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OCENA INTEGRITETA SFERNOG REZERVOARA

INTEGRITY ASSESSMENT OF SPHERICAL STORAGE TANK

Originalni naučni rad / Original scientific paper
UDK /UDC: 620.169.1:621.642
Rad primljen / Paper received: 1.9.2003.

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Ključne reči
- Integritet konstrukcije
- Sferni rezervoar
- Mismečing zavarenog spoja
- J integral

Keywords
- Structural integrity
- Spherical storage tank
- Weldment mismatching
- J integral

IZVOD

Analiziran je integritet sfernih rezervoara za amonijak (zapremine 1000 m^3, prečnika 12400 mm, debljina zida 30 mm), zato što su otkrivene prsline na liniji stapanja, dužine do 300 mm, različite dubine. Direktnim merenjem J integrala određene su J-R krive za dva položaja vrha prsline (finozrni i grubozrni ZUT). Ove krive su upoređene sa silama rasta prsline, dobijenim analitički, da bi se procenila kritična vrednost pritiska.

ABSTRACT

Integrity of spherical storage tanks for ammonia (volume 1000 m^3, diameter 12400 mm, wall thickness 30 mm) has been analysed because cracks have been found along fusion line, of length up to 300 mm and variable depth. By J integral direct measurement J-R curves have been obtained for two positions of crack (fine grain and coarse grain HAZ). These curves are ploted against crack driving forces, analytically obtained, for the estimation of critical pressure.

UVOD

Dva sferna rezervoara za amonijak (zapremine 1000 m^3, prečnika D =12400 mm i debljine zida t=30 mm), sa maksimalnim radnim pritiskom p=16,5 bar i probnim pritiskom p=25 bar, ispitani su 1998. i 1999. godine metodama bez razaranja (IBR). Pronađene su mnogobrojne prsline, od kojih je najopasnija prslina duž linije stapanja, dužine 300 mm, promenljive dubine. Ova prslina je izvađena brušenjem i rezervoar posle toga saniran navarivanjem. Svi podaci i drugi detalji su dati u lit. /1/, /2/.

U ovom radu je prikazano ispitivanje mehanike loma koje je imalo za cilj da omogući ocenu integriteta sfernog rezervoara u prisustvu prsline, slične otkrivenoj.

EKSPERIMENTALNA ISTRAŽIVANJA I REZULTATI

Iz pridružene probe (sl. 1) oblika ploče (400 x 400 mm), su izrađene epruvete za zatezanje (širina W=24 mm, debljina B=20 mm, dužina L=300 mm, sl. 2).

Slika 1. Skica vađenja epruvete iz probne ploče
Figure 1. Scheme of specimen extraction from a spare plate

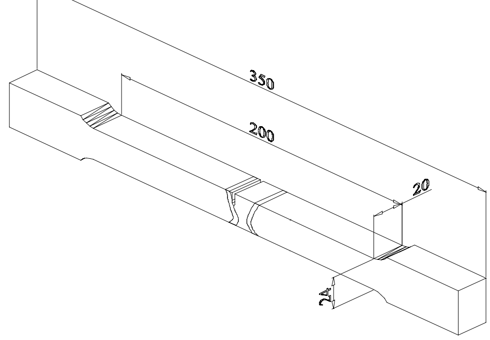
INTRODUCTION

Two spherical storage tanks for ammonia (volume 1000 m^3, diameter D=12400 mm and wall thickness t=30 mm), with the maximum operating pressure p=16.5 bar and the proof pressure p=25 bar, were tested in 1998 and 1999 by non-destructive methods (NDT). Large number of cracks have been found, the most critical of them was the crack along fusion line, 300 mm long, of varibale depth. This crack was grinded and after that the tank was repaired by surfacing. All data and other details are given in Ref. /1/, /2/.

In this paper a fracture mechaincs investigation has been presented with the aim to assess the integrity of the storage tank, in presence of a crack, similar to one detected.

