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Introduction of a New Term - Ferrite Number Density (FND) to Measure the Ferrite Number of Welds on Thin 300 Series Stainless Steel Sheets

Uvođenje novog termina – Gustina feritnog broja (FND) za merenje feritnog broja zavarenih spojeva na tankim limovima od nerđajućeg čelika serije 300

NASTAVAK IZ PREDHODNOG BROJA
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Part 2

Also, at these cooling rates obtained using a TIG welding process, no shift from primary ferrite to primary austenite solidification mode is expected. This conclusion can be extended to thicker sheets (1.5 mm, 2.0 mm and 2.4 mm), but similar curves could not be plotted as the dilution from the filler wire changes the chemistry within the weld pool for every individual experiment.

Due to the contradicting results obtained, metallographic samples were prepared and etched in order to assess the microstructural features of the welds. Figure 5 shows the microstructures of different welds and their measured FNs for 0.7 mm thick sheet welds. In Figure 5, the dark dendritic lines are the retained delta-ferrite. It can be clearly seen that the density of the dark dendritic lines goes on decreasing from Figure 5(a) to 5(d). However, the measured FN has increased from Figure 5(a) to 5(d). On further analysis using ImageJ software, it was concluded that the amount of retained delta-ferrite concentration in the weld pool has in fact decreased from Figure 5(a) to 5(d), as shown in Figure 6. As mentioned previously, some experiments were done by adding certain quantities of nitrogen in the shielding gas in order to validate the above mentioned observations. Nitrogen being a strong austenite promoting element should significantly reduce the amount of residual delta-ferrite concentration in the weld. These experiments were done using the same parameter combinations as those using pure argon. However, nitrogen gas increased the voltage across the arc, increasing the heat input to the weld pool and consequently reducing the cooling rate. This is additionally expected to reduce the FN of the weld. However, in most of the cases, the measured FN was found to increase on addition of nitrogen, again contradicting the results from literature such as those reported by [13] and similar results were also reported by [14]. Figure 7 shows a comparison of measured Ferrite Numbers at different cooling rates, when welding probe, although both lying within the flux area of the probe

Takođe, pri ovim brzinama hlađenja dobijenim postupkom TIG zavarivanja, ne očekuje se pomak od primarnog ferita do primarnog načina očvršćavanja austenita. Ovaj zaključak može se proširiti na debljine limova (1,5 mm, 2,0 mm i 2,4 mm), ali slične krive se ne mogu nacrtati jer razblaživanje iz žice menja hemiju unutar zavarivačke kupke za svaki pojedinačni eksperiment.

Zbog kontradiktornih dobijenih rezultata, metalografski uzorci su pripremljeni i nagriženi u cilju procene mikrostrukturnih karakteristika zavarenih spojeva. Na slici 5 prikazane su mikrostrukture različitih šavov i njihovi izmereni FN za šavove od lima debljine 0,7 mm. Na slici 5, tamne dendritne linije su zaostali delta-ferit. Jasno se može videti kako gustina tamnih dendritnih linija opada sa slike 5 (a) na 5 (d). Međutim, izmereni FN se povećao sa slike 5 (a) na 5 (d). Daljom analizom pomoću ImageJ softvera zaključeno je da se količina zaostalog delta-ferita koncentriše u zavarivačkoj kupki i u stvari smanjila sa slike 5 (a) na 5 (d), kao što je prikazano na slici 6. Kao što je prethodno pomenuto, neki eksperimenti su rađeni dodavanjem određenih količina azota u zaštitni gas da bi se potvrdila gore navedena zapažanja. Azot kao snažni element za podsticanje austenita trebalo bi značajno da smanji količinu zaostale delta-feritne faze u šavu. Ovi eksperimenti su rađeni koristeći iste kombinacije parametara kao i oni koji koriste čisti argon. Međutim, azot povećava napon luka, povećavajući dovod toplote u kupku i posledično smanjujući brzinu hlađenja. Očekuje se da će ovo takođe smanjiti FN šava. Međutim, u većini slučajeva je utvrđeno da se izmereni FN povećava dodavanjem azota, što je opet u suprotnosti sa rezultatima iz literature kao što je ona koja je izneta u [13], a slični rezultati su takođe navedeni u [14]. Slika 7 prikazuje poređenje izmerenih feritnih brojeva sa različitim brzinama hlađenja, kada se zavarivanje koristi čisti argon kao zaštitnim gasom i korišćenjem 10% azota u argonu.



was done using pure argon as the shielding gas and using 10% nitrogen in argon.

Welds in Figure 8(a) and 8(b) are done using exactly the same parameters, except for the shielding gas. The weld in Figure 8(a) is done using pure argon, whereas the one in Figure 8(b) is done using 10% nitrogen in the shielding gas. The image analysis shows a significant reduction in the ferrite content of the weld when nitrogen was added to the shielding gas, whereas the FeritScope® results show an increase in FN in the presence of nitrogen. From all the above analysis, it is evident that there are some parameters, apart from the ones mentioned in FeritScope® user manual, which influence the FeritScope® results.

