Željko Potkonjak

NEZADOVOLJAVANJE ZAHTEVA APSORBOVANE ENERGIJE-CVN POTROŠNOG MATERIJALA ZA EPP ZAVARIVANJE- OSNOVNA ANALIZA UZROKA
CVN FAILURE OF F7A5-EM12K SAW CONSUMABLE - ROOT CAUSE ANALYSIS

Originalni naučni rad / Original scientific paper
UDK / UDC: 621.791.753.5
Rad primljen / Paper received:
Januar 2014.

Adresa autora / Author's address:
Drydocks World Dubai, Jumeirah Road, Dubai, UAE

Ključne reči: zavarivanje, epp, potrošni materijali, apsorbovana energija, ispitivanje žilavosti

Keywords: Welding, SAW, consumables, absorbed energy, toughness testing

Uvod

Zapaženo je tokom regularnog ispitivanja šarže dodatnih materijala za EPP zavarivanje a koji se koriste u FLNG Turret projektu, ponovljeno odstupanje kod F7A5-EM12K (Ref. 6) cenjenog brenda u zadovoljenju minimalne apsorbovane energije CVN (39J) na -400C kako je specificirano u Ref.1.
Namena ovog rada je da predstavi kako kako su ispitni uzroci zavareni i ispitani kao i da objasni osnovni uzrok neuspeha uključujući I predlog korektivnih mera.

Dodatni materijal

Ispod je dat opis praška klase F7A5 i klase žice EM 12K prema podacima proizvođača:
Kombinacija aglomerisanog aluminatnog praška–žica za zavarivanje pod raškom. Opšta namena kombinacije sa odličnim perfomansama zavarivanja i vrlo dobrim operativnim karakteristikama. Vrednosti udarne žilavosti su dobre do -40°C. Veći sadržaj Si je dodat u cilju povećanja tečljivosi rastopljene kupke.Pogodna za konstrukcione čelike, finozrne čelike, posude pod pritiskom, brodograđevinske čelike do F40, cevovode itd. Proizvedena je a postupke sajednom I vise žica, za sučeone I ugaone spojeve. Pogodna za DC I AC struju zavarivanja. Jednoslojno I višeslojno zavarivanje limova neograničene debljine.
Klasifikacija nenetog metala šava:

- SEA/AWS A5.17/A5M.17: F7A5-EM12K (Ref. 2)
- Lloyd's Register (LR): 4Y40M (Ref. 1)

Zavarivanje ispitnih uzoraka

Zavarivanje ispitnih uzoraka je izvedeno prema Ref. 1. Poglavlje 11, deo 4 (videti sliku 1).

Introduction

It has been noted, during regular batch testing of submerged arc welding (SAW) consumables to be used for FLNG Turret project, repeated failure of F7A5-EM12K (Ref. 6) grade from one reputable brand to meet minimum average CVN absorbed energy (39J) at -40^{0}C as specified in Ref.1.
Intention of this paper is to present how test coupons were welded and tested, to explain root cause of failure including proposal for corrective action.

Consumable

Below is description of F7A5 grade flux and EM12K grade wire as given in manufacturer Product Data Sheet:

Agglomerated aluminate-basic flux-wire-combination for Submerged Arc Welding. General purpose combination with excellent welding performance and very good operating characteristics. Impact toughness values down to -40°C. Higher Si content has been added in order to increase the fluidity of the molten pool. Suitable for structural steels, fine grained steels, pressure vessel steels, shipbuilding steels up to F40, line pipe steels, etc. Designed for single and multi wire procedures, for butt and fillet welds. Suitable for DC and AC welding. Single layer and multi layer welding of unlimited plate thickness. Classification of deposited weld metal:

- SEA/AWS A5.17/A5M.17: F7A5-EM12K (Ref. 2)
- Lloyd's Register (LR): 4Y40M (Ref. 1).

Welding of Test Coupons

Welding of test coupons was done as per Ref. 1, Chapter 11, Section 4 (see Fig. 1):

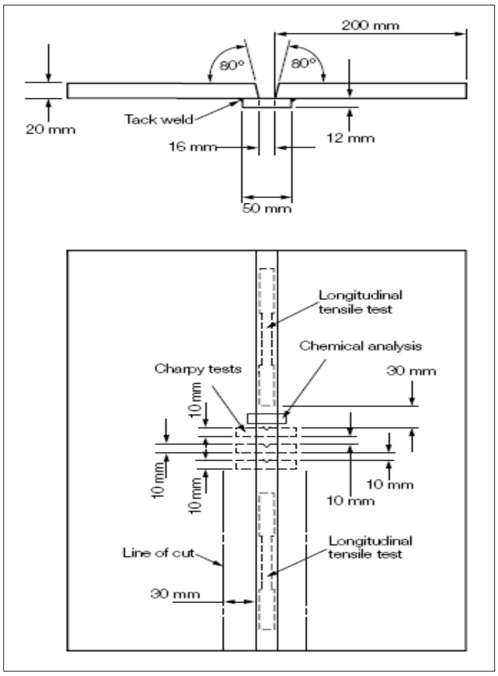

Fig. 1: Deposited weld metal test assembly

Sl. 1 Način nanošenja metala šava za ispitivanje

Ispitivanje

Epruvete za CVN su pripremljene prema Ref.3. Veličina epruveta je 10x10x55 mm.

Sva ispitivanja su izvedena u EIL (Emirates Industrial Laboratory), kancelarija u Dubaiju. Oprema koja je korišćena za isputivanje je :

• A 300J mašina za ispitivanje udarom koja koristi metodu po Šarpiju, Avery Denison 6705U (videti sl.2),

Serijski broj 32466. Poslednja verifikacija mašine je bila 03. 03.2012.

Testing

CVN specimens were prepared as per Ref. 3. Specimen's size: 10x10x55 mm.

All tests were done in EIL (Emirates Industrial Laboratory), Dubai Office. Equipment used for testing:

- A 300J Impact Testing machine using the Charpy method, Avery Denison 6705U (see Fig.2),

Serial No. 32466. Last verification of machine was done 03. 03.2012.

