



Muralimohan Cheepua, Jung Hyun Parkb, Hyo Jin Baekc, Sang Myung Chod

Improvement of hot cracking susceptibility and productivity using Super-TIG welding for 9% Nickel-steel

Poboljšanje osetljivosti na vruće prsline i produktivnosti upotrebom Super-TIG zavarivanja čelika sa 9% nikla

NASTAVAK IZ PREDHODNOG BROJA
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CONTINUED FROM PREVIOUS ISSUE
Part 2

The using of C-filler the higher deposition rate can obtain, due to the high melting efficiency compared to the conventional circular filler. The cross-sectional view of the C-Filler is illustrated in Figure 2. The Super-TIG welding was developed to weld in full automation and the complete equipment for high stability and reproducibility. The developed Super-TIG welding setup and feeding system of C-filler can be seen clearly in Figure 3.

The Fisco hot crack tests were conducted as per the standard test procedure [12]. The welding processes of FCAW and Super-TIG welding method was applied on 9% Ni steel for the evaluation of hot crack susceptibility with the Alloy 625 wire, Alloy C-276 wire and Alloy 625 C-Filler.

Korišćenjem C-dodatnog materijala može se dobiti veća brzina nanošenja, zbog visoke efikasnosti topljenja u poređenju sa klasičnim kružnim dodatnim materijalom. Prikaz poprečnog preseka C-dodatnog materijala ilustrovano je na slici 2. Super-TIG zavarivanje je razvijeno za potpuno automatizovano zavarivanje i kompletnu opremu za veliku stabilnost i ponovljivost. Razvijeni sistem za podešavanje i dodavanje C-dodatnog materijala kod Super-TIG, može se jasno videti na slici 3.

Fisco testovi na vruće prsline, obavljani su prema standardnom postupku ispitivanja [12]. Postupci zavarivanja FCAW i Super-TIG metoda zavarivanja primenjeni su na čeliku sa 9% Ni za procenu osetljivosti na vruće pukotine sa žicom od legure 625, legure C-276 i legure 625 C-dodatnim materijalima.

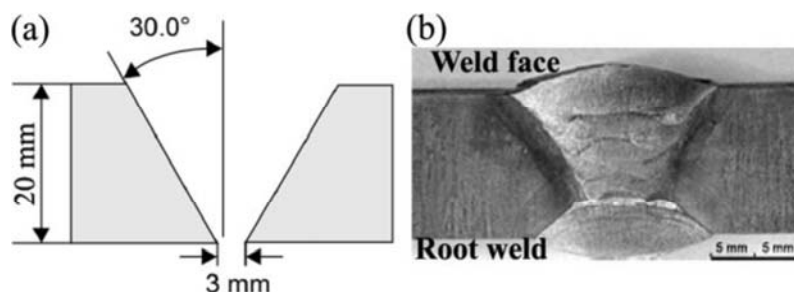


Figure 1. Super-TIG welding of 9% Ni steel butt joint (a) groove design (b) cross-sectional view of weld macrostructure
Slika 1. Super-TIG zavarivanje spoja čelika sa 9% Ni (a) dizajn žljeba (b) pogled na poprečni presek makrostrukture šava

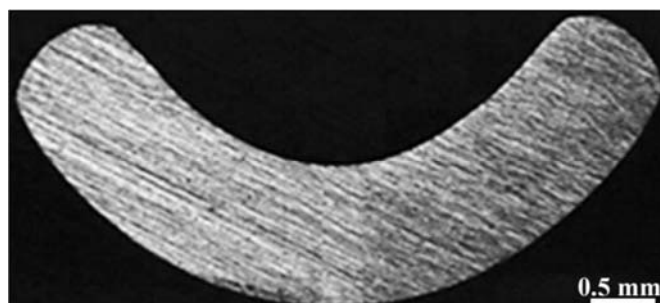


Figure 2. Macro-section of the C-Filler for the Super-TIG welding
Slika 2. Makro-presek C-dodatnog materijala za Super-TIG zavarivanje

After the completion of Fisco hot crack tests weld deposits was cut and observed for the formation of cracks over the weld bead and along the cross-section. The butt welds also were cut in transverse

Nakon završetka Fisco testova na vruće prsline, naneti metal šava je izrezan i uočene su prsline kroz zavar i duž preseka. Sučeoni šavovi su takođe presečeni u poprečnom smeru radi metalurškog pregleda. Ispitivanja zatezanjem su izvedena



direction for the metallurgical examination. The tensile tests were conducted as per the ASTM E8 standard to evaluate the tensile properties of the joints [13]. The Charpy impact test was conducted to investigate the impact energy of the weld metal as per the ASTM A370 standard procedure at a cryogenic temperature of $-196\text{ }^{\circ}\text{C}$ [14]. The welding conditions for Super-TIG welding is different from the conventional TIG welding process due to the high melting efficiency of the filler. The deposition rate and welding currents are also very high per each pass over the conventional TIG welding. During welding, to fill the width of the groove, the oscillation was used for each pass. The inter-pass temperature of $100\text{-}120\text{ }^{\circ}\text{C}$ was maintained throughout the welding. The welding conditions for the Super-TIG welding of butt welds are given in Table 1.