Consequently, only applying the correction factors mentioned in the user manual of the FeritScope® is not sufficient to fully understand the distribution of retained delta-ferrite and its effects on the weld properties, especially in case of thin welded sheets. One of the parameters that might have affected the FN measurements is the weld bead cross-sectional area. It is expected that as the weld area increases, the retained delta-ferrite of the weld reduces, since larger weld area means a higher heat input, which in turn means a lower cooling rate for a particular sheet thickness. For the welds shown in Figure 5 the cross-sectional area of the weld has increased from Figure 5(a) to 5(d). However, in this case the measured FN was found to increase with an increase in cross-sectional area. Similarly, in Figure 8, although the cross-sectional area of the weld in 8(b) was more than that in 8(a), the FN measured of weld 8(b) was more than 8(a). In general for most of the experiments, as the cross-sectional area of the weld bead increased, the measured FN also increased as shown in Figure 9. The trend flattened as the area increased, and beyond roughly 13 mm², this influence was negligible. One of the reasons for all the contradictory results can be that the FeritScope® manual only considers the sheet thickness as a source of error in measuring the FNs, but does not consider weld width as an influential parameter. The effect of this combination of the sheet thickness and weld width (which forms the cross-sectional area) can be explained using Figure 10(a) and Figure 10(b).

Figure 10(a) schematically depicts two scenarios where two thin sheets have been welded together using different input parameters, resulting in two different bead geometries, one significantly larger than the other.

However, the cross-sectional area of both the weld beads varies and changes the interaction area covered by the magnetic flux of the FeritScope®

Zavareni spojevi na slici 8 (a) i 8 (b) rade se pomoću potpuno istih parametara, izuzev zaštitnog gasa. Zavareni spoj na slici 8 (a) se izvodi čistim argonom, dok se na slici 8 (b) izvodi sa 10% azota u zaštitnom gasu. Analiza slike pokazuje značajno smanjenje sadržaja ferita u šavu kada je u zaštitni gas dodan azot, dok rezultati FeritScope® pokazuju porast FN u prisustvu azota.

Iz gore navedene analize vidljivo je da postoje neki parametri, osim onih koji su navedeni u korisničkom priručniku FeritScope®, koji utiču na rezultate FeritScope®.

Prema tome, samo primena korekcijskih faktora navedenih u korisničkom priručniku FeritScope® nije dovoljna da u potpunosti shvatite raspodelu zaostalog delta-ferita i njegove efekte na svojstva šava, posebno u slučaju tankih zavarenih limova.

Jedan od parametara koji bi mogao uticati na mjerenje FN-a je područje poprečnog preseka zavara. Očekuje se da, kako se površina zavara povećava, zadržani delta-ferit u šavu se smanjuje, jer veće područje zavarivanja znači veći unos topline, što zauzvrat znači niži stepen hlađenja za određenu debljinu lima. Za šavove prikazane na slici 5 površina poprečnog preseka zavara povećala se sa slike 5 (a) na 5 (d). Međutim, u ovom slučaju je utvrđeno da se izmereni FN povećava sa povećanjem površine poprečnog preseka. Slično tome, na slici 8, iako je površina poprečnog preseka zavara 8 (b) bila veća od one u 8 (a), FN izmerena zavara 8 (b) bila je veća od 8 (a). Uopšteno, za većinu eksperimenata, kako se površina poprečnog preseka zavara povećavala, izmereni FN se takođe povećavao kao što je prikazano na slici 9. Trend je postajao ravnomerniji kako se površina povećavala, a za otprilike 13 mm², taj uticaj je bio zanemariv. Jedan od razloga svih kontradiktornih rezultata može biti taj što FeritScope® priručnik samo debljinu lima smatra izvorom greške u merenju FN-a, ali ne smatra širinu šava kao uticajni parametar. Učinak ove kombinacije debljine lima i širine šava (koji formira površinu poprečnog preseka) može se objasniti pomoću slike 10 (a) i slike 10 (b).

Na slici 10 (a) šematski su prikazana dva scenarija gde su dva tanka lima spojena zajedno koristeći različite ulazne parametre, što rezultuje u dve različite geometrije zavara, jedna značajno veća od druge.

Međutim, površina poprečnog preseka oba zavara varira i menja područje interakcije prekriveno magnetnim fluksom sonde FeritScope®, iako obe leže unutar područja fluksa sonde.

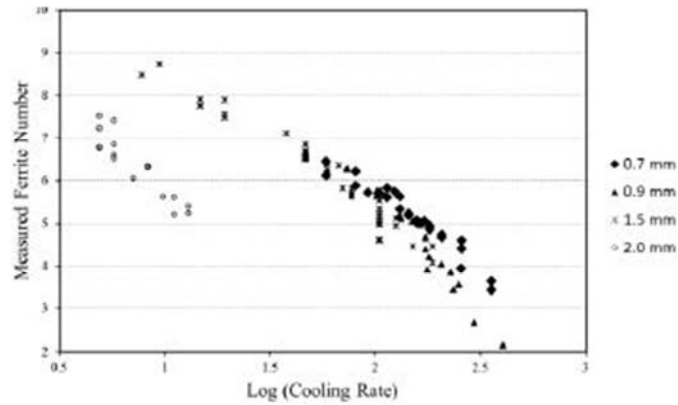


Figure 3. Plots illustrating dependence of retained delta ferrite content on the cooling rate on a logarithmic scale
Slika 3. Grafikoni koji prikazuju zavisnost sadržaja zadržanog delta ferita od brzine hlađenja na logaritamskoj skali

