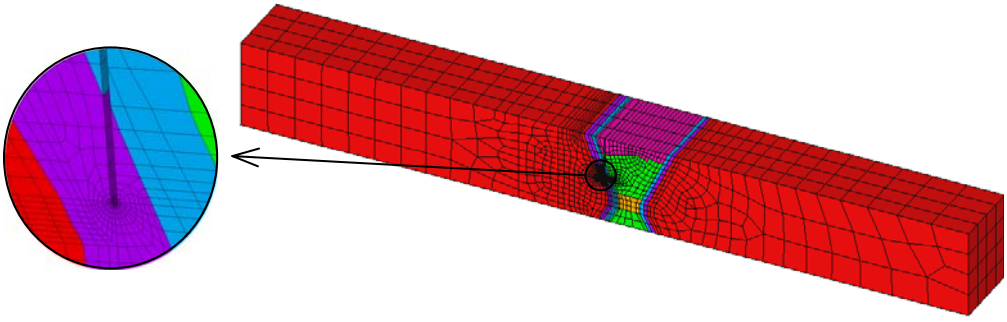
oblast zavarenog spoja
welded joint sight

slučaj 2 – prslina u GZ ZUT
case 2 – crack in CG HAZ

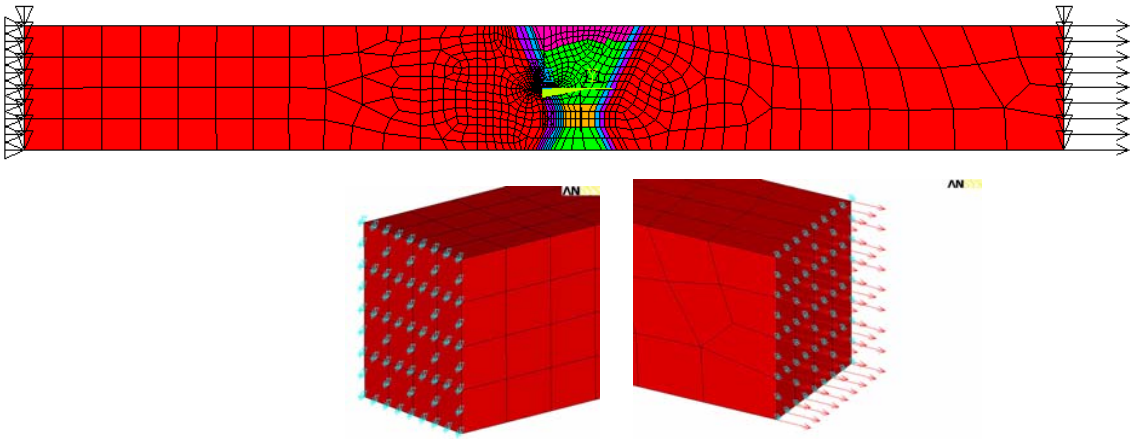
Slika 3. Pojednostavljeni MKE model zavarenog spoja
Figure 3. The simplified FEM model of the welded joint.



Slika 4. Finija mreža oko vrha prsline – uvećana oblast vrha prsline
Figure 4. Refinement of the mesh around the crack tip – enlarged crack tip region.



Slika 5. 3D model sa detaljem oblasti oko vrha prsline
Figure 5. The 3D model with enlarged crack tip region



Slika 6. Granični uslovi
Figure 6. Boundary conditions.

ANALIZA DOBIJENIH REZULTATA

Značajno polje rada ovog istraživanja je analiza uzroka ponašanje loma, koje se pojavljivalo u eksperimentima, /1/, i to usvajanjem pogodnih numeričkih modela za analizu naponsko-deformacionog stanja oko vrha prsline.