EXPERIMENTAL INVESTIGATION AND RESULTS

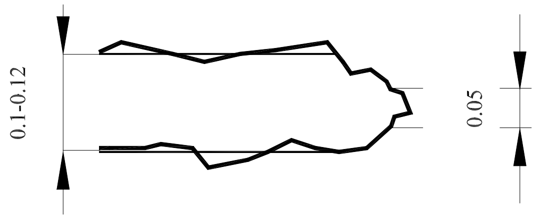
Out of the spare welded sample (Fig. 1), plate (400 x 400 mm), , tensile specimens (width W=24 mm, thickness B=20 mm, length L=300 mm, Fig. 2) were machined.



Slika 2. Izometrija epruvete
Figure 2. Isometry of specimen

Prsline su izrađene elektroerozijom jer je standardnim postupkom zamaranja praktično nemoguće locirati vrh prsline u vrlo uzanoj oblasti ZUT (finozrna – FZZUT ili grubozrna - GZZUT). Primenjena je specijalna procedura, uključujući veoma male jačine struje (cca 1 A) da bi se dobio što oštriji vrh prsline (radijusa manjeg od 0.05 mm, kao što je pokazano šematski na sl. 3).

Cracks were produced by electroerosion because by standard fatigue procedure it was practically impossible to locate the crack tip in the very narrow HAZ subregion (finegrain – FGHAZ or coarse grain - CGHAZ). Special procedure was applied, including very small amperage (cca 1 A) in order to get crack tip as sharp as possible (radius below 0.05 mm, as shown schematically in Fig. 3).



Slika 3. Profil vrha prsline dobijene elektroerozijom

Figure 3. Crack tip obtained by electroerosion

Da bi se utvrdio uticaj otpornosti zavarenog spoja na rast prsline, određene su J-R krive pomoću direktnog merenja J integrala, uvedenog u /3/ i primenjenog na zavarene spojeve u /4/. Merne trake i CMOD merač su postavljeni kao na sl. 4. Deformacije su snimane pri različitim opterećenjima tokom zatezanja.

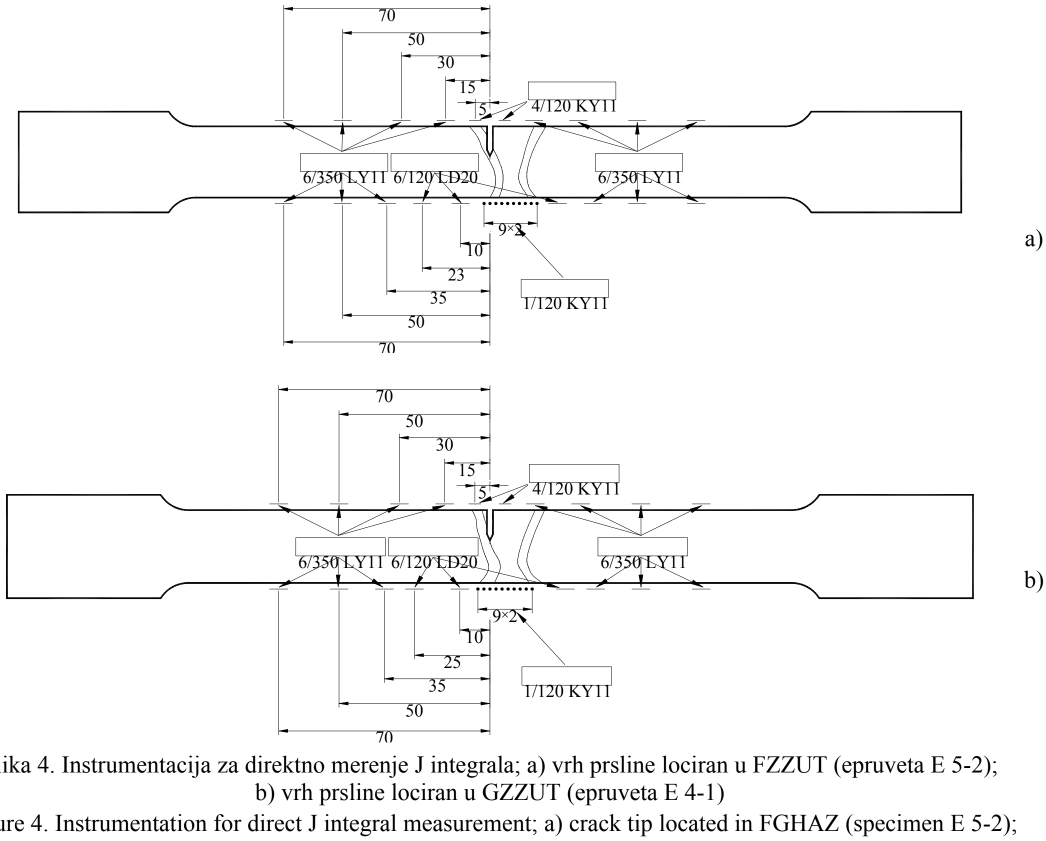
Dužina prsline je određena po sledećoj proceduri:

1. Dužina prsline posle preloma je izmerena na standardni način (prosek merenja u 9 tačaka).
2. Promena nagiba, kao indikacija popustljivosti, je uzeta proporcionalno prirastu dužine prsline.
3. Za početni nagib je pretpostavljeno da je jednak nagibu u linearno elastičnom delu krive sila-CMOD.

In order to evaluate the effect of welded joint resistance to crack propagation, J-R curves were determined by using direct J integral measurement technique, as introduced in /3/ and applied to welded joints in /4/. Strain gauges and CMOD clip gauge were positioned as shown in Fig. 4. Strains were recorded at several loadings during tension.

Crack length was evaluated with following procedure:

1. Crack length after fracture was measured using standard technique (average of measurement in 9 points).
2. The slope change, indicating compliance, is taken as proportional to the crack length extension.
3. Initial slope was assumed to be equal to the slope of linear elastic part of force-CMOD curve.

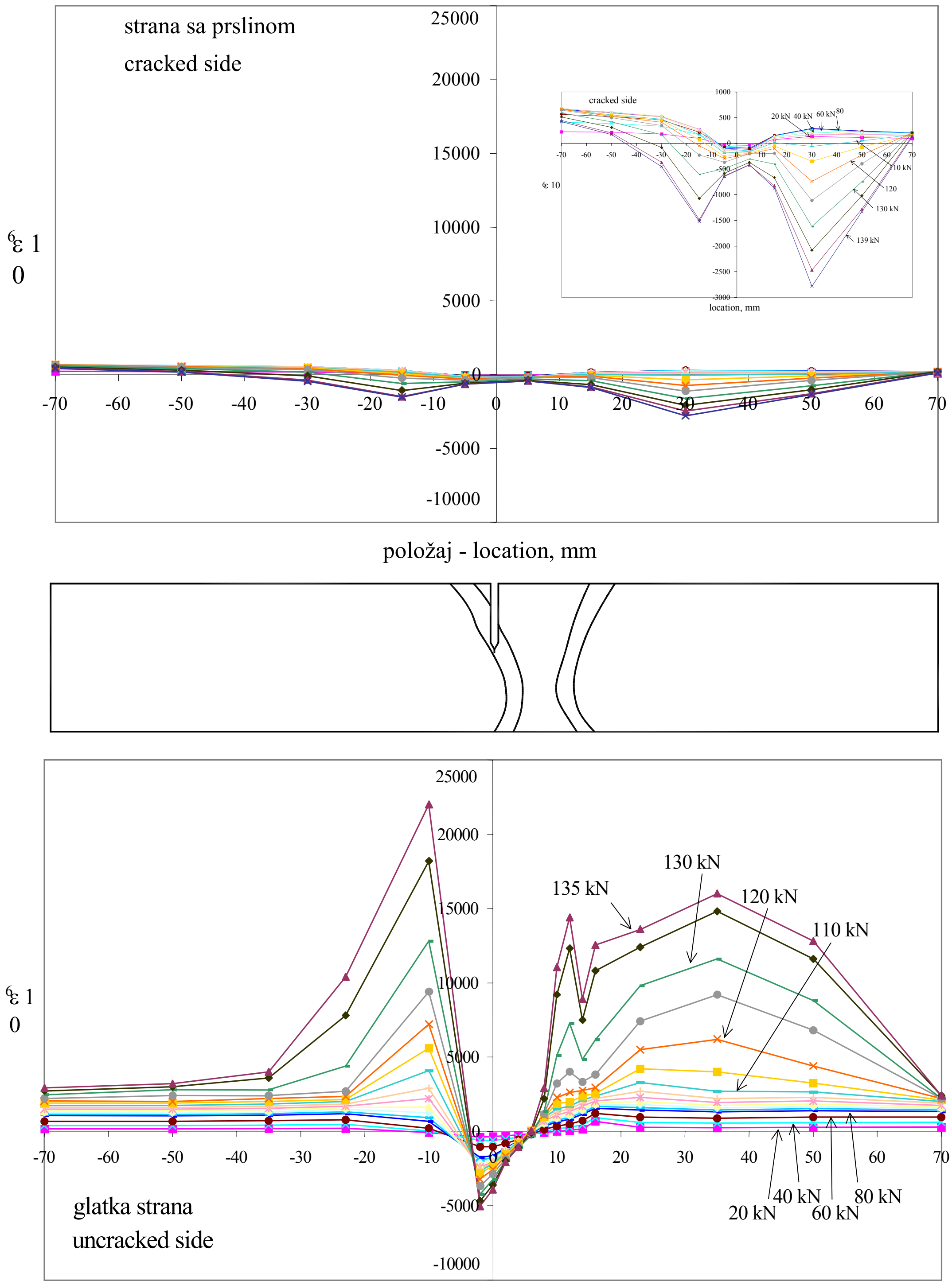


Slika 4. Instrumentacija za direktno merenje J integrala; a) vrh prsline lociran u FZZUT (epruveta E 5-2); b) vrh prsline lociran u GZZUT (epruveta E 4-1)

Figure 4. Instrumentation for direct J integral measurement; a) crack tip located in FGHAZ (specimen E 5-2); b) crack tip located in CGHAZ (specimen E 4-1)