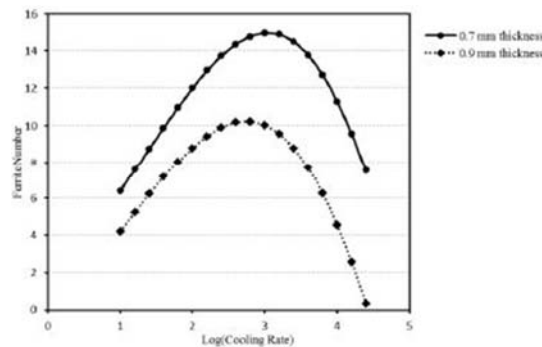


Figure 4. Predicted Ferrite Number using ORFN plotted against cooling rates for 0.7 mm and 0.9 mm thick sheets
Slika 4. Predviđeni feritni broj pomoću ORFN-a iscrtan na osnovu brzina hlađenja za 0,7 mm i 0,9 mm debljine lima

If it is assumed that the concentration of the retained delta-ferrite in both the weld beads is exactly the same, it has been shown that the FeritScope® will record a higher reading for the larger weld as compared to the smaller weld, since the total amount of magnetic delta-ferrite present in the larger weld is more as a result of its size. This will generate a larger magnetic force and increase the FeritScope® reading.

Ako se pretpostavi da je koncentracija zadržanog delta-ferita u obe zavara potpuno ista, pokazalo se da će FeritScope® zabeležiti veće očitavanje većeg zavaru u odnosu na manji zavar, pošto je ukupna količina magnetnog delta-ferita prisutna u većem zavaru, veća je zbog njegove veličine. To će generisati veću magnetnu silu i povećaće očitavanje FeritScope®

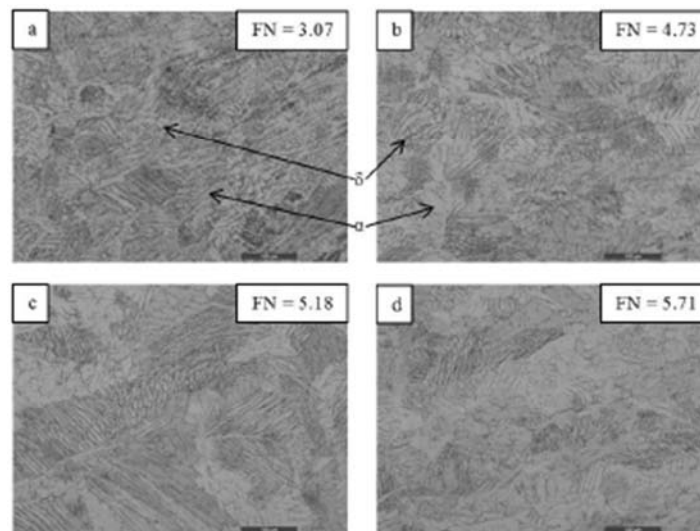


Figure 5. Microstructures (δ = Delta-ferrite; α = Austenite) of welds obtained from 0.7 mm thick sheets through different input parameters

Slika 5. Mikrostrukture (δ = delta-ferit α = austenit) zavara dobijenih na limu debljine 0,7 mm kroz različite ulazne parametre

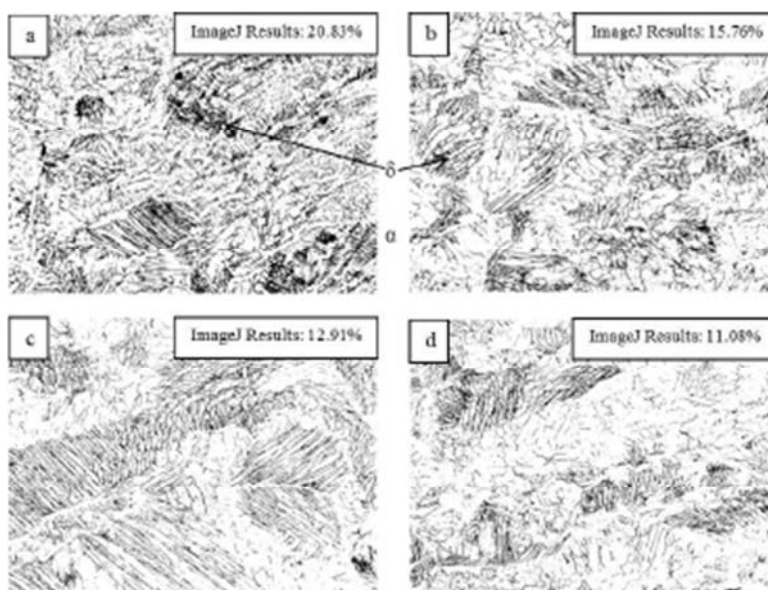


Figure 6. Analysis using ImageJ software on same welds as shown in Figure 5
Slika 6. Analiza pomoću ImageJ softvera na istim zavarima kao što je prikazano na slici 5

However, as shown in Figure 10(b), the weld bead cross-sectional area is greater than the extended magnetic field of the probe; and irrespective of the size of the weld bead, the FN is always measured over a constant volume. The readings from the FeritScope® in such cases will only be based on the concentration of delta-ferrite and will not be influenced by the total amount of delta-ferrite in the weld bead. Consequently, no correction factors based on the plate thickness and the weld width are required and the readings obtained from the FeritScope® can be directly used as an indicator of the ferrite content. From this analysis, it can also be estimated that the area of effective magnetic flux of the probe is roughly 13 mm².

For most of the experiments performed in this research, the cross-sectional area of the welds is smaller than 13 mm² and is expected to fall within the magnetic flux area of the probe.