Numeričku analizu je sačinjavalo 3D i 2D modeliranje. U opštem slučaju, ponašanje epruvete je 3D, ali 2D analiza je takođe korisna jer su uslovi ravnog stanja napona i ravnog stanja deformacija dva granična stanja, koja ograničavaju ponašanje. Prvo, ravno stanje napona, je dominantno na slobodnoj površini, tj. tipično je kod konstrukcija sa malom širinom, a drugo, ravno stanke deformacija, je dominantno u središtu epruvete, tj. tipično je kod konstrukcija sa velikom širinom. Trodimenzionalni uslov je između ova dva ekstremna uslova, jer se širina ispitanih epruveta nalazi između tzv. velike i male širine, prema definiciji.

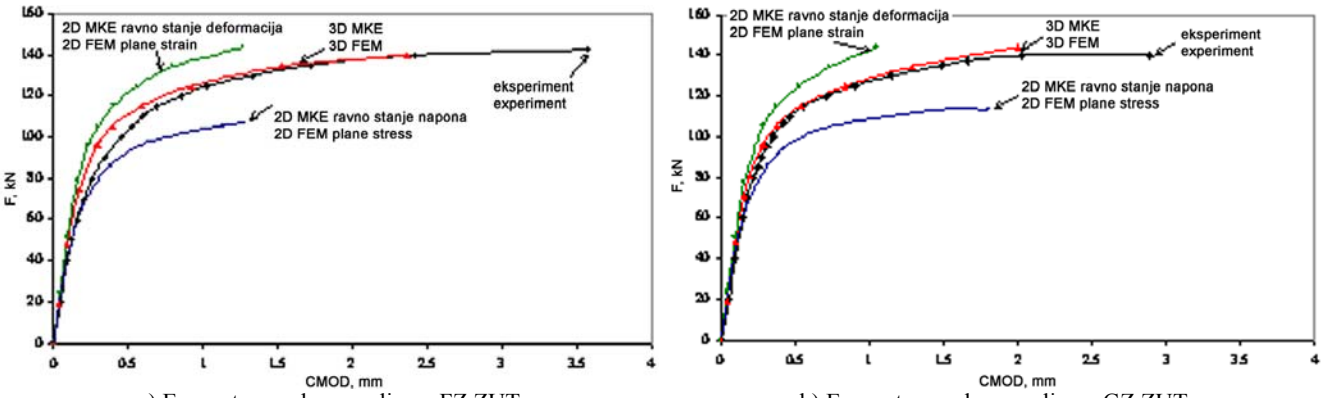
Urađena je numerička analiza tri modela za svaki slučaj: 2D – ravno stanje napona i ravno stanje deformacija, i 3D. Na sl. 7 i 8 su respektivno prikazani numerički rezultati za udaljenu silu F u funkciji CMOD, i za J u funkciji CMOD.

ANALYSIS OF OBTAINED RESULTS

The essential scope of research is analysing the reasons of fracture behaviour exhibited in the experiments, /1/, by adopting proper numerical models for purposes of analyzing the stress-strain state around the crack tip.

Numerical analysis consisted of 3D and 2D modelling. In general, the behaviour of a specimen is 3D, but 2D analysis is also beneficial since the plane stress and plane strain conditions are the two thresholds limiting structural behaviour. The first, plane stress state, is dominant on the free surface, i.e. it is typical for structures of small width, and the second, plane strain, is dominant in the centre of the specimen, i.e. it is typical for structures of greater width. The three-dimensional condition is between these two extreme conditions, since the width of tested specimens is between small and great width, according to definition.

Three models for each case are numerically analyzed: 2D – plane stress and plane strain, and 3D. Numerical results for remote force F vs. CMOD, and for J vs. CMOD are shown in Figs. 7 and 8, respectively.