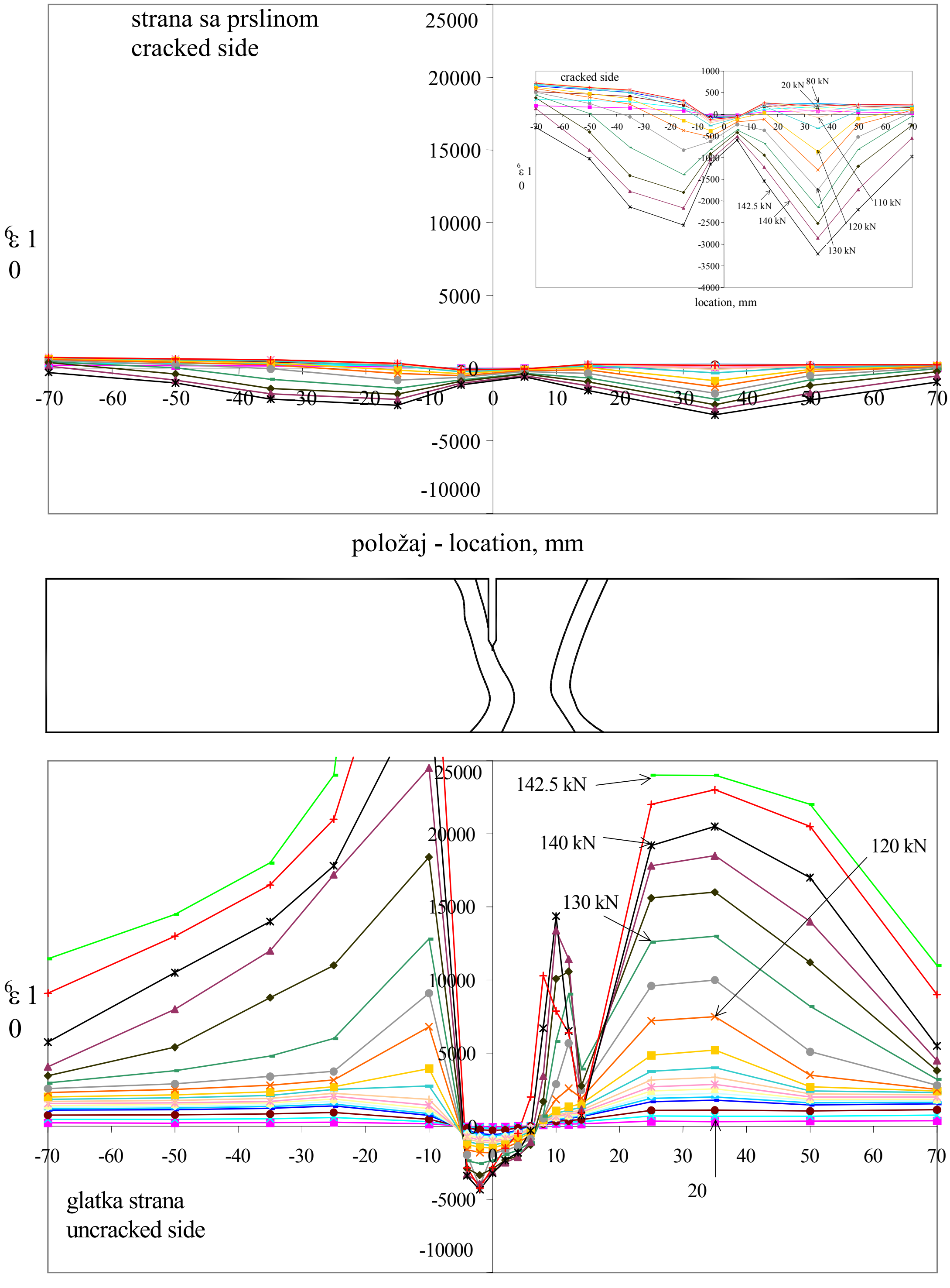
Ispitane su dve epruvete sa različitim položajem vrha prsline (slučaj 1 – vrh prsline lociran u FZZUT i slučaj 2 – vrh prsline lociran u GZZUT). Drugi par epruveta je ispitan na isti način, s tim da se instrumentacija sastojala samo CMOD merača, da bi se verifikovali rezultati. Rezultati dobijeni u vidu raspodele deformacija su prikazani na sl. 5 za slučaj 1 i na sl 6 za slučaj 2. Prikazane su i uvećane deformacije oko vrha psline.

Two specimens with different crack tip position (case 1 - crack tip located in FGHAZ and case 2 - crack tip located in CGHAZ) were tested. Another pair of specimens was tested in the same way, except for the instrumentation which consisted only of CMOD clip gauges, in order to verify results. Results in form of strain distribution are shown in Fig. 5 for case 1 and Fig. 6 for case 2. Magnified deformations around the crack tip are also shown.