Međutim, kao što je prikazano na slici 10 (b), površina poprečnog preseka zavara je veća od proširenog magnetnog polja sonde; i bez obzira na veličinu zavara, FN se uvek meri konstantnom zapreminom. Očitavanje FeritScope®-a u takvim slučajevima zasnivaće se samo na koncentraciji delta-ferita i na njega neće uticati ukupna količina delta-ferita u zavaru. Zbog toga nisu potrebni korektivni faktori na osnovu debljine ploče i širine zavara, a očitavanja dobijena iz FeritScope® mogu se direktno koristiti kao pokazatelj sadržaja ferita. Iz ove analize se takođe može proceniti da površina efektivnog magnetnog toka sonde iznosi otprilike 13 mm².

Za većinu eksperimenata u ovom istraživanju površina poprečnog preseka zavara je manja od 13 mm² i očekuje se da padne unutar magnetnog toka sonde.

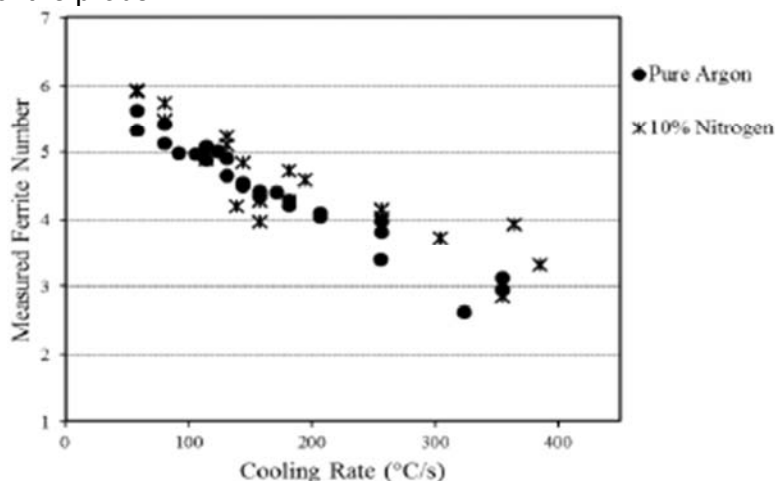


Figure 7. FNs of welds done using Pure Argon and 10% Nitrogen in shielding gas
Slika 7. FN šavova sa čistim argonom i 10% azota u zaštitnom gasu



This is believed to be a potential reason for the controversial results obtained when compared to the literature. Such welds can be better assessed if the FN is replaced by Ferrite Number Density (FND) to indicate the amount of retained delta-ferrite in the weld. The FND can be measured by simply dividing the measured FN with the cross-sectional area of the weld. Although in many practical applications the cross-sectional area of the weld cannot be physically determined, however it can be estimated through predictive computational models such as regression analysis, artificial neural networks, etc. The development of such models is beyond the scope of this research and can be found elsewhere. For example, [15] used an artificial neural network to predict the bead height obtained in a robotic arc welding process, while [16] used an artificial neural network to predict the transverse and angular distortions of a TIG welding process. FND can eliminate the effect of both, the sheet thickness as well as the weld width, thus providing a number that can be used to compare all the welds of small cross-sectional areas ($< 13 \text{ mm}^2$) on a common scale. Use of FND instead of FN also justifies all the contradictions obtained when the results were compared to those in literature.

Veruje se da je to potencijalni razlog za kontroverzne rezultate dobijene u poređenju sa literaturom. Takvi zavari se mogu bolje proceniti ako je FN zamenjen gustinom feritnog broja (FND) da pokaže količinu zaostalog delta-ferita u šavu. FND se može meriti jednostavnim deljenjem izmerenog FN-a sa površinom poprečnog preseka zavara. Iako se u mnogim praktičnim primenama površina poprečnog preseka zavara ne može fizički odrediti, ipak se može proceniti pomoću prediktivnih računarskih modela kao što su regresijska analiza, veštačke neuronske mreže itd. Razvoj takvih modela je izvan obima ovog istraživanja i mogu se naći negde drugde. Na primer, [15] je koristila veštačku neuronsku mrežu da predvidi visinu zavara koja je dobijena robotskim postupkom zavarivanja, dok je [16] koristila veštačku neuronsku mrežu za predviđanje poprečnih i ugaonih izobličenja kod postupka TIG zavarivanja. FND može eliminisati efekat oba, debljine lima kao i širine zavara, pružajući tako broj koji se može koristiti za upoređivanje svih zavarenih malih površina poprečnog preseka ($< 13 \text{ mm}^2$) na zajedničkoj skali. Upotreba FND-a umesto FN-a takođe opravdava sve kontradikcije dobijene prilikom upoređivanja rezultata sa onima iz literature.