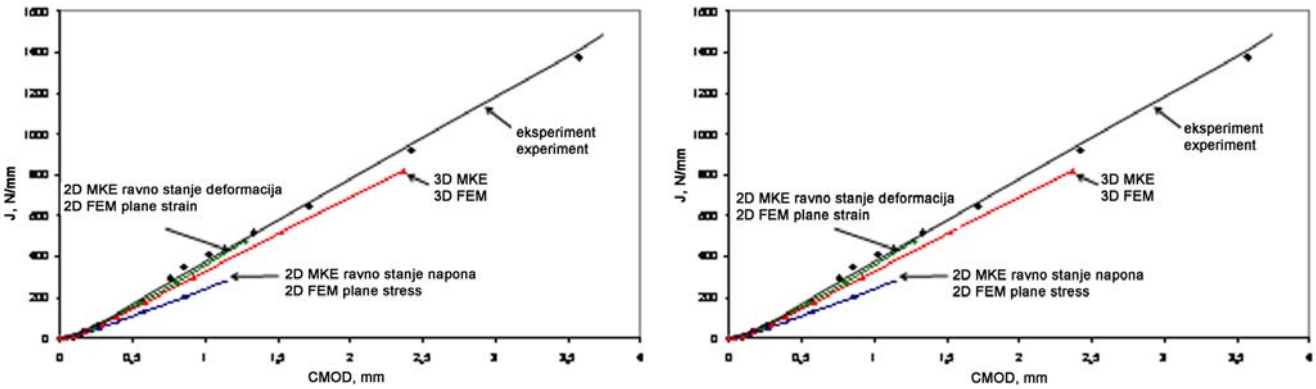


a) Epruveta sa vrhom prsline u FZ ZUT
a) Specimen with crack tip in FG HAZ.

b) Epruveta sa vrhom prsline u GZ ZUT
b) Specimen with crack tip in CG HAZ.

Slika 7. Krive F–CMOD

Figure 7. F vs. CMOD curves.



a) Epruveta sa vrhom prsline u FZ ZUT
a) Specimen with crack tip in FG HAZ.

b) Epruveta sa vrhom prsline u GZ ZUT
b) Specimen with crack tip in CG HAZ.

Slika 8. Krive J–CMOD

Figure 8. J vs. CMOD curves.

Oba para krivih, F–CMOD i J–CMOD pokazuju dobro slaganje sa eksperimentom i 3D numeričkim rezultatima, sl. 7 i 8. U poređenju sa 2D analizom, eksperimentalne krive se nalaze između dva ekstremna uslova, što je i očekivano.

Both pairs of curves, F–CMOD and J–CMOD exhibited good agreement with experimental and 3D numerical results, Figs. 7 and 8. Comparing with 2D analysis, experimental curves were between two extreme conditions, as expected.

Delimično neslaganje numeričkih i eksperimentalnih rezultata se može objasniti sledećim rezonovanjem: a) geometrijsko uprošćenje zavarenog spoja, podrazumevajući oblik, dimenzije, kao i sastav koji je aproksimiran sastavom korena, popune i pokrivnih prolaza, iako je sačinjen iz mnogo više različitih mikrostrukturnih oblasti sa različitim mehaničkim osobinama; b) uprošćenje ponašanja materijala, imajući u vidu analitičko određivanje – procenu σ–ε krivih za oblasti zavarenog spoja koristeći zakon Ramberg-Ozgud; i c) analiza konačnim elementima koja je ovde upotrebljena ne uključuje i širenje prsline.

Dobro slaganje eksperimenta i numeričke simulacije je očigledno, što dozvoljava dalje razmatranje dobijenih rezultata, posebno raspodele napona i deformacija.

Radi procene ponašanja spoja, sledi raspodela deformacija i napona u sredini debljine epruvete za različite nivoe napona.

Konture na slikama su podešene radi prikaza tipičnih vrednosti deformacije: 0.2% – što odgovara naponu tečenja, i izduženja A (%) – u trenutku loma. Analizirani su ekvivalentni Fon Mizes deformacija i napon.

Kao što se vidi, mismečing čvrstoće šava ima značajnu ulogu raspodeli deformacija, u oba slučaja.