Fig. 2: EIL Charpy Machine

Sl. 2: Šarpiteg

Kriterijumi prihvatljivosti

Kriterijumi prihvatljivostisu prema Ref.1, Poglavlje 11, deo 4, Tabela 11.4.2- Klasa 4Y40:

Acceptance Criteria

Acceptance criteria was as per Ref. 1, Chapter 11, Section 4, Table 11.4.2 - Grade 4Y40:

Grade	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation on 50 mm % minimum	Charpy V-notch impact tests	
				Test temperature °C	Average energy (see Note) J minimum
1N, 2N, 3N	305	400 – 560	22	+20, 0, –20	34
1Y, 2Y, 3Y, 4Y	375	490 – 660	22	+20, 0, –20, –40	34
2Y40	400	510 – 690	22	0	39
3Y40	400	510 – 690	22	–20	39
3Y42	420	530 – 680	20	–20	47
3Y46	460	570 – 720	20	–20	47
3Y50	500	610 – 770	18	–20	50
3Y55	550	670 – 830	18	–20	55
3Y62	620	720 – 890	18	–20	62
3Y69	690	770 – 940	17	–20	69
4Y40	400	510 – 690	22	–40	39
4Y42	420	530 – 680	20	–40	47
4Y46	460	570 – 720	20	–40	47
4Y50	500	610 – 770	18	–40	50
4Y55	550	670 – 830	18	–40	55
4Y62	620	720 – 890	18	–40	62
4Y69	690	770 – 940	17	–40	69
5Y42	420	530 – 680	20	–60	47
5Y46	460	570 – 720	20	–60	47
5Y50	500	610 – 770	18	–60	50
5Y55	550	670 – 830	18	–60	55
5Y62	620	720 – 890	18	–60	62
5Y69	690	770 – 940	17	–60	69
1 1/2 Ni	375	460	22	–80	34
3 1/2 Ni	375	420	25	–100	34
5 Ni	375	500	25	–120	34
9 Ni	375	600	25	–196	34

Note: For Charpy V-notch tests, a set of three test specimens is to be prepared and the average energy value is to comply with the requirements of above table. One individual value may be less than the required average value provided that it is not less than 70 percent of this value.
Primedba: Za ispitivanje po Šarpiju pripremljen je set od po tri epruvete i srednja vrednost zadovoljava zahteve iz pomenute tabele. Neka pojedinačna vrednos može biti manja odzahtevane srednje vrednosti ali ne manje od 70% te vrednosti.

Rezultati

Rezultati ispitivanja CVN prikazani su u Tabeli 1:

Results

Results of CVN testing are presented in Table 1 below:

Table 1:
Tabela 1:

Test #	Batch # Šarža (Flux-prašak)	Batch # Šarža (Wire-žica)	Dia. Preč. (mm)	Absorbed Energy (J) at -40^0C (10x10x55)						Result Rezultat	Remarks Primedbe
				#1	#2	#3	#4	#5	Avg.		
1	XXXX1588	YY1031786	4	18	18	16	N/A	N/A	17	Failed Nije zadovoljilo	Flux not baked. Praša knije sušen
2	XXXX1588	YY2034646	4	16	14	18	16	20	17	Failed Nije zadovoljilo	Flux not baked. Prašak nije sušen
3	XXXX3511	YY8038419	4	32	48	24	N/A	N/A	35	Failed Nije zadovoljilo	Flux not baked. Prašak nije sušen
4	XXXX3511	YY9038419	3.2	44	24	56	N/A	N/A	41	Failed Nije zadovoljilo	Flux not baked. Prašak nije sušen
5	XXXX2596	YY8038419	4	54	24	20	20	18	27	Failed Nije zadovoljilo	Flux not baked. Prašak nije sušen
6	XXXX3511	YY8038419	4	62	78	88	50	56	67	**Pass Prošlo**	Flux baked: 300^0C/2hSušenje praška
7	XXXX1588	YY2034646	4	92	56	46	102	126	84	**Pass Prošlo**	Flux baked: 300^0C/2h Sušenje praška

Makro i mikro strukturna analiza urađena je na uzorku #1 (CVN nije zadovoljio) i #7 (CVN je zadovoljio) (za detalje, pogledati Tabelu 1.) Nalazi su dati ispod:

Macro and micro structural analysis has been done on sample #1 (CVN fail)& #7 (CVN pass) (for details, please refer to Table 1 above). Findings are presented below

