This paper was presented at the Fourteenth Meeting
"New Trends in Fatigue and Fracture" (NT2F14)
Belgrade, Serbia, 15–18 September, 2014

Sergiu Valentin Galatanu[1,2], Nicolae Faur[1], Doru Romulus Pascu[2]

MECHANICAL PROPERTIES OF HEAT AFFECTED ZONES AT MACRO- AND MICRO-STRUCTURAL LEVEL, USING THERMAL CYCLE SIMULATION

MEHANIČKE OSOBINE ZONE UTICAJA TOPLOTE NA MAKRO- I MIKROSTRUKTURNOM NIVOU PRIMENOM SIMULACIJE TOPLOTNOG CIKLUSA

Originalni naučni rad / Original scientific paper
UDK /UDC: 669.14:621.791.051
Rad primljen / Paper received: 23.09.2014

Adresa autora / Author's address:
1) Politehnica University Timişoara
2) National R&D Institute for Welding and Material Testing ISIM Timişoara

Keywords
- welding
- macro- microstructural examinations
- HV10 hardness
- thermal cycle simulator

Abstract

It is almost impossible to produce welded joints with homogeneous structure. This structure is composed from at least three different regions: base material, weld metal and heat affected zone (HAZ). In many welded structures the coarse-grained HAZ is considered to be the preferred location for initiation and propagation of cracks.

Since the HAZ is too small, and it is very difficult to obtain data on mechanical properties, in this paper a thermal cycle simulator is used to achieve some test specimens from P355NH steel for pressure vessels.

This paper offers information regarding the chemical content of welded joints in percent, estimation of macro-microstructure in specific areas of the welded edge joints and determination of HV10 hardness of specific areas of the welded joints, both for butt welding and thermal cycle simulator specimens.

Ključne reči
- zavarivanje
- ispitivanja makro- i mikrostrukture
- tvrdoća HV10
- simulator toplotnih ciklusa

Izvod

Skoro je nemoguće proizvesti zavarene spojeve sa homogenom strukturom. Datu strukturu sačinjava bar tri različite oblasti: osnovni materijal, metal šava i zona uticaja toplote (ZUT). Kod mnogih zavarenih konstrukcija, grubozrni ZUT se smatra za osetljivu lokaciju za inicijaciju i rast prslina.

Kako je ZUT vrlo mala zona, te je veoma teško dobiti podatke o osobinama materijala, u ovom radu je primenjen simulator toplotnog ciklusa za ispitivanje uzoraka od čelika za posude pod pritiskom tipa P355NH.

U radu su dati podaci procentualnog hemijskog sastava zavarenih spojeva, procena makro- i mikrostrukture u pojedinim oblastima sučeonih zavarenih spojeva i predstavljeno je određivanje tvrdoće HV10 u pojedinim oblastima zavarenih spojeva, istovremeno za sučeono zavarene spojeve i za epruvete kod simulacije toplotnog ciklusa.

INTRODUCTION

It is known that welded joints are characterized by different regions with different strengths, which is referred to as the mismatching phenomenon, /1, 2/.

Different microstructures and mechanical properties of the base metal (BM), weld metal (WM) and heat-affected-zone (HAZ) leads to the presence of micro- and macro-heterogeneities in welded joints and from this to a non-uniform distribution of stress and strain, /3, 4/.

Throughout this paper a comparison is presented between the results obtained using welded joints and thermal cycle simulator specimens made from material P355NH of thickness 22 mm, intended for pressure vessels, /5, 6/. Two types of thermal cycle simulator specimens are used: one specimen without post-simulation heat treatment and the other one with post-simulation heat treatment. For the welded joint specimen, Mn3Ni1CrMo filler material is used.

EXPERIMENTAL PROCEDURE

Chemical composition

First, the chemical composition of the used base material is verified. The chemical composition of the base material is determined with the INNOVIX-Systems and the results are in compliance with SR EN 10028-3 standard, /7/.

Macroscopic examinations

For butt welded specimens and also for thermal cycle simulated specimens, the macroscopic examinations are performed with stereo optical microscope, type MAK-MS. The results are presented in Figs. 1, 2, and 3, /8/.