prema standardu ASTM E8 za procenu zateznih svojstava spojeva[13]. Charpi test je sproveden kako bi se iznašla udarna energija metala šava prema ASTM A370 standardu pri kriogenoj temperaturi od $-196\text{ }^{\circ}\text{C}$ [14]. Uslovi zavarivanja za Super-TIG zavarivanje su različiti od uobičajenih postupaka zavarivanja TIG, zbog visoke efikasnosti topljenjadodatnog materijala. Brzina nanošenja i struje zavarivanja su takođe vrlo visoke po svakom sloju u odnosu na uobičajeno TIG zavarivanje. Tokom zavarivanja, za popunjavanje širine žljeba, oscilacija je korišćena za svaki prolaz. Međuslojna temperatura od $100\text{-}120\text{ }^{\circ}\text{C}$ održavana je tokom zavarivanja. Uslovi zavarivanja za Super-TIG zavarivanje sučeonih šavova dati su u Tabeli 1.

Table 1. Welding conditions for the Super-TIG welding of 9% Ni steel butt joints [11]

Tabela 1. Uslovi zavarivanja za Super-TIG zavarivanje čelika sa 9% Ni [11]

Filler	Alloy 625 C-Filler							
Shielding gas	Ar+7%He							
Deposition method	Single pass per single layer							
Pass	Front size						Back size	
Current (A)	F1	F2	F3	F4	F5	F6	B1	B2
Welding speed (cm/min)	135	360	420	480	480	420	300	460
Welding speed (cm/min)	11,9	28,6	28,3	25	22,8	22,0	28,2	20,4
Deposition rate (Kg/hr)	1,7	3,6	5,0	5,5	6,0	5,0	2,5	6,0

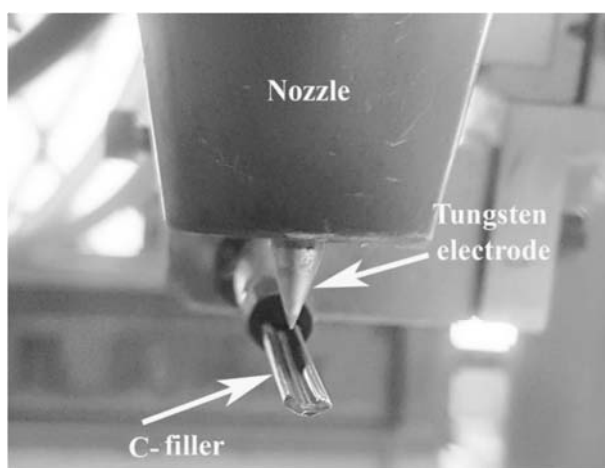


Figure 3. Super-TIG welding experimental setup

Slika 3. Super-TIG podešavanje zavarivanja tokom eksperimenta

3. Results and Discussions

3.1 Hot cracking test

The welding of structural components required high deposition rates with stable and reliable welding processes. To obtain these conditions using conventional welding methods is very difficult due to the narrow range of heat input rate for special

3. Rezultati i diskusija

3.1 Test na vruće prsline

Zavarivanje konstrukcionih delova zahteva velike brzine nanošenja, stabilnim i pouzdanim postupcima zavarivanja. Dobijanje ovih uslova korišćenjem konvencionalnih postupaka zavarivanja je veoma teško zbog uskog raspona



alloys. Super-TIG welding has been applied to overcome these issues. Super-TIG welding can melt the C-Filler much faster compared to conventional circular filler. Therefore the deposition rate much higher at the controlled heat input level as the fastest growing of technology in various fields demands the most rapid fabrication fuel tanks techniques to fulfill their needs in a short time.

Most recently, the demand for liquified natural gas is increasing across the world, which is an environmentally friendly source of energy. The number of shipbuilding orders for large-sized carriers for a large amount of transportation is rising. Such large tanks need a quite higher thickness of 9% Ni steel of 20 mm thick is required [7]. Also, the using of LNG for marine fuel has been emerging due to the regulations in MARPOL Annex VI air pollutants in ship's exhaust gas. Due to this, the construction of LNG fuelled ships gradually increasing, though relevant LNG vessels, storage tanks, and LNG bunkering ships are being continuously developed. The change of fuel tanks in marine ships challenges the fabrication of LNG.