Specimen #1:
Uzorak#1

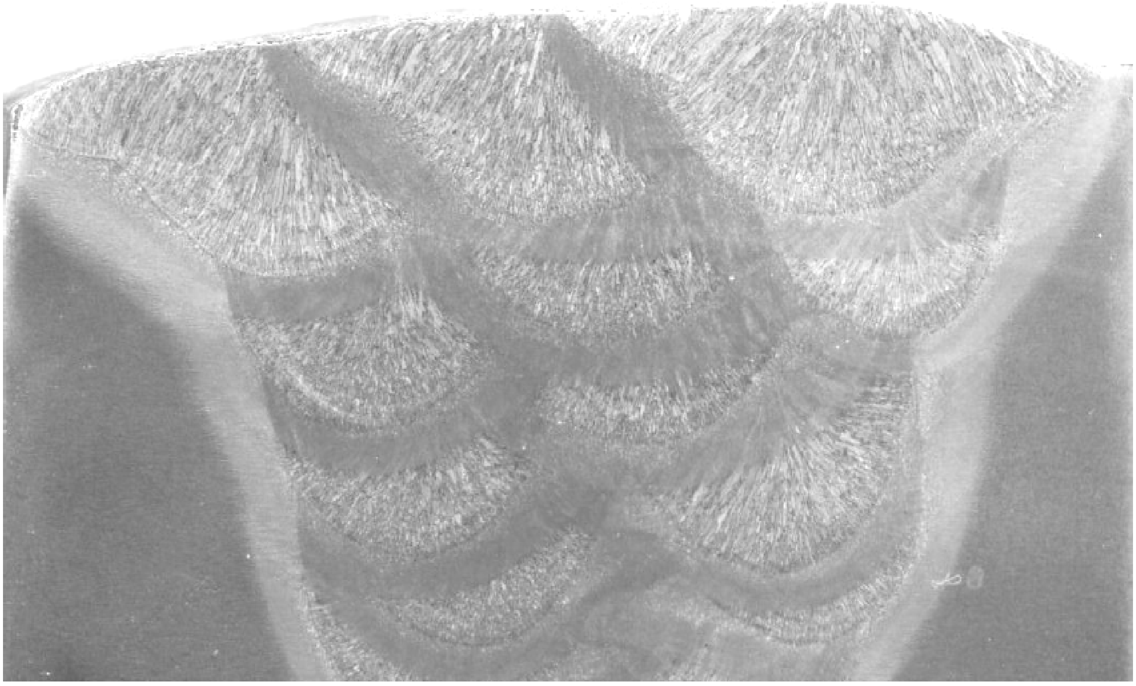

Fig. 3: Weld Macro Photograph – Specimen #1
Sl.3: Makrofotografija šava-epruveta#1

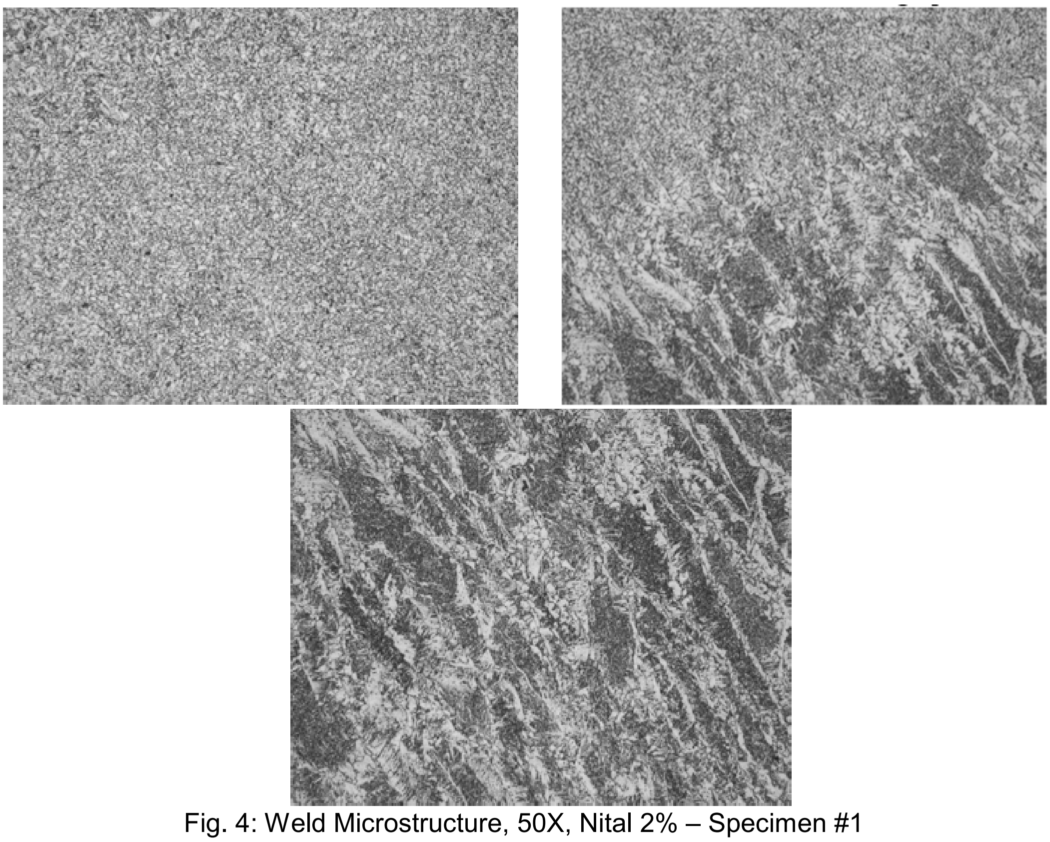

Fig. 4: Weld Microstructure, 50X, Nital 2% – Specimen #1
Sl.4: Mikrostruktura šava 50X, Nital 2% – epruveta #1

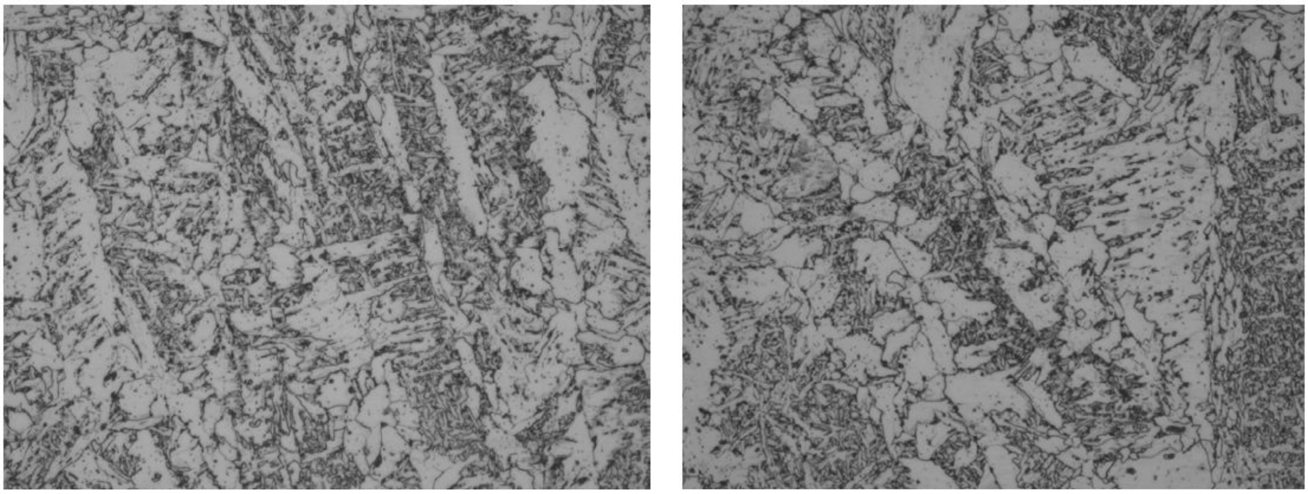

Fig. 5: Weld Microstructure, 200X, Nital 2% – Specimen #1
Sl.5: Mikrostruktura šava,200X, Nital 2% – epruveta #1