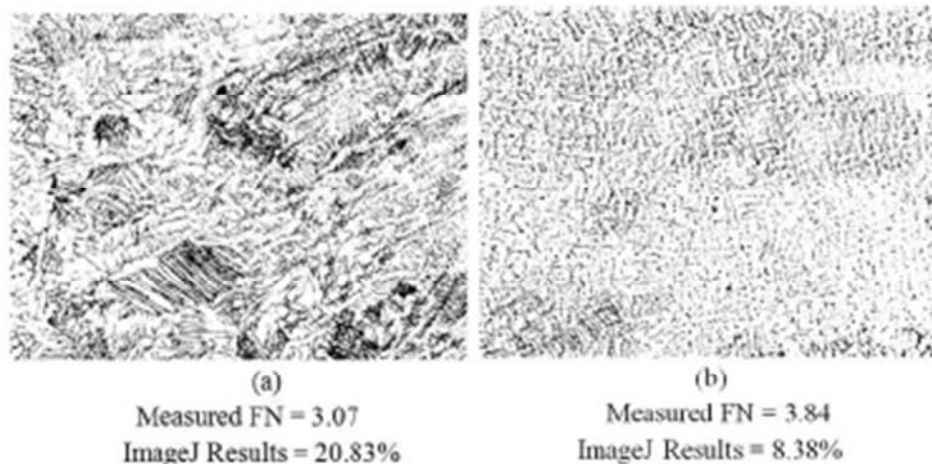
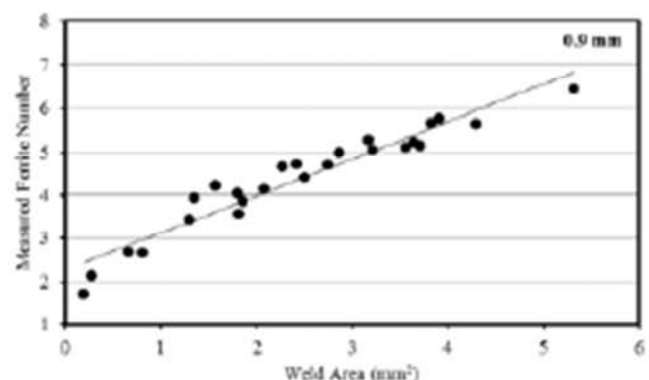
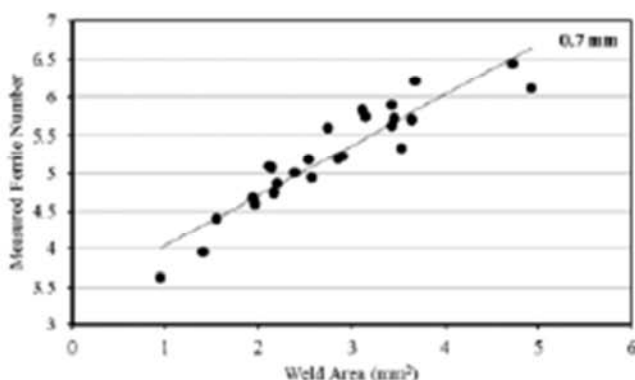


Figure 8. Ferrite content observed in welds done using (a) Pure Argon; (b) 10% Nitrogen in Argon as shielding gas
Slika 8. Sadržaj ferita primećen u šavovima sa (a) čistim argonom; (b) 10% azota u argonu kao zaštitnom gasu



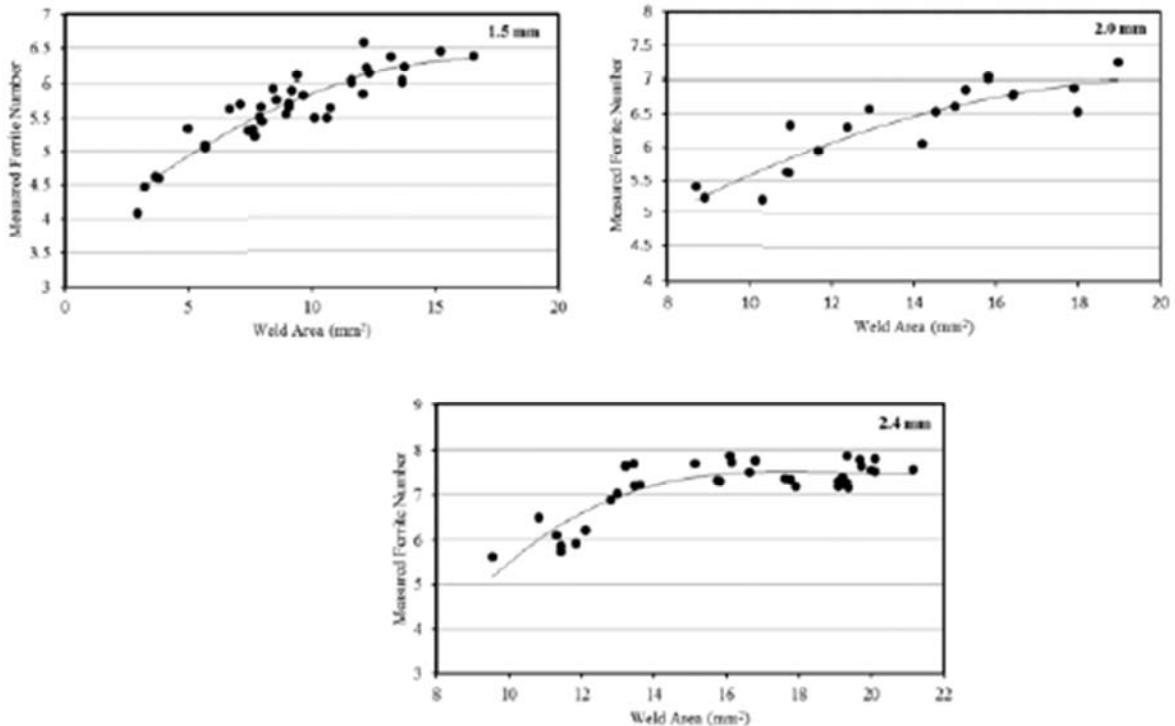


Figure 9. Measured FNs plotted against weld area obtained from various thickness sheets
Slika 9. Izmereni FN-i iscrtani na površini šava dobijeni iz limova različitih debljina