Raspodela deformacija za slučaj 1 (vrh prsline je lociran u finozrnom ZUT), prikazano na sl. 9a, pokazuje jak uticaj okolnih oblasti sa različitim osobinama i dimenzijama, potiskujući deformaciju u pravcu osnovnog materijala. Ovaj efekt je posledica nekoliko istovremenih uticaja. Zapravo, prslina se nalazi u oblasti finozrnog ZUT, koja se nalazi između grubozrne oblasti sa većim naponom tečenja ($R_{p0,2}$ = 605 MPa) i osnovnog materijala sa manjim naponom tečenja ($R_{p0,2}$ = 420 MPa). Deformacija je blokirana u pravcu metala šava i usmerena je ka osnovnom materijalu pri manjim, a isto tako i pri većim opterećenjima. Ovo se može objasniti sledećim razlozima: prvo, GZ ZUT visoke čvrstoće deluje kao barijera, sprečavajući razvoj deformacije u pravcu manje duktilnih struktura; drugo, usled tog ograničenja i velike koncentracije napona oko vrha prsline, deformacija je usmerena ka osnovnom materijalu; i treće, pomeranje deformacije ka osnovnom materijalu je takođe poduprto metalom šava, iako mu je čvrstoća malo veća od osnovnog materijala, sl. 2, ali ima mnogo veću dimenziju u odnosu na ZUT.

U slučaju 2, sl. 9b, prslina se nalazi u materijalu sa vrlo velikim naponom tečenja, koji je okružen duktilnijim finozrnim ZUT i metalom šava, sa sličnim naponima tečenja, $R_{p0,2}$ = 461 i 478 MPa, respektivno. Pri manjim opterećenjima, sa boljom duktilnošću, okolni finozrni ZUT, kao i metal šava, oba apsorbuju deformaciju, time opuštajući oblast vrha prsline lociranoj u grubozrnom ZUT. Pri većim opterećenjima, ne samo usled nešto manjeg napona tečenja, već i zbog pomerenog centra rotacije, deformacija se pomera ka osnovnom materijalu kroz finozrni ZUT, sl. 9b. Usled te apsorpcije deformacije, plastična zona oko vrha prsline je manja u poređenju sa onom u slučaju 1.

Tipične raspodele napona u trenutku inicijacije prsline u osnovnom materijalu su prikazane na sl. 10.

The partial disagreement between numerical and experimental results can be explained by the following reasoning: a) geometrical simplification of the welded joint, including its shape, dimensions, and its composition which is approximated as composed of root, fill, and surface passes, although it contains much more different microstructural regions with different mechanical properties; b) material behaviour simplification, having in mind the analytical determination – assessment of σ–ε curves for welded joint regions using Ramberg-Osgood law; and c) the finite element analysis used here did not include crack extension.

Good agreement between experiment and numerical simulation is obvious, thus allowing further consideration of the revealed results, particularly of the stress and strain distribution.

In order to assess joint behaviour, in the following the distribution of strain and stress at thickness centre of specimen is shown for different loading levels.

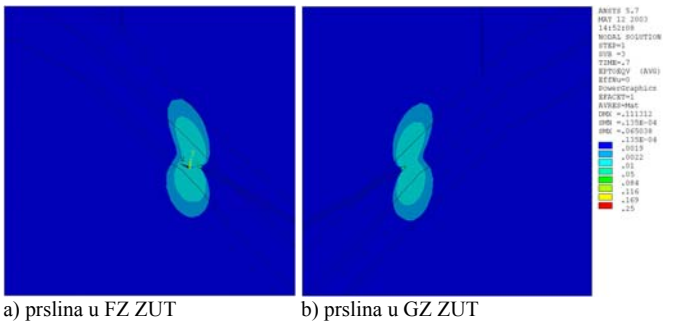
The contour displays are set to represent typical strain values: 0.2% – corresponding to Yield strength, and elongation A (%) – corresponding to rupture stage. The equivalent von Mises strain and stress are analysed.

As shown, in both cases the weld strength mismatch has significant role in strain distribution.