So far, the maximum thickness of LNG fuel tanks is about 15 mm and are welding with FCAW process using Alloy 625 and Alloy C-276 wires. Currently, the large-sized fuel tanks for the large LNG carrier ships demanding to built for a large number of ships. For the above requirements, the fabrication industry is always searching for solutions to made faster weld deposits without losing welds strength and quality. The use of the higher welding current in FCAW or any other process for the higher depositions always encountered a large number of problems. Moreover, the cost of the filler is another problem when using the Hastelloy filler in FCAW process. Most recently, Super-TIG welding has proven to be deposit higher weld metal depositions with the controlled heat input and without any welding defects. Since 9% Ni steels are susceptib FCAW weld metal le to hot cracks at higher currents or high heat input and degradation of its corrosion properties. To prove that the weldability evaluation tests were conducted for Super-TIG and FCAW welding processes using Alloy 625 and Alloy C-276 consumables. The Fisco hot crack tests used widely for weldability evaluation 9% Ni steels. The present study applied this test in the assessment of hot crack test for the wide range of welding current. For the maximum allowable current, the Fisco hot crack test weld beads presented in Fig. 4. The welds with FCAW for the Alloy 625 wire showed the presence of cracks along with the weld bead and are widens compared to other welding methods.

unosa toplote za specijalne legure.

Za prevazilaženje ovih problema primenjeno je Super-TIG zavarivanje. Super-TIG zavarivanje može rastopiti C-dodatni materijal mnogo brže u poređenju sa klasičnim kružnim dodatnim materijalom. Stoga je brzina nanošenja znatno viša na nivou kontrolisanog unosa toplote jer najbrže rastuća tehnologija u raznim oblastima, zahteva najbrže tehnike izrade da bi se u kratkom roku ispunile potrebe. U poslednje vreme, širom sveta raste potražnja za utečnjem prirodnim gasom, koji je ekološki prihvatljiv izvor energije. Povećava se broj porudžbina za izgradnju brodova za velike prevoznike. Takvi veliki rezervoari zahtevaju prilično veću debljinu čelika sa 9% Ni, debljine 20 mm [7]. Takođe, upotreba TPG-a za gorivo pojavila se zbog propisa u MARPOL-u Aneks VI zagađivača vazduha u brodskim izduvnim gasovima. Zbog toga se izgradnja brodova za pogon na TPG postepeno povećava, mada se kontinuirano razvijaju relevantni brodovi za TPG, rezervoari za skladištenje i TPG-ovi brodovi. Promena rezervoara za gorivo na brodovima dovodi u pitanje proizvodnju rezervoara za gorivo TPG.

Do sada, maksimalna debljina rezervoara za gorivo TPG iznosi oko 15 mm i zavaruju se FCAW postupkom koristeći žice od Alloy 625 i Alloy C-276. Trenutno, veliki rezervoari goriva za velike brodove na UPP zahtevaju ih za veliki broj brodova.

Za gore navedene zahteve, proizvodna industrija uvek traži rešenja za brže nanošenje zavara bez gubitka čvrstoće i kvaliteta zavarivanja. Upotreba većih struja zavarivanja u FCAW ili bilo koji drugi postupak za veća deponovanja uvek je nailazila na veliki broj problema. Štaviše, trošak za dodatni materijal je još jedan problem kada se koristi Hastelloy dodatni materijal kod FCAW postupka. Nedavno se pokazalo da Super-TIG zavarivanje ostavlja veće metalne depozite sa kontrolisanim unosom toplote i bez grešaka u zavarivanju. Pošto je čelik sa 9% Ni podložan pri FCAW zavarivanju, odn. metal šava vrućim prslinama pri većim strujama ili visokim unosom toplote i degradaciji svojstava korozije. Radi dokazivanja, sprovedena su ispitivanja za postupke zavarivanja Super-TIG i FCAW korišćenjem dodatnog materijala Alloy 625 i Alloy C-276. Fisco testovi na vruće prsline se široko koriste za procenu zavarljivosti čelika sa 9% Ni. Ova studija je koristila ovaj test u proceni ispitivanja na vruće prsline za široki opseg jačina struje zavarivanja. Za maksimalnu dozvoljenu struju, Fisco test je predstavljen na slici 4. Zavarivanje FCAW žicom od legure 625 pokazalo je prisustvo prsline duž zavara u šavu i šire se, u poređenju s drugim postupcima zavarivanja.

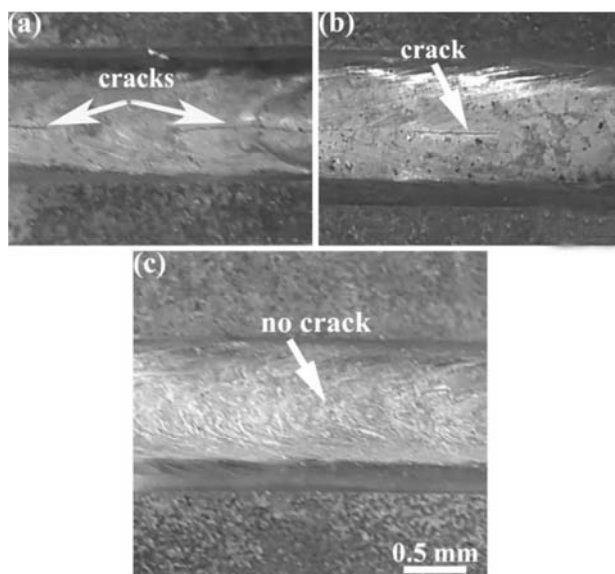


Figure 4. Weld beads with hot cracks (a) FCAW with Alloy 625 wire (b) FCAW with Alloy C-276 wire and (c) Super-TIG welding with Alloy 625 C-Filler after Fisco hot crack test