W1 specimen is a butt welded joint with a number of layers: 5+2. S2 specimen is a sample simulated with thermal cycles without post-simulation heat treatment and S3 specimen is a sample simulated with thermal cycles with post-simulation heat treatment. Post-simulation heat treatment applied to S3 specimen is: TT (600°C 2h + 400°C 2h).

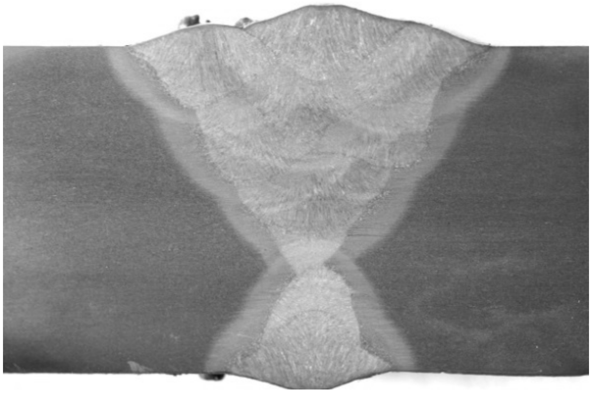

Figure 1. W1 Specimen (Attack Nital 10%).
Slika 1. W1 epruveta (nagrizanje nitalom 10%)

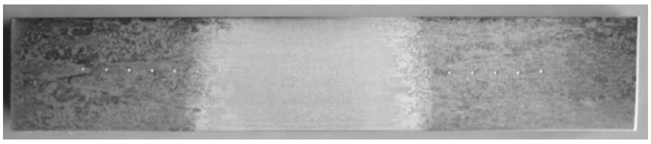

Figure 2. S2 Specimen (Attack Nital 10%).
Slika 2. S2 epruveta (nagrizanje nitalom 10%)

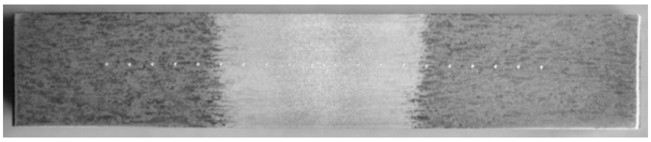

Figure 3. S3 Specimen (Attack Nital 10%).
Slika 3. S3 epruveta (nagrizanje nitalom 10%)

Microscopic examinations

The microscopic examination is performed with a MeF2 optical microscope.

Microscopic examinations performed on butt welded W1 specimen using MIG-MAG welding processes, indicate the formation of banded ferrite and pearlite in the base material, ferrite, pearlite and acicular ferrite in heat affected zone and ferrite and pearlite in a dendritic structure of the casting in weld metal (Figs. 4, 5 and 6).

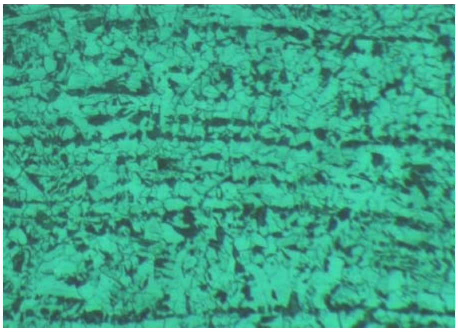

Figure 4. W1 specimen, BM (Nital 2%, ×100).
Slika 4. W1 epruveta, osnovni materijal (nital 2%, ×100)

Microscopic examinations performed on the S2 specimen, simulated with thermal cycle, without post-simulation heat treatment, indicate the formation of martensitic layer with unevenly distributed acicular ferrite (Figs. 7 and 8).