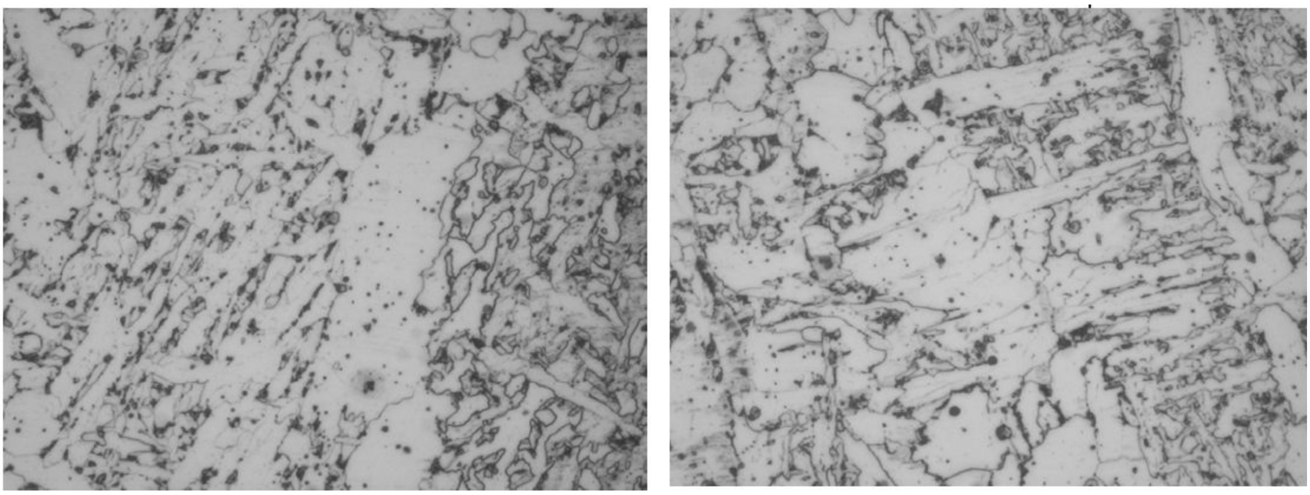

Fig. 6: Weld Microstructure, 500X, Nital 2% – Specimen #1
Sl.6: Mikrostruktura šava,500X, Nital 2% – epruveta #1

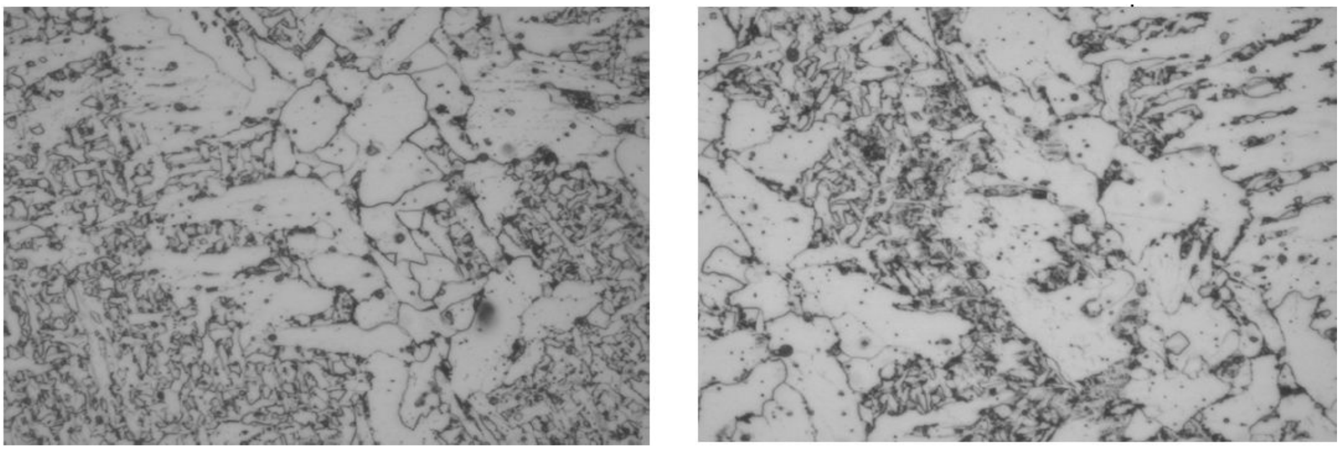

Fig. 7: Weld Microstructure, 1000X, Nital 2% – Specimen #1
Sl.7: 50X, Mikrostruktura šava,1000X, Nital 2% – epruveta #1

Mikrostruktura ispitivana u metalu šava sastoji se od različitih faza ferita kao što je ferit sa granicama zrna, Widmanstätten-ov ferit (uglavnom), acikularni ferit, poligonalni ferit sa rasutim karbidima i loptastim uključcima oksidnog tipa.

Microstructure examined at weld consists of various phases of ferrite such as grain boundary ferrite, Widmanstätten ferrite (predominantly), acicular ferrite, polygonal ferrite with dispersed carbides and globular oxide type inclusions.