Slika 5. Raspodela deformacije - epruveta E 5-2 (slučaj 1)

Figure 5. Strain distribution - specimen E 5-2 (case 1)

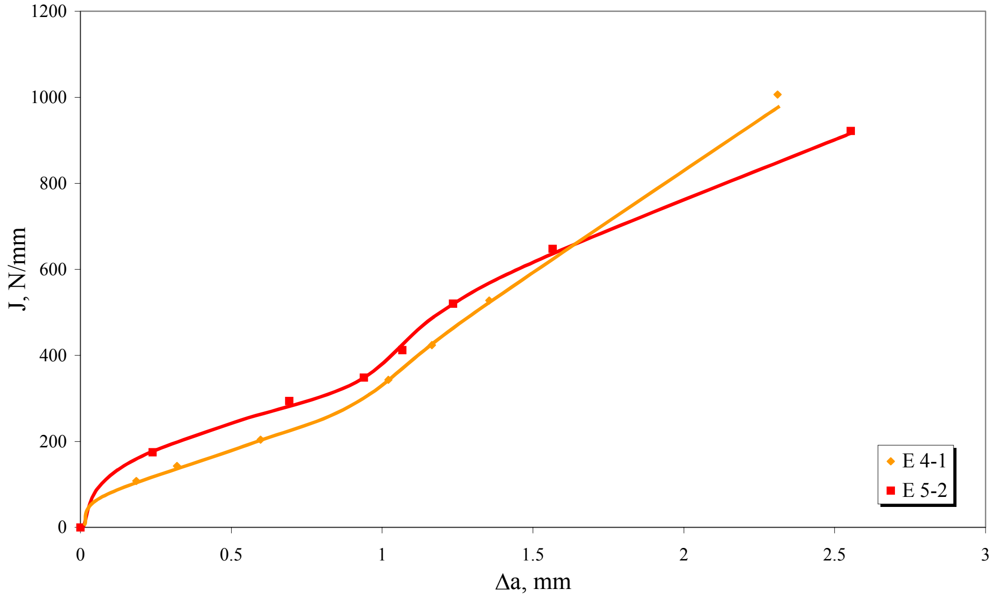


Slika 6. Raspodela deformacije - epruveta E 4-1 (slučaj 2)

Figure 6. Strain distribution-specimen E 4-1 (case 2)

Korišćenjem procedure definisane koju je definisao Rid /2/ izračunat je J integral. Uticaj mismečinga nije uzet u obzir zbog male razlike u naponima tečenja metala šava (MŠ), osnovnog metala (OM), FZZUT i GZZUT. Rezultati u obliku J-R krivih su pokazani na sl. 7. Treba uočiti porast J integrala posle izvesnog prirasta dužina prsline, što je pripisano uticaju mismečinga i ometene deformacije, kao što je kasnije objašnjeno.

Using procedure defined by Read /2/ J integral was evaluated. The influence of weldment mismatching was estimated as negligible, due to small difference in yield strengths of weld metal (WM), base metal (BM), CGHAZ and FGHAZ. Results in form of J-R curves are shown in Fig. 7. One should notice the increase of J integral after certain crack length extension, being the consequence of mismatching and constraint effects, as explained later.



Slika 7. J-R krive za epruvetu 5-2 sa vrhom prsline u FZZUT i za epruvetu 4-1 sa vrhom prsline u GZZUT

Figure 7. J-R curves for specimen 5-2 with crack tip in FGHAZ and for specimen 4-1 with crack tip in CGHAZ