Slika 4. Zavari u šavu sa vrućim prslinama (a) FCAW sa žpcom od legure 625 (b) FCAW sa žicom od legure C-276 i (c) Super-TIG zavarivanje sa legrom 625 C-dodatnim materijalom, nakon Fisco testa na vruće prsline

As shown in Figure 4(a) the continuous cracks at center of the weld. The stresses induced in the weld metal in a narrow test coupon showed the solidification issues with the higher welding speed and current. At these conditions, the deposited weld from FCAW is highly susceptible to hot cracks. Even though its behavior almost similar to Alloy 625 when using of Alloy C-276 wire. However, the formation of cracks and total crack length for the Alloy C-276 welds is less, and it is moderately susceptible to hot cracks at the higher deposition rates. Whereas the Super-TIG welding with C-Filler of Alloy 625 weld bead showed no evidence of cracks formation through the weld. The higher welding speed and almost two times of higher welding current were used for Super-TIG welding. Figure 4(c) clearly shows the clean and crack-free weld bead formation at higher deposition rates. Therefore the FCAW welds are highly susceptible to hot cracks while the Super-TIG welding is less susceptible. After the Fisco hot crack tests, the weld bead was cleaned and applied the penetration test to identify the micro cracks in the welds. Moreover, the weld beads are also inspected by its cross-sectional macrostructure

The microstructures of the cross section of the weld beads depicted in Figure 5. Based on the cross-sectional macrostructure of the weld metal, depth and its direction of the hot crack was observed. The large penetration cracks are not suggestible for the higher deposition rates. The depth of the crack in Alloy C-276 wire weld metal is comparatively less over the Alloy 625 wire. There are no cracks identified even in the thickness direction of the weld metal of Super-TIG welding.

Na slici 4 (a) prikazane su neprekidne prsline u sredini zavara. Naprezanja koja su indukovana u metalu šava u uskom ispitnom komadu, pokazala su probleme pri otvrdnjavanju sa većom brzinom i strujom zavarivanja. U tim uslovima, deponovani šav izveden FCAW je visoko podložan vrućim prslinama. Ponašanje je gotovo slično sa Alloy 625 kada se koristi Alloy C-276 kao žica. Međutim, formiranje prsline i ukupna dužina prsline za legure C-276 je manje, i umereno je podložno vrućim prslinama pri većim brzinama nanošenja. Dok Super-TIG zavarivanje sa C-dodatnim materijalom od legure 625 u šavu se nije pokazalo postojanje prsline kroz zavar. Veća brzina zavarivanja i gotovo dva puta veća struja zavarivanja korišćeni su za zavarivanje Super-TIG. Slika 4 (c) jasno pokazuje čist metal šava i bez prsline pri većim brzinama nanošenja. Stoga su FCAW šavovi vrlo podložni vrućim prslinama, dok je zavarivanje Super-TIG-om manje osetljivo. Nakon Fisco testova na vruće prsline, zavareni su očišćeni i primenjen je test prodiranja kako bi se identifikovale mikro prsline u šavovima. Pored toga, je proveren makrostrukturnim ispitivanjem poprečnog preseka. Mikrostrukture poprečnog preseka zavara prikazane na slici 5. Na osnovu makrostrukture porečnog preseka metala šava, ustanovljena je dubina i smer vruće prsline. Velike prodorne prsline nisu preporuka za veće brzine nanošenja. Dubina prsline žice od legure C-276 je relativno manja u odnosu na žicu od Alloy 625. Ne postoje prsline čak ni u pravcu debljine kod metala šava zavarenog Super-TIG-om.



Figure 6 illustrates the enlarged view of the microstructures of Fisco hot crack welds. The formation of microcracks identified in the welds made by FCAW for both the wires of Alloy 625 and Alloy C-276. Along with the cracks, there are inclusions in the weld metal which are possible to form from the FCAW slag. In the case of Super-TIG welding, tiny size inclusions identified with less number of inclusions in the weld metal. The microstructure characteristics of the butt welds have also exhibited the presence of inclusions in the weld metal. These inclusions have mainly consisted of Ti, Mo, and O abundant elements.