Specimen #7:
Epruveta #7:

Fig. 8: Weld Macro Photograph – Specimen #7
Sl.8: Makrofotografijašava - epruveta #7

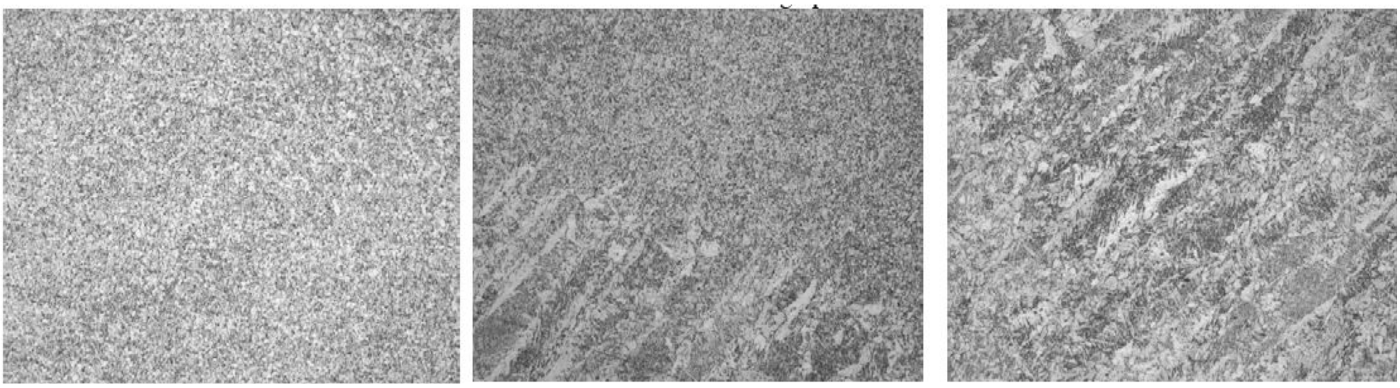

Fig. 9: Weld Microstructure, 1000X, Nital 2% – Specimen #7
Sl.9: Mikrostruktura šava,1000X, Nital 2% – epruveta #7

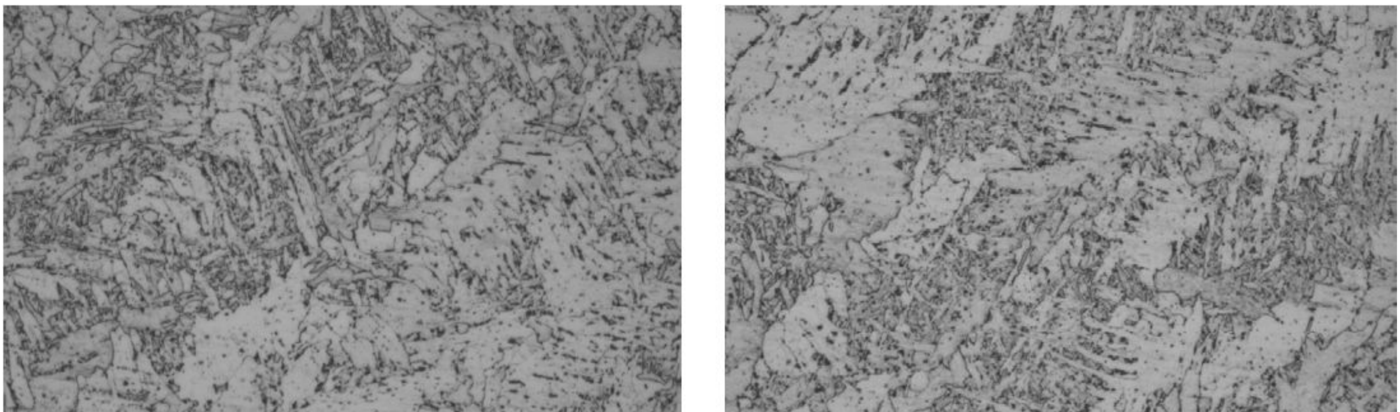

Fig. 10: Weld Microstructure, 200X, Nital 2% – Specimen #7
Sl.10: Mikrostruktura šava,200X, Nital 2% – epruveta #7

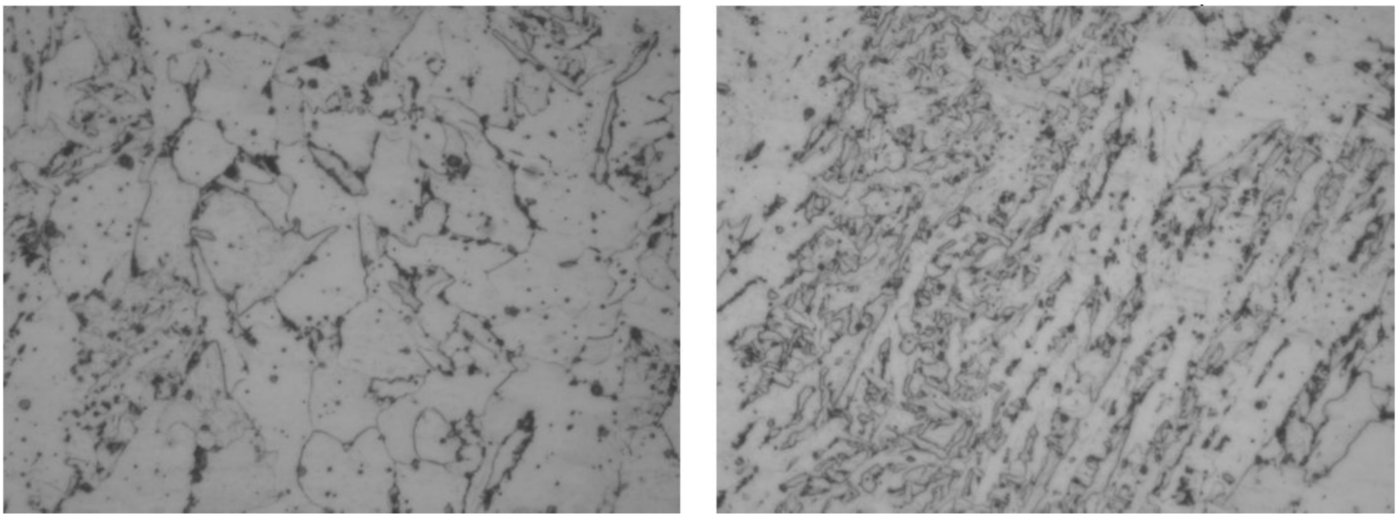

Fig. 11: Weld Microstructure, 500X, Nital 2% – Specimen #7
Sl.11: Mikrostruktura šava,500X, Nital 2% – epruveta #7