Strain distribution for case 1 (crack tip located in fine-grained HAZ), as presented in Fig. 9a, shows strong influence of surrounding regions with different properties and size, pushing the deformation in the direction of the base metal. This effect is a consequence of several associated influences. Namely, the crack is located in fine-grained HAZ region which is placed between coarse-grained region with higher yield strength ($R_{p0.2}$ = 605 MPa) and base metal with lower yield strength ($R_{p0.2}$ = 420 MPa). The deformation is blocked in the direction of weld metal and is directed towards the base metal for lower, but also for higher loads. This could be explained by following reasons: first, the high strength CG HAZ acts like a barrier, preventing the propagation of deformation in the direction of less ductile structures; and second, due to this constraint and high stress concentration around the crack tip, deformation is directed toward the base metal; and third, the shifting of deformation towards the base metal is supported by weld metal as well, although having only slightly higher strength than the base metal, Fig. 2, but much larger size compared to HAZ.

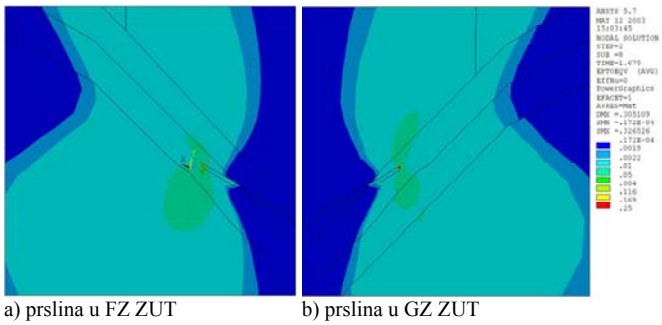
In case 2, Fig. 9b, the crack is located in the material with high yield strength, surrounded by more ductile fine-grained HAZ region and weld metal, having similar yield strengths, $R_{p0.2}$ = 461 and 478 MPa, in respect. At lower loads, having better ductility, the surrounding fine-grained HAZ, as well as the weld metal, both absorb deformation, thus relaxing the crack tip region placed in coarse-grained HAZ. At higher loads, not only because of slightly lower yield strength, but also because of the shifted rotation centre, deformation shifts toward the base metal through fine-grained HAZ, Figs. 9b. Due to this absorption of deformation, the plasticized zone around the crack tip is smaller compared to the one in case 1.

Typical stress distributions at the instant of crack initiation in base metal are shown in Figs. 10.



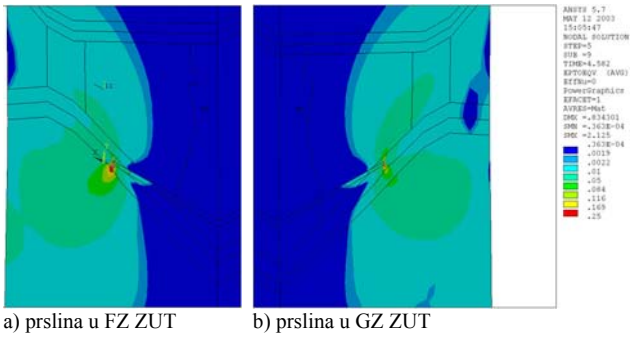
a) prslina u FZ ZUT b) prslina u GZ ZUT
b) crack in FG HAZ b) crack in CG HAZ

Ekvivalentna deformacija pri udaljenom naponu σ = 83,33 MPa ≡ F = 4 t
Equivalent strain at remote stress σ = 83.33 MPa ≡ F = 4 t.



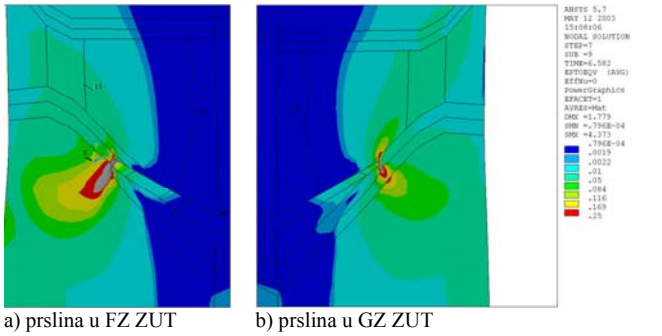
a) prslina u FZ ZUT b) prslina u GZ ZUT
b) crack in FG HAZ b) crack in CG HAZ

Ekvivalentna deformacija pri udaljenom naponu σ = 166.67 MPa ≡ F = 8 t
Equivalent strain at remote stress σ = 166.67 MPa ≡ F = 8 t.