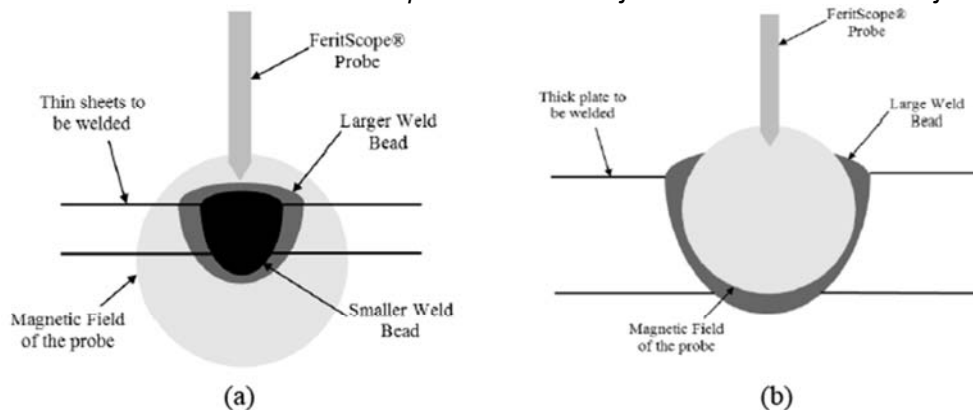


Figure 10. Schematic explaining a possible reason for the error in measured FN
Slika 10. Šematsko objašnjenje mogućeg razloga greške u izmerenom FN

However, care must also be taken that for welds with cross-sectional area more than 13 mm²; the ferrite content of the welds is assessed using the FNs and not the FNDs. This is because the magnetic flux of the FeritScope® probe does not cover the entire area of the weld and dividing the FN with the cross-sectional area will lead to incorrect estimation of FND. An alternative for this is that for all the welds having the cross-sectional area over 13 mm², the FND be calculated by dividing the measured FN by 13 mm², which is roughly the area over which the FN is measured. It is important to note here that the minimum aspect ratio (Crown Width: Penetration) for all the welds that were fully penetrated was 2.36. Consequently, taking a slightly conservative approach, for the above analysis to hold true, the

Međutim, mora se paziti i na zavare sa površinom preseka većom od 13 mm²; sadržaj ferita u zavarima se procenjuje korišćenjem FN, a ne FND. To je zbog toga što magnetni tok FeritScope® sonde ne pokriva celokupno područje zava i deljenje FN sa površinom poprečnog preseka dovodi do pogrešne procene FND. Alternativa za to je da za sve zavare koji imaju površinu poprečnog preseka preko 13mm² FND izračunava se deljenjem izmerenog FN sa 13 mm², što je otprilike površina preko koje se meri FN. Važno je ovde napomenuti da je najmanji odnos slike (širina vrha: uvarivanje) za sve zavarene spojeve sa potpunim uvarivanjem bio 2,36. Prema tome, uzimajući blago konzervativan pristup, da bi gornja analiza bila



aspect ratio of the weld must be greater than 2.5 (which are common for a TIG welding process). If the welds are too narrow and deep, such as those obtained using activated TIG welding (A-TIG) process, even welds with area smaller than 13 mm² may not completely lie within the magnetic flux field of the probe. This will change the cut-offs for switching between FND and FN for such welds. The following sections show the analysis of the welds done using FND as an indicator of the ferrite content. As mentioned previously, it can be established from the literature that increasing the cooling rate must increase the amount of retained delta-ferrite in an FA-type of solidification. If the measured FN in Figure 2 is replaced with the FND, the results obtained are in agreement with the literature. This is shown in Figure 11 for 0.7 mm and 0.9 mm thick sheets as an example. Similarly, it can also be shown for thin sheet welds that the addition of nitrogen in the shielding gas affects only the FND and not the total FN of the weld. A comparison of FND obtained when welds are done using pure argon and 10% nitrogen in shielding gas for 0.7 mm thick sheets is shown in Figure 12. Unlike in Figure 7, this can explain the strong austenite-promoting behaviour of nitrogen, as there is a significant drop in the FND observed in using an Ar/N₂ (90:10) shielding gas mixture. This further supports the statement that for thin sheets, FND is a better indicator of the amount of retained delta ferrite in the weld structure. As the sheet thickness is increased, the welds become wider for a TIG welding process, consequently increasing their cross-sectional areas. As mentioned earlier, after a cross-sectional area of roughly 13 mm² associated with an aspect ratio of at least 2.5, its effect on the measured FN becomes insignificant. The minimum and maximum weld cross-sectional area obtained from the experiments, considering only fully penetrated welds on different thickness sheets is shown in Table 5.