Slika 6 ilustruje uvećani izgled mikrostrukture vrućih prslina kod Fisco testa. Stvaranje mikro pukotina identifikovanih u šavovima zavarenim FCAW-om je i za žice od Alloy 625 i legure C-276. Pored prslina, u metalu šava, postoje uključci koji mogu nastati iz troske pri FCAW. U slučaju zavarivanja Super-TIG, uključci sitnih dimenzija su identifikovani ali sa manjim brojem uključaka u metalu šava. Karakteristike mikrostrukture sučeonih spojeva takođe su pokazale prisustvo uključaka u metalu šava. Ovi uključci su se uglavnom sastojali od Ti, Mo i O kao zastupljenih elemenata.

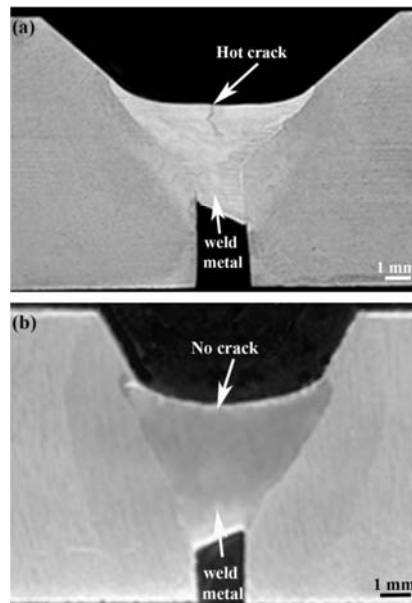


Figure 5. Cross-section after the Fisco hot crack test for welded samples (a) FCAW (b) Super-TIG
Slika 5. Presek nakon Fisco testa na vruće prsline zavarenih uzoraka (a) FCAW (b) Super-TIG

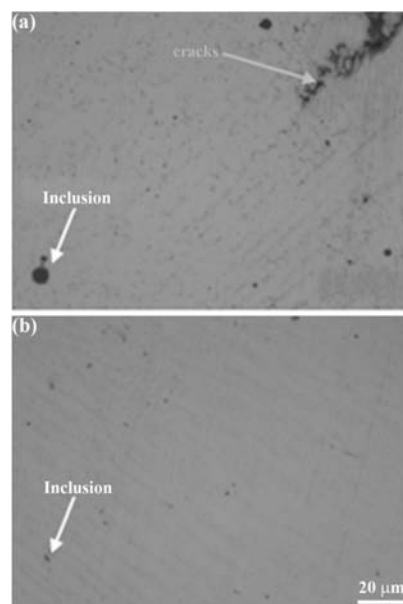


Figure 6. Microstructure with crack and inclusions after the Fisco hot crack test for welded samples (a) FCAW (b) Super-TIG
Slika 6. Mikrostruktura sa prslinama i uključcima nakon Fisco testa na vruće prsline zavarenih uzoraka (a) FCAW (b) Super-TIG



Figure 7 shows the Fisco hot crack test results of 9% Ni steel with the different filler metals by FCAW welding process by Kobelco steel. This test greatly evaluated the weld metal's resistance to hot cracking [15]. The area marked with a dotted line with the welding speed of 40 cpm and current of 270 A in this graphs means that an area is belonged to crack free zone for Alloy 625 wire. The area above this in dotted line is for the Alloy C-276 wire. This area is resistance for without hot cracks. The zone of welding conditions outside the dotted line is prone to have hot cracks in the welds very seriously. These are the primary sources for the reduction of the strength of the weld metal. The range of heat input or the welding conditions is very narrow in FCAW welding process. The welding currents more than 270 A showing the formation of cracks in the welds. Figure 8 represents the Fisco hot crack test results for the FCAW and Super-TIG welding process with Alloy 625 and Alloy C-276 consumables. The large area of the dark shaded region enables to understand the full range of control of the welding conditions in the Super-TIG welding. Moreover, this region belongs to the crack free zone, and these welding conditions can apply for higher deposition rates. The hot cracks region in the Super-TIG welding is far away from the FCAW's maximum allowable welding current. The welding speed is kept constant to understand the maximum range of welding current for the higher deposition. This broader range of crack-free zone of Super-TIG welding is even more than the conventional TIG and gas metal arc welding (GMAW) welding processes of welding current. The maximum conditions of FCAW welds are the minimum conditions for the Super-TIG welding of Ni-based consumables.