PROCENA INTEGRITETA SFERNOG REZERVOARA

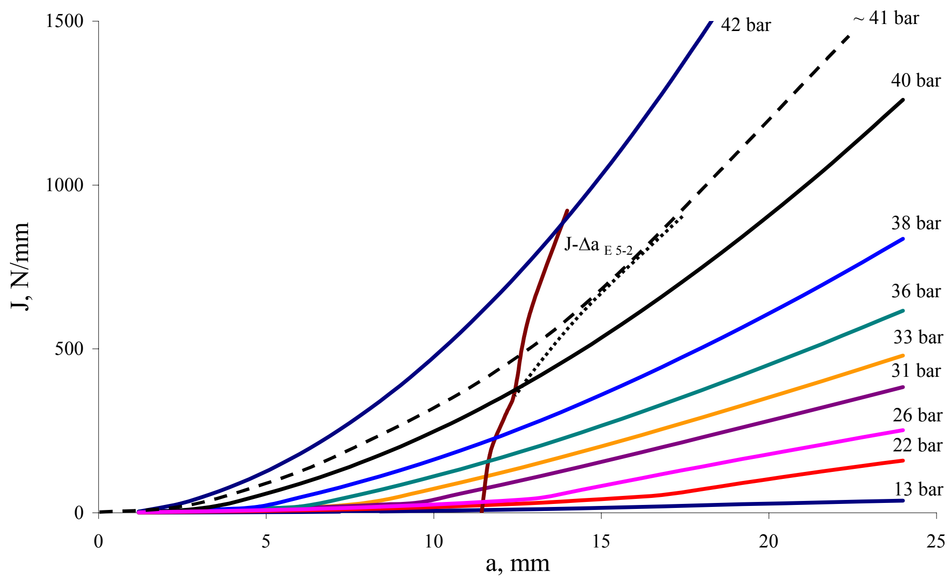
Radi procene integriteta sfernog rezervoara sile rasta prsline pri različitim opterećenjima su upoređene sa otpornošću materijala na rast prsline (*J-Δa* kriva), sl. 8-9. Sile rasta prsline su dobijene pomoću metode niza opruga, primenjene u skladu sa Kingovim modelom /3/, u modifikovanoj varijanti datoj u /6/. Kingov model je korišćen kao najjednostavniji analitički model koji tretira površinske prsline. Pri tome je uticaj heterogenosti zavarenog spoja zanemaren.

Kao što se vidi sa sl. 8 kritični pritisak za slučaj 1 iznosi 41 bar (ako se zanemari porast otpornosti na rast prsline, tj. promena počenog nagiba *J-R* krive), dok je za slučaj 2 ta vrednost veća i iznosi 49 bara, sl. 9. Sličan relativni odnos postoji i ako se promena nagiba *J-R* krivih uzme u obzir.

ASSESSMENT OF SPHERICAL TANK INTEGRITY

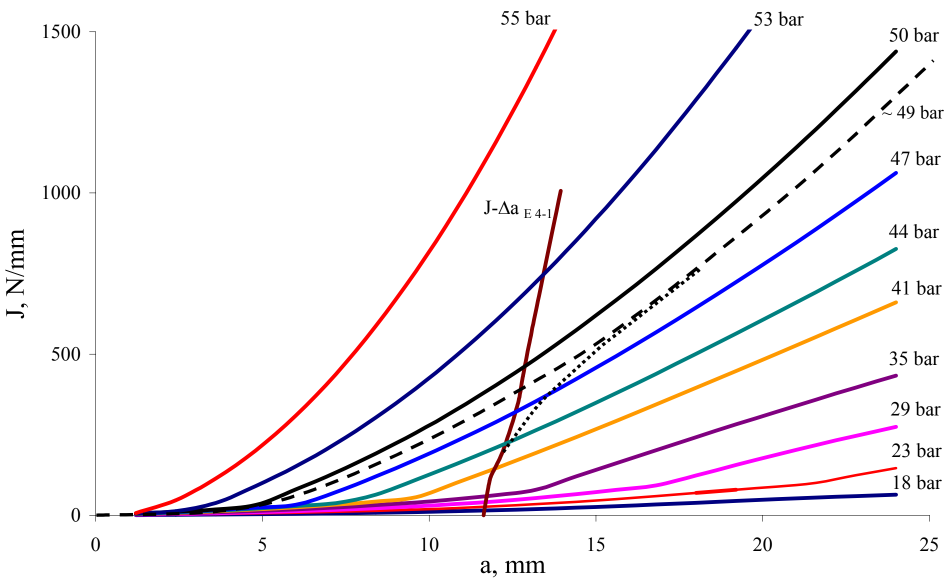
For assessment of the spherical tank integrity crack driving force for different loadings were compared with the material resistance to crack growth (*J-Δa* curves), Fig. 8-9. The crack driving force curves were obtained by the King's model /3/, using the modified variant as given in /6/. The King's model is used as the simplest analytical model treating surface cracks. The influence of weldment heterogeneity was neglected.