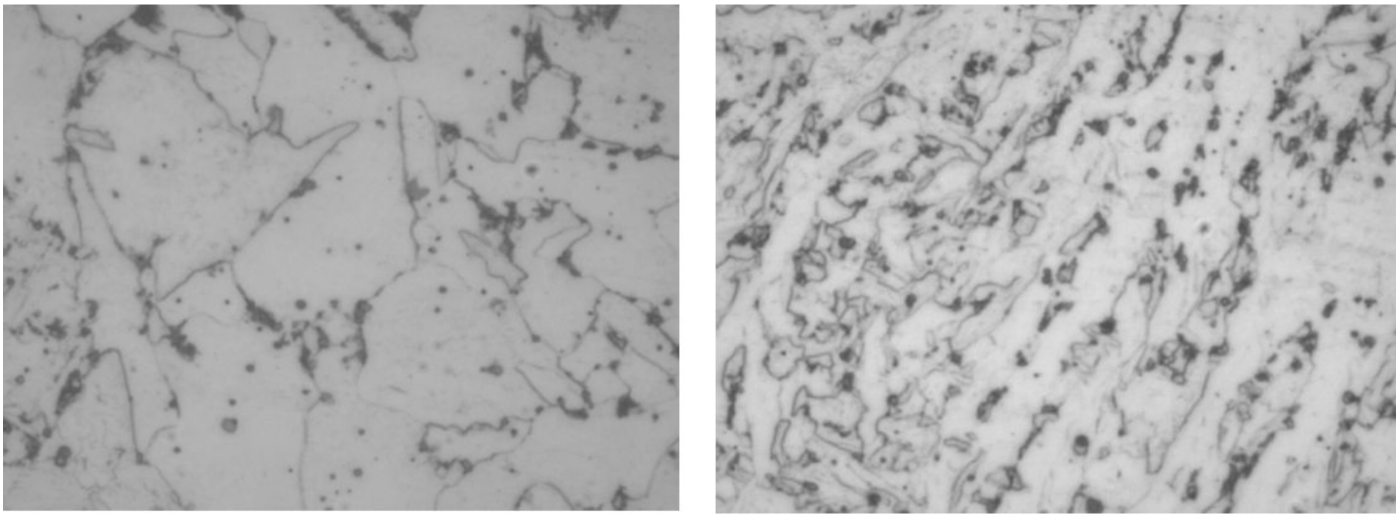

Fig. 12: Weld Microstructure, 1000X, Nital 2% – Specimen #7
Sl.12: 50X, Mikrostruktura šava,1000X, Nital 2% – epruveta #7

Mikrostruktura ispitivana u metalu šava sastoji se od različitih faza ferita kao što je ferit sa granicama zrna, Widmanstätten-ov ferit (uglavnom), poligonalni ferit sa rasutim karbidima i loptastim uključcima oksidnog tipa.

Osnovna analiza uzroka

Zapaženo je da je sušenje praška na 3000C u trajanju od 2 sata i držanje na približno 1500C, kada se primenjuje, značajno poboljšavalo postignute vrednosti apsorbovane energije na -400C. S obzirom da je namena sušenja upravo to da smanji nivo vlage u prašku, logično je zaključiti da vlaga nepovoljno utiče na CVN osobine metala šava. Predmetni prašak jeklasifikovan kao aglomerisani bazični prašak (B>1.2-2). Tipičninivo kiseonika kod oog tipa praška je 300 – 500ppm.

Kako sadržaj kiseonika ugrožava udarne osobine metala šava?

Generalno, veća bazičnost podrazumeva veću čistoću sa aspekta nemetalnih uključaka(to je u suštini masnji

Microstructure examined at weld consists of various phases of ferrite such as grain boundary ferrite, acicular ferrite (predominantly), Widmanstätten ferrite, polygonal ferrite with dispersed carbides and globular oxide type inclusions.

Root Cause Analysis

It has been noted that baking of flux at 3000C for 2 hours and keeping it at approx. 1500C until used significantly improves achieved CVN absorbed energy at -400C. Since purpose of baking is to reduce level of moisture in the flux, it is logical to conclude that moisture contamination of flux has deteriorated specified CVN properties of weld metal. Subjected flux has been classified as agglomerated basic flux (B>1.2-2). Typical oxygen level for this kind of flux is 300 – 500ppm.

How content of Oxygen is affecting Impact Properties of Weld Metal?

In general, the higher the basicity, the cleaner the weld with respect to nonmetallic inclusions (that is, lower weld sadržaj kiseonika u metalu šava). Kao posledica toga, proizvođači potrošnih materijala za zavarivanje klasifikuju I reklamiraju svoje praškove sa tim indeksom. Veruje se da veća bazičnost znači i veću žilavost, dok kiseliji prašak znači odlično ponašanje šljake, karakteristiku intersantnu za poboljšanje morfologije zavara I brzinu nanošenja. Slaka ispod ilustruje korelaciju između kiseonika u metalu šava I indeksa bazičnosti (BI) kod nekih sistema praškova. Sadržaj kiseonika u metalušava značajno opada kada BI raste do 1.2 a potom ostaje relativno konstantan pri oko 20 ppm O.

metal oxygen content). Consequently, manufacturers of welding consumables have classified and advertised their fluxes with this index. It is believed that high basicity means high toughness, while an acidic flux means excellent slag behavior, a characteristic of interest to improve weld bead morphology and deposition rate. Figure below illustrates the correlation between weld metal oxygen and the basicity index (BI) for some flux systems. The weld metal oxygen content drops significantly as the BI is increased to 1.2 and then remains relatively constant at about 250 ppm O.