a) prslina u FZ ZUT b) prslina u GZ ZUT
b) crack in FG HAZ b) crack in CG HAZ

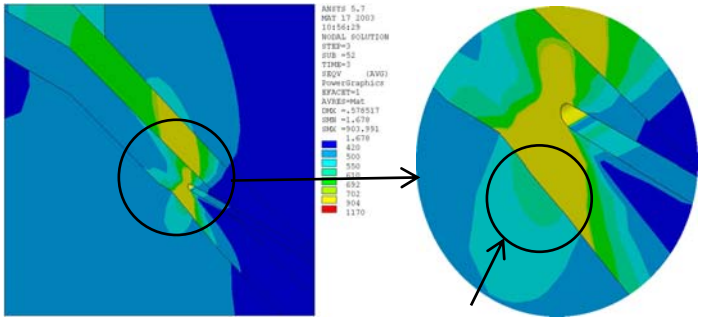
Ekvivalentna deformacija pri udaljenom naponu σ = 250 MPa ≡ F = 12 t
Equivalent strain at remote stress σ = 250 MPa ≡ F = 12 t.



a) prslina u FZ ZUT b) prslina u GZ ZUT
b) crack in FG HAZ b) crack in CG HAZ

Ekvivalentna deformacija pri udaljenom naponu σ = 291.7 MPa ≡ F = 14 t
Equivalent strain at remote stress σ = 291.7 MPa ≡ F = 14 t.

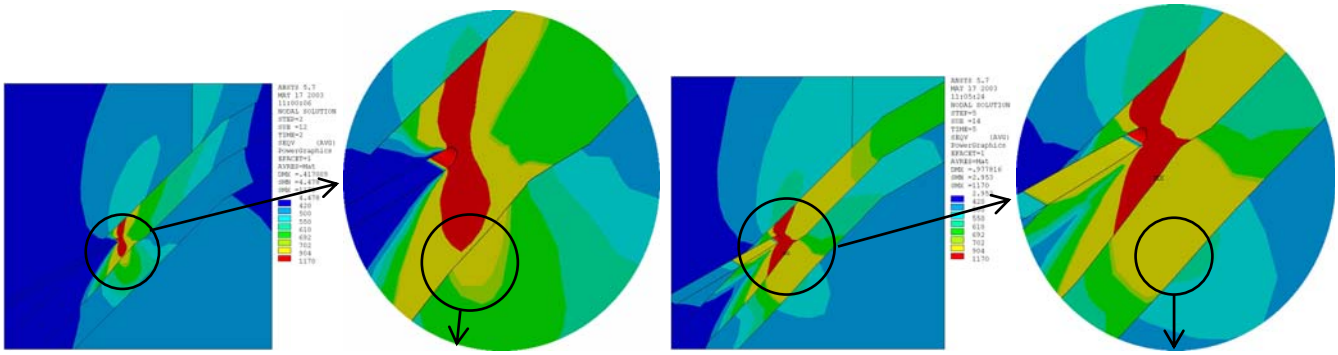
Slika 9. Prostiranje deformacija u frontu prsline
Figure 9. Strain propagation at the crack front.



pri udaljenom naponu σ = 220 MPa ≡ F = 10,6 t
at remote stress σ = 220 MPa ≡ F = 10.6 t

dostizanje R_m osnovnog materijala
reaching R_m of the base metal

Slika 10. Raspodela napona za slučaj 1 (vrh prsline lociran u FZ ZUT)
Figure 10. Stress distribution for case 1 (crack tip located in FG HAZ).



a) dostizanje R_m FZ ZUT pri udaljenom naponu σ = 200 MPa (F = 9,6 t)
a) reaching R_m of the FG HAZ, a) at remote stress σ = 200 MPa (F = 9.6 t)

b) dostizanje R_m osnovnog materijala pri udaljenom naponu σ = 260 MPa (F = 12,5 t)
b) reaching R_m of the base metal at remote stress σ = 260 MPa (F = 12.5 t)

Slika 11. Raspodela napona za slučaj 2 (vrh prsline lociran u GZ ZUT)
Figure 11. Stress distribution for case 2 (crack tip located in CG HAZ).