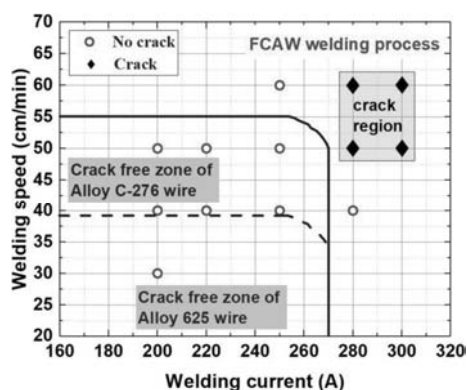


Figure 7. The results of the Fisco crack test by FCAW with Inconel and Hastelloy wires [15]

Slika 7. Rezultati Fisco testa na prsline kod FCAW sa žicama Inconel i Hastelloy [15]

Slika 7 prikazuje rezultate Fisco testa na vrućeprslina čelika sa 9% Ni sa različitim dodatnim materijalima FCAW postupkom zavarivanja od Kobelco čelika. Ovaj test je uveliko procenio otpornost metala šava na vruće prsline [15]. Područje označeno isprekidanom linijom, sa brzinom zavarivanja od 40 cpm i strujom 270 A na ovim grafikonima znači da području pripada zona bez prslina za žicu od legure 625. Područje iznad ove isprekidane linije je za žicu od legure C-276. Ovo područje je otporno na pojavu prslina. Zona zavarivanja izvan tačkaste linije sklona je vrućim prslinama na metalu šava. Ovo su osnovni izvori za smanjenje čvrstoće dodatnog materijala. Raspon unosa toplote ili uslova zavarivanja vrlo je uzan pri FCAW postupku zavarivanja. Struje zavarivanja veće od 270 A pokazuju formiranje prslina na šavu. Slika 8 predstavlja rezultate Fisco testa na vruće prsline za FCAW i Super-TIG postupak zavarivanja sa dodatnim materijalom od legure 625 i legure C-276. Veliko zatamnjeno područje omogućava razumevanje punog raspona kontrole uslova zavarivanja pri Super-TIG zavarivanju. Štaviše, ovo područje pripada zoni bez prslina, a ovi uslovi zavarivanja se mogu primeniti za veće brzine nanošenja. Područje vrućih prslina kod Super-TIG zavarivanja je daleko od najveće dozvoljene najveće dozvoljene struje zavarivanja kod FCAW. Brzina zavarivanja se održava konstantnom kako bi se razumeo maksimalni opseg struje zavarivanja za veće nanošenje. Ovaj širi opseg zone bez prslina kod Super-TIG postupka, čak je veći nego kod konvencionalnih postupaka zavarivanja TIG i MIG/MAG (GMAW). Maksimalni uslovi FCAW zavarivanja su minimalni uslovi za Super-TIG zavarivanje dodatnim materijalima na bazi Ni.

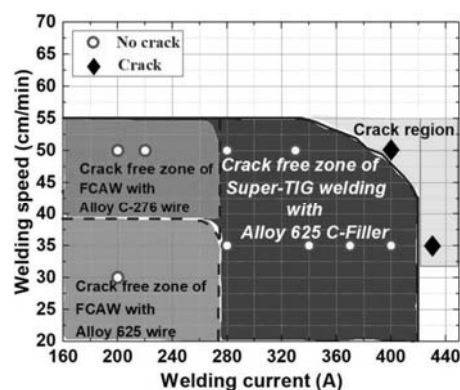


Figure 8. The results of the Fisco crack test by FCAW with Alloy 625 and Alloy C-276 wires, and Super-TIG with Alloy 625 C-Filler
Slika 8. Rezultati Fisco testa na prsline kod FCAW sa žicama od legure 625 i legure C-276 i Super-TIG sa dodatnim materijalom od legure 625 C

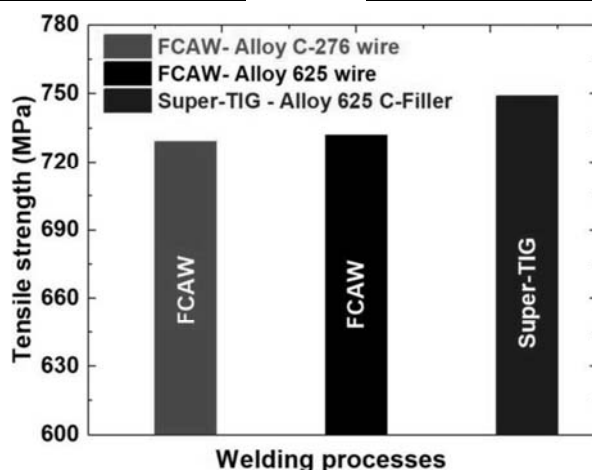


Figure 9. The tensile strength of weld metal according to welding methods
Slika 9. Zatezna čvrstoća metala šava prema metodama zavarivanja

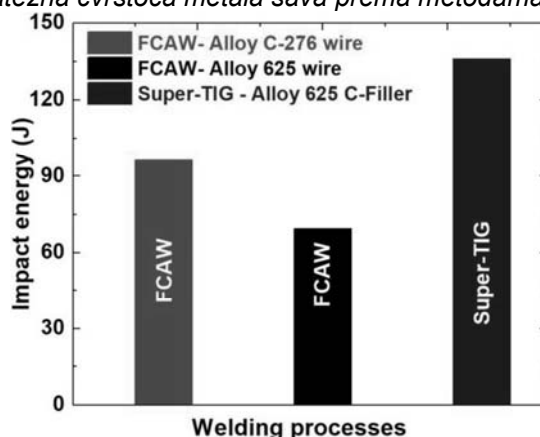


Figure 10. The impact energy (-196 °C) of weld metal according to welding methods
Slika 10. Energija udara (-196 °C) metala šava prema metodama zavarivanja