As one can see from Fig. 8 the critical pressure for the case 1 is 41 bar (if an increase of crack growth resistance is neglected, i.e. the change of the initial slope of the *J-R* curve), whereas for the case 2 it is 49 bar, Fig. 9. Similar relation exists if the change in *J-R* curve slopes is taken into account.



Slika 8. Zavisnost sile rasta prsline i otpornosti na rast prsline za epruvetu 5-2 sa vrhom prsline u FZZUT (slučaj 1)

Figure 8. Relationship of crack driving force and crack resistance for specimen 5-2 with crack tip in FGHAZ (case 1)



Slika 9. Zavisnost sile rasta prsline i otpornosti na rast prsline za epruvetu 4-1 sa vrhom prsline u GZZUT (slučaj 2)

Figure 9. Relationship of crack driving force and crack resistance for specimen 4-1 with crack tip in CGHAZ (case 2)

DISKUSIJA I ZAKLJUČCI

Relativno mali overmečing može da bude efikasna zaštita zavarenog spoja od rasta prsline koja je nastala duž linije stapanja u uslovima naponske korozije. U oba razmatrana slučaja (vrh prsline u FZ ili GZ ZUT) posle početnog perioda rasta prsline, dolazi do njenog skretanja prema duktilnijem osnovnom materijalu, što smanjuje brzinu rasta.

Ometena deformacija i prisustvo barijera, u slučaju prsline u FZZUT, uslovila je smanjenje otpornosti na rast prsline u poređenju sa standardnom epruvetom za savijenje u tri tačke (SENB) izvađene iz simuliranog uzorka /1/. S druge strane, u slučaju GZZUT, otpornost na rast prsline dobijena epruvetama korišćenim u ovom radu je povećana u odnosu na standardne epruvete iz simulirane GZZUT /1/. Ova razlika u ponašanju različitih epruveta ukazuje na važnost direktnog merenja J integrala u slučaju izraženog ometanja deformacije i barijera, što je tipično za zavarene spojeve /1/.

Prema tome, može da se zaključi da direktno merenje J integrala omogućava dobijanje *J-R* krivih za nestandardne epruvete, bez ograničenja u pogledu njihovog oblika i veličine, kao i veličine prsline. U kombinaciji sa jednostavnim modelom za određivanje sile rasta prsline, kao što je Kingov model, *J-R* krive omogućavaju procenu integriteta jednostavnih konstrukcija, kao što su sferni rezervoari.

DISCUSSION AND CONCLUSIONS

The small overmatch in the welded joint can be effective protection of carack growth initiated along fusion line in stress corrosion condition. In both considered cases (crack tip in FGHAZ or CGHAZ) after the initial crack growth, its advancement direction turned to more ductile base metal, thus decreasing the propagation rate.

The constraint and the barrier effect, in case of crack in FGHAZ caused decreasing of the fracture resistance compared with the fracture resistance of standard SENB specimens with simulated FGHAZ /1/. On the other hand, in case of crack in CGHAZ this influence has increased the fracture resistance compared with the fracture resistance of standard SENB specimens with simulated CGHAZ /1/. This difference in behaviour indicates siginficance of direct measurement of J integral in the case of constraint and acting barriers that is typical for weldments /1/.

Therefore, one can conclude that the method of direct J integral measurement enables evaluation of *J-R* curves for non-standard specimens, with no limits regarding their shape and dimensions, as well as the crack size. Through its combination with simple analytical model for crack driving force evaluation, like the King's model, *J-R* curves enables an integrity assessment of simple structure like spherical tank.

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