ZAKLJUČCI

Ponašanje prsline locirane u finozrnom ZUT je pod značajnim uticajem susednog grubozrnog ZUT, koji je takođe poduprt i metalom šava. Blokiranjem slobodne deformacije, ovaj efekt izaziva jako troosno naponsko stanje. Iako, s druge strane, duktilniji osnovni materijal prima deformaciju, to dovodi do slabljenja otpornosti na lom finozrnog ZUT, u poređenju sa njegovim ponašanjem u stanju kada nema efekta mismečinga, /7/. U drugom slučaju, postoji grubozrni ZUT sa manjom žilavošću loma, ali pošto je okružen oblastima sa manjom čvrstoćom i većom plastičnošću, taj efekt dovodi do apsorpcije deformacija od strane tih duktilnijih oblasti, izazivajući pogodnije naponske uslove u grubozrnom ZUT, naspram njegovog ponašanja pri stanju kada nema efekta mismečinga, /7/.

U svakom slučaju, u oba slučaja postoji velika otpornost na lom zbog efekta barijere mismečinga. Posle inicijalnog širenja prsline u FZ ZUT ili GZ ZUT, relativno mala pojava overmečinga je preusmerila pravac širenja prsline ka slabijem i duktilnijem osnovnom materijalu, što je usporilo brzinu rasta prsline.

U opštem slučaju, pogodnije stanje napona-deformacije oko vrha prsline postiže se u slučaju kada okolni susedni materijal ima manju čvrstoću i veću plastičnost (overmečing), tako da taj materijal apsorbuje deformaciju pod dejstvom opterećenja, time smanjujući napone u zoni vrha prsline, povećavajući otpornost na lom. Ovo se prevashodno odnosi na metal šava, kao najopasnijoj zoni za pojavu prsline. Pristup sa andermečingom je prihvaćen /3–6/ zbog shvatanja da za povoljnije stanje napona-deformacija oko vrha prsline, metal šava treba da je duktilniji i žilaviji, da bi bio u stanju da nosi moguće prsline sa većom sigurnošću. Međutim, ova kombinacija ograničava deformisanje unutar metala šava, što može povećati napone do vrlo kritičnog nivoa, dovodeći do iznenadnog loma.

CONCLUSIONS

Behaviour of the crack placed in fine-grained HAZ is under significant influence of adjacent coarse-grained HAZ supported by the weld metal as well. By blocking the free deformation, this effect causes high tri-axial stress state. Although on the other side, the more ductile base metal receives the deformation, this leads to deterioration of the fracture behaviour of fine-grained HAZ, compared with its behaviour in a state without the effect of mismatch, /7/. In the other case, there is coarse-grained HAZ with lower fracture toughness, but since it is surrounded by regions with lower strength and higher plasticity, this effect leads to absorption of deformation by these more ductile regions, causing more favourable stress conditions for coarse-grain HAZ, compared to its behaviour in a state without the effect of mismatch, /7/.

Anyhow, both cases exhibited high fracture resistance, due to the barrier effect of mismatching. After the initial propagation of the crack in FG HAZ or CG HAZ, relatively small overmatching has changed the crack propagating direction toward weaker and more ductile base metal, thus decreasing the speed of crack propagation.

In general, more favourable stress-strain state around the crack tip is being achieved in the case when the surrounding adjacent material has lower strength and higher plasticity (overmatching), so this material absorbs the deformation under loading, thus reducing stresses in the crack tip zone, and improving fracture resistance. This mostly relates to weld metal, as the most dangerous zone of crack occurrence. Undermatching approach was adopted /3–6/ due to the understanding that for more beneficial stress-strain state around the crack tip, the weld metal should be more ductile and tough, so it can carry the possible cracks with more safety. But, this combination constraints the deformation within the weld metal which could increase the stress level to a very critical value, thus leading to sudden failure.

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