The mechanical properties of butt welded joints were evaluated to determine the tensile and Charpy impact energy. Figure 9 describes the tensile strength of the welds made of Alloy 625 and Alloy C-276 wires for FCAW and Alloy 625 C-Filler for Super-TIG welding. The strength of the FCAW welds is almost same for both wires with the small amount of difference between these wires. Whereas the strength of the welds made of Super-TIG welding obtained is higher than the FCAW welds. The similar structure of weld metal due to the consistency of melting of the filler builds the stronger welds for Super-TIG welding. The Charpy impact test results of the weld metal shown in Fig. 10. The impact tests conducted at the subzero temperature of -196 °C. The welds made of FCAW with Alloy 625 wire showed low toughness compared to the remaining welding methods. The welds produced of Super-TIG welding obtain the highest toughness, which is almost two times of FCAW's Inconel wire weld toughness. The reason for the low strength in FCAW welds is mainly due to the formation of microcracks and slag inclusions.

Mehanička svojstva sučeonih zavarenih spojeva su procenjena preko zatezne čvrstoće i Charpi-energije udara. Slika 9 opisuje zateznu čvrstoću šavova, izrađenih od legure 625 i legure C-276 za FCAW i legure 625 C-dodatni materijal za Super-TIG. Čvrstoća FCAW šavova je gotovo jednaka za obe žice uz malu razliku između ovih žica. Čvrstoća metala šava dobijenih Super-TIG zavarivanjem veća je od FCAW. Slična struktura metala šava, zbog konzistentnosti topljenja dodatnog materijala, stvara jace zavare za Super-TIG zavarivanje. Rezultati ispitivanja Charpi-udara metala šava prikazani na slici 10. Ispitivanja udarom izvedena na temperaturi od -196 °C. Šavovi izvedeni sa FCAW sa Alloy 625 žicom pokazali su malu žilavost u odnosu na preostale metode zavarivanja. Šavovi proizvedeni Super-TIG zavarivanjem postižu najveću žilavost, što je skoro dva puta u odnosu na žilavost FCAW Inconel žice. Razlog niske čvrstoće kod FCAW šavova je uglavnom zbog stvaranja mikroprslina i uključaka troske. Čak i mala veličina uključka takođe ima značajan uticaj na smanjenje žilavosti metala. Žilavost šava je jedan od glavnih



Even the small size of inclusion also has a significant effect on the reduction of weld metal toughness. The weld toughness is one of the primary criteria for the 9% Ni steel LNG tanks to meet the requirements. Therefore, Super-TIG welding produces clean weld metal with the minimum number of low-temperature inclusions in the weld metal. The higher melting efficiency of fillers and cooling rates enhances the mechanical and microstructural properties.

3.2 Productivity of Super-TIG welding

The productivity of the Super-TIG welding and FCAW processes determined for the Alloy 625 and Alloy C-276 consumables for the 9% Ni steel welding for LNG applications. As discussed earlier, the fabrication of thick sections, which is about 20 mm thickness of LNG fuel tanks demand the higher production of welding processes. The most suitable welding process of FCAW for 9% Ni steel restricted to a narrow range of production rates due to the presence of welding defects and hot cracks. The maximum deposition rate of the FCAW and Super-TIG welding processes are determined for the maximum allowable welding current (see Fig. 8). Figure 11 demonstrates the deposition rate of the weld metal among the three welding methods. The deposition rate of the FCAW process with Alloy 625 wire is lower than the others. Both of the wires of FCAW weld deposits obtained almost the same amount of 5 kg/hr. The similar deposition of weld metal results also determined by other consumable manufacturers. The highest deposition rate of 6 kg/hr and above is possible by Super-TIG welding. The melting efficiency of the C-filler in Super-TIG welding is higher and increase the metal transfer mode to deliver continuous and regular liquid metal droplets to weld pool. In Super-TIG welding, the broader area of the C-filler under the arc plasma column melts higher amount, where the possibility for feeding of filler much faster than the normal speed. The regular bridging transfer and consistency in the weld deposition are higher in Super-TIG welding. Therefore, the productivity of the Super-TIG welding is improved over the FCAW and the conventional TIG welding processes. The use of Super-TIG welding for 9% Ni steel with Alloy 625 filler can replace the FCAW of Alloy C-276 welding method. Hence, the cost of the consumables and total welding cost reduced while the higher productivity.

kriterijuma da rezervoari za TPG od čelika sa 9% Ni ispunjavaju zahteve. Stoga Super-TIG zavarivanje proizvodi čist metal šava sa minimalnim brojem niskotemperaturnih uključaka. Veća efikasnost topljenja dodatnih materijala i brzina hlađenja povećavaju mehanička i mikrostrukturalna svojstva.