Note: This theory is not applicable for fluxes with high content of amphoteric oxides (Al2O3, TiO2…)
Primedba: Ova torija nije prihvatljiva za praškove sa visokim sadržajem amfoternih oksida (Al2O3, TiO2…)

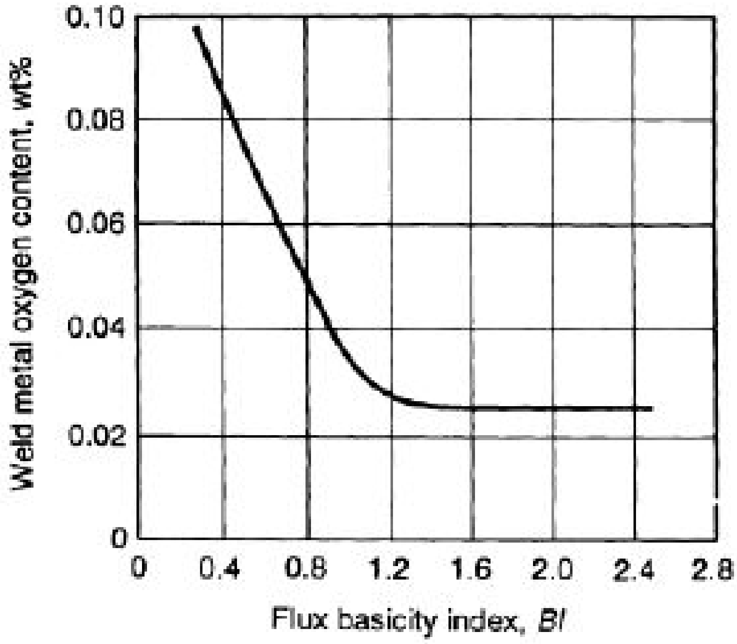

Fig. 13: Effect of Flux Basicity Index on Weld Metal Oxygen Content when using SAW Process (Source: Ref. 4)
Sl.14: Uticaj indeksa bazičnosti na sadržaj kiseonika u metalu šava pri EPP zavarivanju (Izvor : Ref.4)

Sa slike 14. vidljivo je da se za postizanje najmanje CVN prelazne temperature, zahteva optimalni sadržaj uključaka. Na prelaznu temperaturu prevashodno utiče lom usled cepanja, a njegov tok zavisi od toga koliko je efektivno propagirana prslina cepanja u smislu promene pravca tokom svog prostiranja kroz mikrostrukturu. Pri manjem sadržaju uključaka, zapaža se struktura gornjeg beinita i sastoji se od paralelnih pločica ferita (u jednom paketu) koje rastu na površinama granica zrna. Kod optimalnog sadržaja uključaka, javlja se pretežno struktura acikularnogferita, I ovde susedne pločice ferita teže da da se sire u mnogo različitih pravaca od mesta nastanka uključka. Pri većem sadržaju uključaka, udeo structure plčastog ferita raste, imajući opet skoro paralelne pločice ferita (Widmanstätten-ov ferit). Najveća žilavost (znači i najmanja prelazna temperatura) javlja se samo u "haotičnoj" mikrostrukturi acikularnog ferita zato što je najmanja efektivna veličina feritnog zrna.

From Fig. 14 below it is seen that optimum inclusion content is required to obtain the lowest CVN transition temperature. The transition temperature is mainly governed by cleavage fracture, and this in turn depends on how effectively a propagating cleavage crack is forced to change direction as it traverses the microstructure. At low inclusion contents, an upper bainitic structure is obtained, and this consists of parallel platelets of ferrite (in a single packet) growing from the grain boundary surfaces. With optimum inclusion content, a predominantly acicular ferrite structure is obtained, and here the adjacent ferrite platelets tend to radiate in many different directions from inclusionnucleation site. At higher inclusion contents, the amount of ferrite sideplate structures increases, again having nearly parallel ferrite platelets (Widmanstätten ferrite). The highest toughness (that is, the lowest transition temperature) is obtained only in the "chaotic" microstructure of acicular ferrite because it has the smallest effective ferrite grain size.

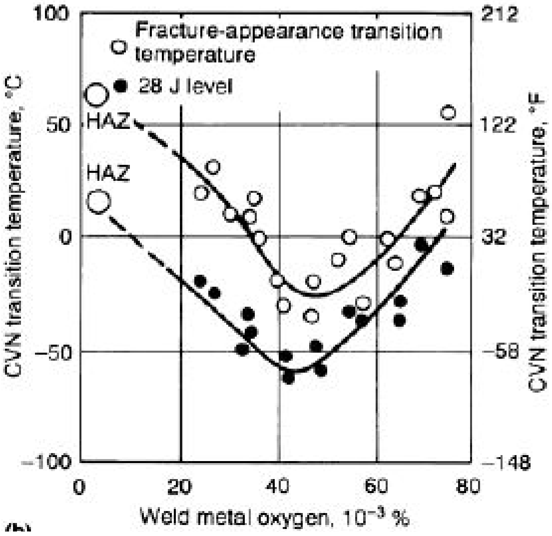

Fig. 14: Effect of Oxygen Content on CVN Transition Temperature (Source: Ref. 5)
Sl.14: Uticaj sadržaja kiseonika na CVN prelaznu temperature (Izvor: Re.5)