istinita, odnos širine zavara mora biti veći od 2,5 (što je uobičajeno za TIG postupak zavarivanja). Ako su zavarivi preuski i duboki, kao što su oni dobijeni postupkom aktiviranog TIG zavarivanja (A-TIG), čak i zavari sa površinom manjom od 13 mm² možda neće u potpunosti ležati unutar polja magnetnog fluksa sonde. Ovo će promeniti prekidače za prebacivanje između FND i FN za takve zavare. Sledeći odeljci prikazuju analizu zavarenih spojeva rađenih korišćenjem FND-a kao pokazatelja sadržaja ferita. Kao što je prethodno spomenuto, iz literature se može utvrditi da povećavanje brzine hlađenja mora povećati količinu zaostalog delta-ferita u očvršćavanju tipa FA. Ako se izmereni FN na slici 2 zameni sa FND, dobijeni rezultati se slažu sa literaturom. To je prikazano na slici 11 za primere limova debljine 0,7 mm i 0,9 mm. Slično, može se pokazati i za zavarivanje tankih ploča da dodatak azota u zaštitnom gasu utiče samo na FND, a ne i na ukupni FN zavara. Upoređivanje FND-a dobijenog kada se zavarivanje upotrebljava čisti argon i 10% azota u zaštitnom gasu za limove debljine 0,7 mm, prikazano je na slici 12. Za razliku od slike 7, ovo može objasniti snažno ponašanje azota koji promovira austenit. značajan pad FND primećen korišćenjem Ar / N₂ (90:10) mešavine zaštitnog gasa. Ovo dalje potkrepljuje tvrdnju da je za tanke ploče FND bolji pokazatelj količine zaostalog delta ferita u strukturi šava. Kako se povećava debljina lima, šavovi postaju širi za TIG postupak zavarivanja, usled čega se povećavaju njihove površine poprečnog preseka. Kao što je ranije spomenuto, nakon površine poprečnog preseka otprilike 13 mm² koja je jednaka proporciji od najmanje 2,5, njen uticaj na izmereni FN postaje neznan. Minimalna i maksimalna površina poprečnog preseka šava dobijena eksperimentima, uzimajući u obzir samo potpuno uvarene zavare na limu različite debljine prikazani su u Tabeli 5.

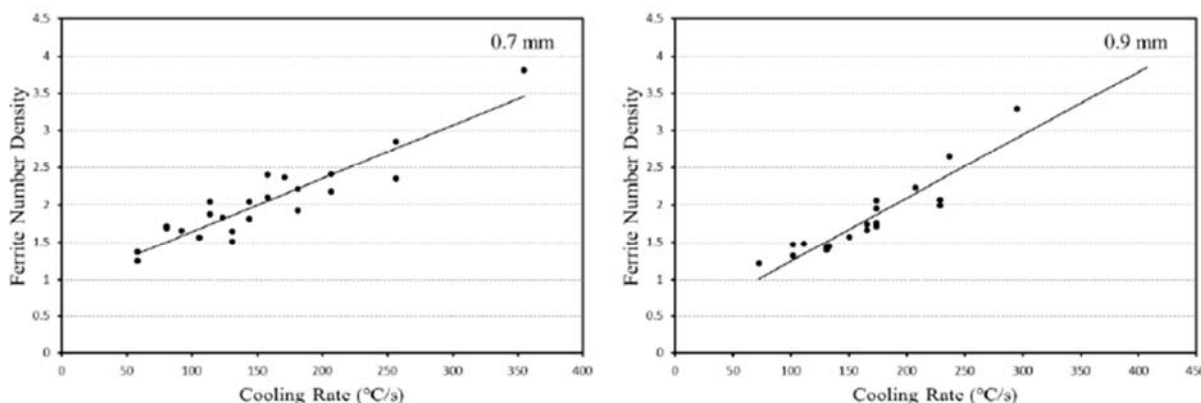


Figure 11. Effect of cooling rate of the weld pool on the FN Density

Slika 11. Uticaj brzine hlađenja kupke na gustinu FN

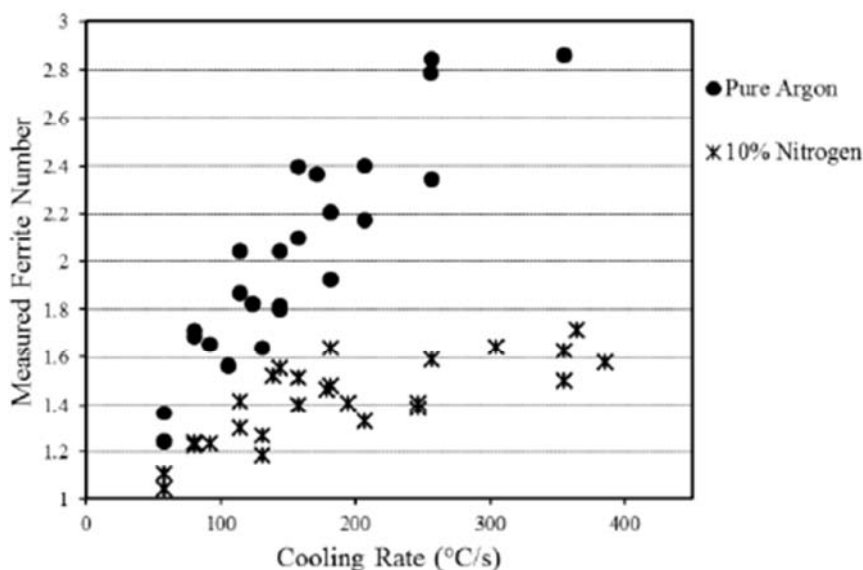


Figure 12. Effect of addition of nitrogen in shielding gas in the FN Density

Slika 12. Uticaj dodavanja azota u zaštitni gas u gustini FN

Considering the values in Table 5, it can be generalised that for fully penetrated welds obtained through a TIG welding process, the term FN can be used to assess weld microstructure only if the sheet thickness is greater than or equal to 2.4 mm. For sheets thinner than 0.9 mm, the weld cross-sectional area is likely to lie within the magnetic flux area of the probe, for which FND must be used as an indicator of the ferrite content of the welds. For sheet thicknesses between 0.9 and 2.4, the use of either FN or FND depends on the cross-sectional area of the weld obtained. However, a common FND scale can also be used for all the welds if it is calculated by dividing the measured Ferrite Number by 13 mm², for the welds having an area more than this value and having an aspect ratio greater than 2.5. All this analysis is only applicable if the FN is measured using a FeritScope® with an FGAB1.3-Fe probe. For any other probe, the thickness and the weld area that lies within the magnetic flux field may change, which will require similar analysis to obtain a cut-off thickness of the sheets.