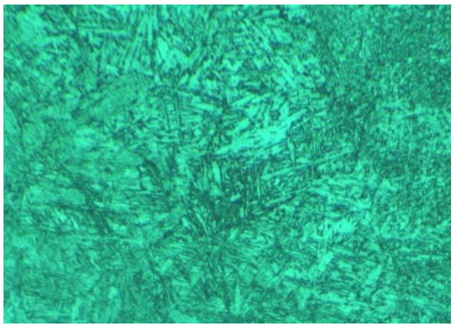

Figure 5. W1 specimen, HAZ (Attack Nital 2%, ×100).
Slika 5. W1 epruveta, ZUT (nital 2%, ×100)

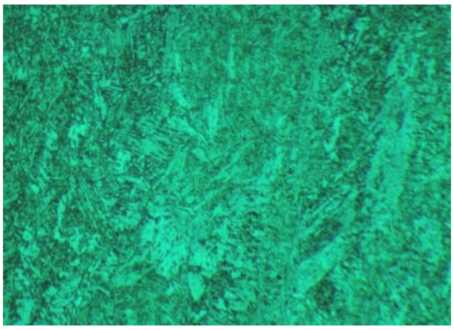

Figure 6. W1 specimen, weld (Nital 2%, ×100).
Slika 6. W1 epruveta, metal šava (nital 2%, ×100)

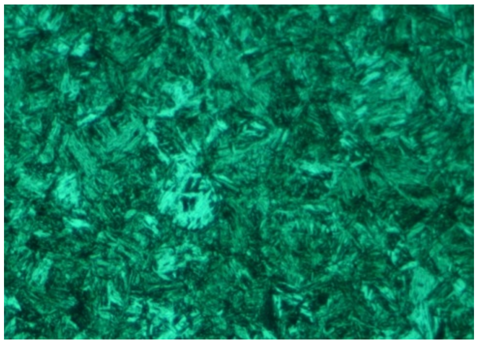

Figure 7. S2 specimen, HAZ (Nital 2%, ×100).
Slika 7. S2 epruveta, ZUT (nital 2%, ×100)

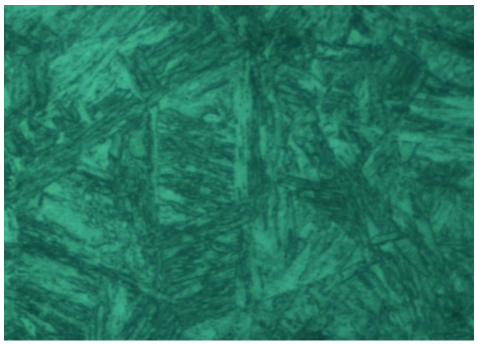

Figure 8. S2 specimen, HAZ (Nital 2%, ×500).
Slika 8. S2 epruveta, ZUT (nital 2%, ×500)

Microscopic examinations performed on specimen S3, simulated with thermal cycle, with post-simulation heat treatment, indicate the formation of sorbite structure with acicular ferrite and pearlite areas crowded on sorbite background (Figs. 9 and 10).

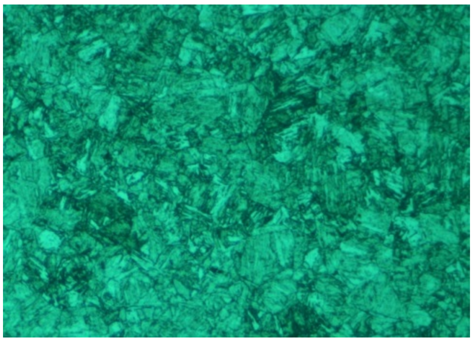

Figure 9. S3 specimen, HAZ (Attack Nital 2%, ×100).
Slika 9. S3 epruveta, ZUT (nital 2%, ×100)

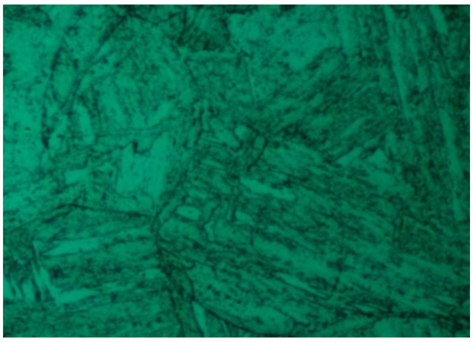

Figure 10. S3 specimen, HAZ (Attack Nital 2%, ×500).
Slika 10. S3 epruveta, ZUT (nital 2%, ×500)

Determination of HV10 hardness

Based on the determination of HV10 hardness performed on the characteristic areas of the W1, S2, S3 specimens, the values of the hardening of structure estimator ΔHV10 /9/, between the characteristic areas (weld, HAZ, BM) (Table 1), are determined using the mathematical equation /1/:

$$\Delta HV10 = \frac{HV10_{max} - HV10_{min}}{HV10_{max}} \cdot 100\ (\%) \qquad (1)$$

where: $HV10_{max}$ – is the maximum HV10 hardness determined in one investigated area of the sample; $\Delta HV10_{min}$ – is the minimum HV10 hardness determined in another investigated area of the sample.