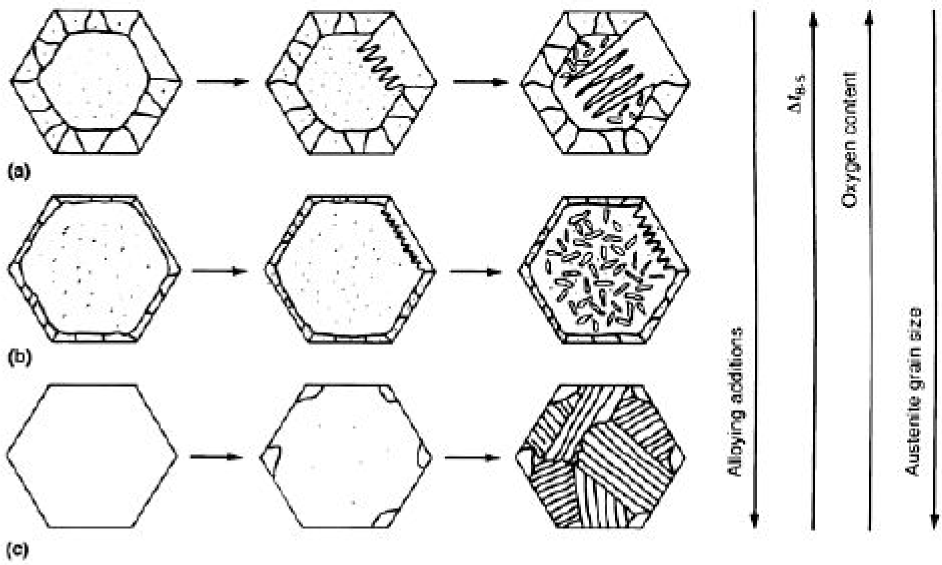

Fig. 15: Effect of Oxygen Content on the Development of Microstructure (Source: Ref. 6)
Sl. 15: Uticaj sadržaja kiseonika na razvoj mikrostrukture (izvor: Ref. 6)

Zaključak

Tri napred ispitana lota praška F7A5 nisu zadovoljili zahteve udarnog opterećenja CVN zbog prisustva vlage. Prašak je korišćen direktno iz vreće po preporuci proizvođača.

Analizirajući podatke za isporuku praška iz sladištenja proizvođača I skladišta krajnjeg potrošača i stvarnog zavarivanja (videti tačke ispod), treba zapaziti da je prašaka skladišten u skladištu krajnjeg potrošača jako kratko, tako da je kontaminacija praška unutar skladišta korisnika nemoguća. Na osnovu prikazanih podataka, izgleda da je do kontaminacije praška došlo pre isporuke u skaldište proizvođača.

XXXX1588 (U skladištu proizvođača: 03.05.2012, skladištu krajnjeg korisnika: 04.05.2012 – zavarivanje 06.05.2012);

Conclusion

7.1. Three above tested lot numbers of F7A5 flux were not able to satisfy CVN impact requirements due to moisture contamination. Flux was used directly from the bag as recommended by the manufacturer.

Analyzing dates of flux delivery to the manufacturer warehouse, end user warehouse and actual welding (see points below), it should be noted that flux was stored in end user warehouse very short time before it was used for welding, so contamination of flux due to storage conditions inside end user warehouse is very unlikely. Based on dates presented, it looks like contamination of flux could happen before delivery to manufacturer warehouse.

XXXX1588 (IN Manufacturer Warehouse: 03.05.2012, End User Warehouse: 04.05.2012 – welding 06.05.2012);

XXXX3511 (U skladištu proizvođača: 10.05.2012, skladištu krajnjeg korisnika: 06.06.2012 – zavarivanje 09.06.2012);
XXXX2596 (U skladištu proizvođača: 06.05.2012, skladištu krajnjeg korisnika: 07.05.2012 – zavarivanje 12.06.2012);

Tokom provere skladišta proizvođača, zapažen je nedostatak dokumentovanih dokaza o čuvanju proizvoda (posebno o sadržaju vlage) koi je kontrolisan tokom različitih stadijuma transporta od proizvođača dok ne stigne do krajnjeg korisnika. Takođe, proizvođač nije bio u mogućnosti da prikaže podatke o sadržaju vlage koji je nađen u tri predmetna lota praška, tokom proizvodnje i finalnog pakovanja.

Uzimajući u obzir sve ovo, može se zaključiti da se predmetna klasa praška može koristiti za -400C CVN primene ali uz obavezno sušenje praška na 3000C/2h I potom držanja na ~1500C. Proizvođač treba da reviduje sadašnje izdanje kataloga svojih proizvoda sa uputstvima za korišćenje u smislu rešavanja ovog problema uz mnogo specifičniji opis.

XXXX3511 (IN @ Manufacturer Warehouse: 10.05.2012, End User Warehouse: 06.06.2012 – welding 09.06.2012);
XXXX2596 (IN @ Manufacturer Warehouse: 06.05.2012, End User Warehouse: 07.05.2012 – welding 12.06.2012);

During audit in manufacturer warehouse, it has been noted lack of documented evidence that preservation of product (especially content of moisture) is controlled during various stages of transport from manufacturer till it reaches end user. Also, manufacturer was not able to present data of moisture content found in subjected three lots of flux during production and before final packing.

Considering all above, it can be concluded that subjected brand of flux can be used for -400C CVN applications but drying of flux at 3000C/2h and then holding it at ~1500C till used is mandatory. Manufacturer shall revise current edition of consumable handling handbook addressing this issue and describe it in more specific manner.

References

- LR RULES FOR MANUFACTURE, TESTING AND CERTIFICATION OF MATERIALS, PART 2;
- SEA/AWS A5.17/A5M.17:SPECIFICATION FOR CARBON STEEL ELECTRODES AND FLUXES FOR SUBMERGED ARC WELDING
- ISO 148-1: METALLIC MATERIALS - CHARPY PENDULUM IMPACT TEST - PART 1: TEST METHOD
- S.S. TULIANI, T. BONISZEWSKI, AND N.F. EATON, NOTCH TOUGHNESS OF COMMERCIAL SUBMERGED ARC WELD METAL, *WELD. MET. FABR.*, VOL 37 (NO. 8), 1969, P 27
- B. AHLBLOM, "OXYGEN AND ITS ROLE IN DETERMINING WELD METAL MICROSTRUCTURE AND TOUGHNESS--A STATE OF THE ART REVIEW," DOC. NO. IX-1322-84, INTERNATIONAL INSTITUTE OF WELDING, 1984
- "GUIDE TO THE LIGHT MICROSCOPE EXAMINATION OF FERRITIC STEEL WELD METALS," DOC. NO. IX-1533-88, INTERNATIONAL INSTITUTE OF WELDING, 1988
- AUDIT REPORT, DOC. REF. NO: DDWD_XXXX_01