Uzimajući u obzir vrednosti iz tabele 5, može se generalizovati da se za potpuno uvarene zavare dobijene postupkom TIG zavarivanja, termin FN može koristiti za procenu mikrostrukture šava samo ako je debljina lima veća od ili jednaka 2,4 mm. Za limove debljine veće od 0,9 mm, područje poprečnog preseka šava verovatno će ležati unutar područja magnetskog fluksa sonde, za koju se FND mora koristiti kao pokazatelj sadržaja ferita u šavovima. Za debljine lima između 0,9 i 2,4, upotreba ili FN ili FND zavisi od površine poprečnog preseka dobijenog zavara. Međutim, zajednička FND skala takođe se može koristiti za sve zavare ako se izračuna tako što se izmereni feritni broj podeli sa 13mm², za zavare koji imaju površinu veću od ove vrednosti i imaju odnos slike veći od 2,5. Sva ova analiza je primenljiva samo ako se FN meri pomoću FeritScope® sa FGAB1.3-Fe sondom. Za bilo koju drugu sondu, debljina i područje zavara koji se nalazi unutar polja magnetnog fluksa mogu se promeniti, što će zahtevati sličnu analizu da bi se dobila debljina presečne ploče.

Sheet Thickness (mm)	Minimum Area (mm ²)	Maximum Area (mm ²)	Minimum Aspect Ratio
0.7	0.952	5.682	2.71
0.9	1.202	6.479	2.65
1.5	3.968	16.544	2.58
2.0	8.826	22.626	2.47
2.4	13.547	25.356	2.36

Table 5. Minimum and maximum weld areas obtained from the experiments for various thickness sheets

Tabela 5. Minimalne i maksimalne površine šavova dobijene eksperimentima za različite limove debljine



4. Conclusion

From the analysis of the measured FN done in this research, the following can be concluded:

1. The measured Ferrite Number can decrease with an increase in cooling rate of the welding process, contradicting to what is mentioned in the literature. However, the Ferrite Number Density will increase with an increase in the cooling rate in an FA type of solidification, for low and moderate cooling rates, irrespective of the size of the weld bead.
2. FND is a better indicator of the ferrite content of the weld bead, especially when welding thin sheets. FND follows all the expected trends when compared to the literature, which the FN values don't.
3. The cut-off weld area under which the FND is superior to the FN value was found to be 13 mm² when the aspect ratio is greater than 2.5. For welds with cross-sectional area larger than this value, FN can be directly used as an indicator of ferrite content, or alternatively, the measured FN must be divided by 13 mm² instead of the actual cross-sectional area to obtain the FND so long as the minimum aspect ratio criteria of the weld is not violated.
4. For the TIG welding process producing fully penetrated weldments, the minimum cross-sectional area of welds done on 2.4 mm thick sheets was found to be 13.547 mm², which is more than the FGAB1.3-Fe probe magnetic flux field. Consequently to simplify, the cut-off values for sheets having a thickness greater than 2.4 mm, the FN can be used as a direct indicator of the ferrite content of the weld. For sheets thinner than 0.9 mm with an aspect ratio greater than 2.5, the FND must be used as an indicator of the ferrite content in the weld. For sheet thicknesses in between 0.9 and 2.4, FN or FND may be used depending on the cross-sectional area of the weld and its aspect ratio.

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4. Zaključak

Iz analize izmerenog FN-a urađenog u ovom istraživanju može se zaključiti sledeće:

1. Izmereni feritni broj može se smanjiti s povećanjem brzine hlađenja postupka zavarivanja, suprotno onome što je navedeno u literaturi. Međutim, gustina feritnog broja će se povećavati s povećanjem brzine hlađenja u FA tipu očvršćavanja, za niske i umerene brzine hlađenja, bez obzira na veličinu zavara.
2. FND je bolji pokazatelj sadržaja ferita u zavaru, posebno kada se zavarivaju tanki limovi. FND prati sve očekivane trendove u poređenju sa literaturom, koju vrednosti FN-a nemaju.
3. Presečno područje šava ispod kojeg je FND superiorno, FN vrednost iznosi 13 mm² kada je odnos slike veći od 2,5. Za zavare sa površinom poprečnog preseka većom od ove vrednosti, FN se može direktno koristiti kao pokazatelj sadržaja ferita, ili alternativno, izmereni FN mora biti podeljen sa 13 mm² umesto stvarne površine poprečnog preseka da bi se dobio FND tako dugo dok kriterijumi za minimalni odnos šava nisu prekršeni.
4. Za postupak zavarivanja TIG koji proizvodi potpuno uvarene zavarene spojeve, utvrđeno je da minimalna površina poprečnog preseka zavarenih ploča debljine 2,4 mm iznosi 13,547 mm², što je više od polja magnetnog fluksa sonde FGAB1,3-Fe. Shodno tome, pojednostavljene vrednosti za limove debljine veće od 2,4 mm FN mogu se koristiti kao direktan pokazatelj sadržaja ferita u šavu. Kod limova tanjih od 0,9 mm sa proporcijama većim od 2,5, FND se mora koristiti kao pokazatelj sadržaja ferita u šavu. Za debljine lima između 0,9 i 2,4, FN ili FND se mogu koristiti u zavisnosti od površine poprečnog preseka zavara i njegovog odnosa slike.

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