It is considered that if ΔHV10 ≥ 50%, accentuated local hardening develops in the examined area, with the high risk of producing brittle fracture, /9/.

RESULTS AND DISCUSSION

Butt welded joints made of P355NH material, welded with Mn3Ni1CrMo alloy (marked as W1), showed no welding defects such as cracks when subjected to macroscopic examination (Fig. 1). Thermal cycle simulation of S2 specimen without post-simulation heat treatment, and also of S3 specimen with post-simulation heat treatment, subjected to macroscopic examination, showed no defects such as cracks after the simulation (Figs. 2 and 3).

Table 1. Values of the hardening of structure estimator ΔHV10 between characteristic areas.
Tabela 1. Vrednosti procene ojačavanja strukture prema ΔHV10 u karakterističnim oblastima

Specimen	Hardening HV10						ΔHV5 estimator (%)		
	BM		HAZ		WELD		BM	HAZ	WELD
	Minimum values	Maximum values	Minimum values	Maximum values	Minimum values	Maximum values			
Butt welded joints									
W1	144	154	181	302	247	270	6.49	40.06	8.51
Thermal cycle simulation without post-simulation heat treatment									
S2	150	186	230	437	-	-	19.35	47.37	-
Thermal cycle simulation with post-simulation heat treatment									
S3	146	150	150	268	-	-	2.66	44.03	-

Microscopic examination revealed normal pearlitic-ferritic structures in the heat affected zone of welded joints, although in the simulated heat affected zone the structures with hard martensitic areas are detected, with maximum hardness of 437 HV10 for specimen S2 without post-simulation heat treatment.

In the S3 specimen with post-simulation heat treatment, the structures are sorbitic in the heat affected zone, with maximum hardness of 268 HV10.

Microscopic examination of the area showed no microcrack defects.

Figure 11 shows the variance of the ΔHV10 estimator on the butt welded W1 specimen and on the thermal cycle simulation S2, S3 specimens.

Figure 12 presents the variation of hardness for W1 specimen (butt welded joints), S2 specimen (thermal cycle simulation without post-simulation heat treatment) and S3 (thermal cycle simulation with post-simulation heat treatment) for specific area (BM, HAZ, weld).

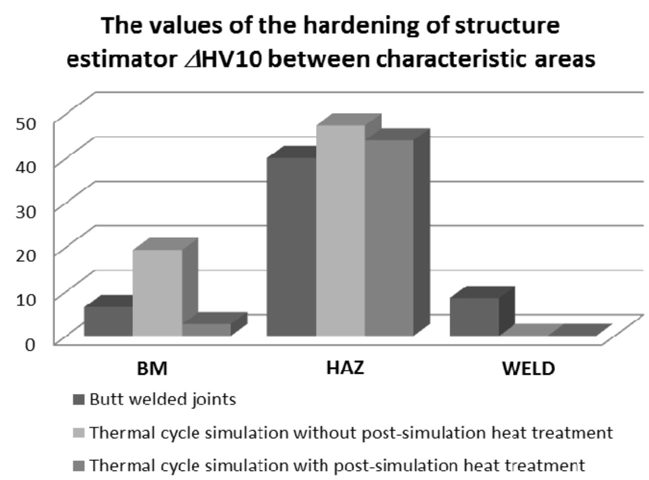

Figure 11. ΔHV10 Variation = *f* (characteristic areas).
Slika 11. ΔHV10 varijacija = *f* (karakteristične oblasti)