3.2 Produktivnost Super-TIG zavarivanja

Produktivnost postupaka zavarivanja Super-TIG i FCAW određena je za dodatni materijal Alloy 625 i Legura C-276 za zavarivanje čelika sa 9% Ni za primenu TPG. Kao što je ranije rečeno, izrada debelih preseka, debljine oko 20 mm rezervoara za TPG gorivo, zahjeva veću proizvodnju postupaka zavarivanja. Najprikladniji postupak zavarivanja FCAW za čelik sa 9% Ni, ograničen je na uski raspon brzina proizvodnje usled prisustva grešaka zavarivanja i vrućih prslina. Maksimalna brzina nanošenja FCAW i Super-TIG postupka zavarivanja određuje se za najveću dozvoljenu struju zavarivanja (vidi Sliku 8). Slika 11 prikazuje brzinu nanošenja metala šava među tri postupka zavarivanja. Brzina nanošenja FCAW postupka sa žicom od legure 625 niža je od ostalih. Obe žice za nanošenje kod FCAW zavarivanje postigle su gotovo istu količinu od 5 kg/sat. Slično deponovanje metala šava utvrdili su i ostali proizvođači dodatnih materijala. Najveća brzina nanošenja od 6 kg/h i više moguća je Super-TIG zavarivanjem. Efikasnost topljenja C-dodatnog materijala kod Super-TIG zavarivanja je veća i povećava način prenosa metala za isporuku kontinuiranih i regularnih kapljica tečnog metala u zavarivačku kupku. Kod Super-TIG zavarivanja, šira površina C-dodatnog materijala ispod plazma luka, topi veću količinu, pri čemu je mogućnost dodavanja dodatnog materijala mnogo veća od uobičajene brzine. Regularno premošćavanje prenosa i konzistencija u nanošenju šava su veći kod Super-TIG zavarivanja. Stoga je produktivnost Super-TIG zavarivanja poboljšana u odnosu na FCAW i konvencionalne TIG postupke zavarivanja. Upotreba Super-TIG zavarivanja čelika sa 9% Ni sa Alloy 625 dodatnim materijalom, može zameniti FCAW sa Alloy C-276. Dakle, trošak dodatnog materijala i ukupni trošak zavarivanja su se smanjili dok je povećana produktivnost.

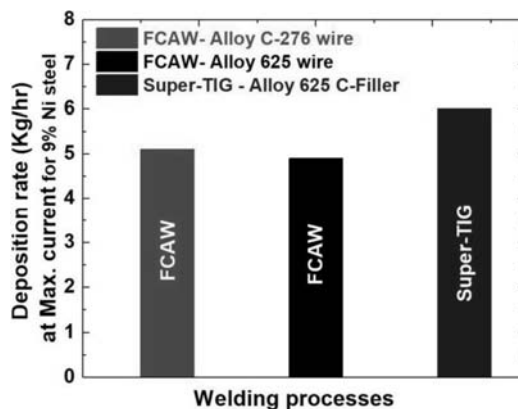


Figure 11. The productivity of the Super-TIG welding compared to FCAW process
Slika 11. Produktivnost Super-TIG zavarivanja u poređenju sa FCAW postupkom

4. Conclusions

We examined Fisco hot crack test and mechanical properties for the weld metal by 3 welding methods with 3 types of wires. The obtained results are as follows

1. In the results of Fisco hot crack test, FCAW bead with Inconel wire showed high susceptibility and with Hastelloy wire had medium susceptibility, but Super-TIG bead with Inconel C-filler indicated low susceptibility (high resistance) for hot crack.
2. Due to no interpass grinding in the Super-TIG welding, the productivity of Super-TIG welding was distinguished comparing to FCAW with Inconel or Hastelloy wires.
3. In the results of Charpy Impact test, weld metal by Super-TIG showed excellent comparing to FCAW with Inconel or Hastelloy wires.

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4. Zaključci

Ispitali smo Fisco test na vruće prsline i mehanička svojstva metala šava pomoću 3 postupka zavarivanja sa 3 vrste žica. Dobijeni rezultati su sledeći

1. U rezultatima Fisco testa na vruće prsline, FCAW zavar sa žicom Inconel pokazala je veliku osetljivost i Hastelloy žicom koja je imala srednju osetljivost, ali Super-TIG zavar sa Inconel C-dodatnim materijalom ukazuje na malu osetljivost (visoku otpornost) na vruće prsline.
2. Zbog nepotrebnog brušenja između slojeva, kod Super-TIG zavarivanja, produktivnost zavarivanja Super-TIG se izdvaja u poređenju sa FCAW sa Inconel ili Hastelloy žicama.
3. U rezultatima Charpi testa, metal šava izveden Super-TIG-om pokazao se odličnim u poređenje sa FCAW sa žicama Inconel ili Hastelloy.

Zahvalnost

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