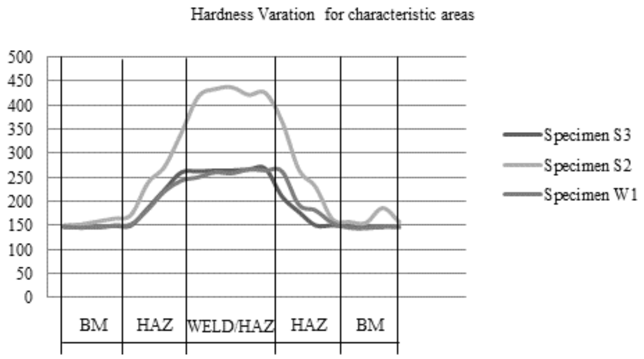

Figure 12. Hardness HV10 Variation for specimen W1, S2, S3.
Slika 12. Varijacija tvrdoće HV10 epruveta W1, S2 i S3

CONCLUSION

The absence of cracks in welded joints proves that the thermal cycle simulation and MIG-MAG welding processes were performed in accordance with welding thermal cycles applied during heating and cooling.

In the analysed case the values obtained for the hardening estimator for heat affected zone are less than 50% (47.37% for S2 specimen – thermal cycle simulation without post-simulation heat treatment, and 44.03% for S3 specimen – thermal cycle simulation with post-simulation heat treatment), indicate that the obtained structures do not lead to the development of brittle fracture.

A good correlation is observed between the results of thermal cycle simulation with post-simulation heat treatment and results obtained by welding.

ACKNOWLEDGEMENTS

This work is partially supported by the strategic grant POSDRU/159/1.5/S/137070 (2014) of the Ministry of National Education, Romania, co-financed by the European Social Fund – Investing in People, within the Sectoral Operational Programme Human Resources Development 2007-2013.

REFERENCES

1. Schwalbe, K.H., Basic engineering methods of fracture mechanics and fatigue. Geesthacht: GKSS Research Center; 2001.
2. Kocak, M., editor. Weld mis-match effect. International Institute of Welding (IIW), IIW Document X-1419-98; 1998.
3. Hertzberg, R.W., Deformation and fracture mechanics of engineering materials. New York: Wiley; 1996.
4. Burstow, M.C., Howard, I.C., Ainswort, R.A., *The influence of constraint on crack tip stress fields in strength mismatched welded joints*, J Mech Phys Solids 1998.
5. SR EN 10028 – 3 Produse plate din oțel pentru recipient sub presiune, Partea 3: Oteluri sudabile cu granulatie fina, normalizate (in Romanian).
6. Pascu, D.R., Doctoral thesis: Influența factorilor structurali asupra caracteristicilor tehnologice și proprietăților mecanice ale oțelului slab aliat pentru construcții sudate supus tratamentelor termice post-sudare, 1983 (in Romanian).
7. Vuherer, T., et al., *Microstructural investigation on the heat-affected zone of simulated weld joint of P91 steel*, Metalurgija 52 (2013) 3, pp.317-320.
8. SR EN ISO 17639:2014, Încercări distructive ale îmbinărilor sudate din materiale metalice. Examinarea macroscopică și microscopică a îmbinărilor sudate (in Romanian).
9. Safta, I., Încercări tehnologice și de rezistență ale îmbinărilor sudate sau lipite, Editura Sudura, Timișoara, România, 2006 (in Romanian).

ESIS CALENDAR OF CONFERENCES & WORKSHOPS

Event	Date	Location	Contact
2015			
3rd Int. Conf. on Material and Component Performance under Variable Amplitude Loading (VAL2015)	23-26 March	Prague (Czech Republic)	www.val-conf.org
6th Int. Conf. on Mechanics and Materials in Design (M2D'2015)	26-30 July	Ponta Delgada (Azores)	paginas.fe.up.pt/clme/m2d2015/
SMiRT 23 – 23rd Conference on Structural Mechanics in Reactor Technology International	10-14 August	Manchester	www.smirt23.org
CP 2015 – 5th International Conference on Crack Paths	16-18 September	Ferrara, Italy	www.structuralintegrity.eu
2016			
ECF21 – 21st European Conference on Fracture	19-24 June	Catania, Italy	www.structuralintegrity.eu
2017			
ICF14 – Fourteenth International Conference on Fracture	7-13 May	Rhodes, Greece	www.icfweb.org