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WELDABILITY ASSESSMNENT AND CRACK RESISTANCE OF MICROALLOYED STEEL

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ABSTRACT

The results of weldability assessment of high strength low carbon microalloyed steel are presented. Weldability assessment included the tests of mechanical and structural properties of welded joints, welded joint susceptibility to hot (FISCO test), cold cracking (Control Thermal Severity – CTS test), reheat cracks (Tanaka-test) and to lamellar tearing (Windows test). Transition temperature values, i.e. 50% Charpy impact energy test, were used for determination of behaviour of welded joints related to brittle fracture. .

The experiments were performed on thermo - mechanically control processed (TMCP) high strength low carbon steel, microalloyed with Ti and Nb. Welded joints were performed by Shield Metal Arc Welding (SMAW) welding process.

Results have shown that mechanical properties and crack resistance of welded joints obtained by specified welding technology have satisfactory quality.

Keywords: Weldability, microalloyed steels, crack resistance of weldments, transition temperatures

1. INTRODUCTION

In order to meet the strong requirements for welded structures, pressure vessels and pipelines in production, weldability of high strength low alloyed (microalloyed) steels are designed with higher strength, improved toughness and lower nil-ductility transition temperature compared to traditional manganese structural steel.

Two aspects of behaviour must be considered for evaluating the weldability of higher strength steel [1]. At first, the risk of cracking during fabrication and secondly, the risk of failure during service. Since the weldability of the steels is a complex property, it covers three main indications of weldability. Indications of the weldability are summarized as follows [2]:

- Sensitivity of weld metal (WM) and heat affected zone (HAZ) to any type of cracking during or after welding,
- Mechanical and technological properties of welded joint, macro and microanalysis of base metal, heat affected zone and weld metal and
- Behaviour related to brittle fracture.

2. EXPERIMENTAL PROCEDURE

Experimental procedure was performed on Thermo Mechanical Control Processed Steel (TMCP Steel), basically low carbon higher strength low alloyed steel microalloyed with Nb and Ti. The applications of this steel were found in fabrication of welded constructions for general purpose.

Considering the applications those steels must have the following properties: good weldability (low carbon equivalent) without preheating by welding, good notch toughness at low temperatures, good cold formability and resistance to stress corrosion and/or hydrogen induced cracking.

2.1. Base and filler material properties

Steel grade E380 TM (API 5L-X56; API 5CT-J55), was used for experimental welding. Steel sheet, thickness 7 mm, was thermo-mechanically processed in Hot Strip Mill in order to improved base metal (BM) properties and to make better weldability.

All experiments related to weldability evolutions were performed by Shield Metal Arc Welding (SMAW) process using basic coated low hydrogen electrodes as filler metal. Those electrodes were developed for welding of low carbon high strength microalloyed steel. Actually, it is a basic 2.5 NiMo electrode classified as E 55 2 2Ni Mo B 42 according to EN 757. Chemical compositions and mechanical properties of base and filler materials are given in tables 1 and 2, respectively.

Table 1. Chemical composition of E380TM steel and filler material, wt.%

	C	Si	Mn	P	S	Cu	Al	Ti	Nb	Ca	N	Ni	Mo
base material	0.065	0.261	1.36	0.02	0.007	0.049	0.028	0.013	0.035	0.0024	0.006		
filler material	0.08	0.5	0.95									2.5	0.36

Table 2. Mechanical Properties of base and filler material

	Yield strength [MPa]	Tensile strength [MPa]	Elongation A_5 [%]	Bending angle [^{0}]	KV - Notch Toughness -ISO [J] Test Temperature [°C]					
					+20	0	-20	-40	-60	-80
base material	490	550	32	180	85	85	80	75	70	55
filler material	550-600	650-750	22-26				120-160	60-90		

2.2. Butt welding

Seven millimetres thick plates were used for determination of mechanical, technological and structural properties of welded joints. Following requirements for SMAW, "V" groove was prepared. During welding, following parameters were recorded: V - Arc voltage, I - Current and v - Welding speed. Heat input was calculated using following formula:

$$E= U \times I / v \tag{1}$$

3. RESULTS AND DISCUSSION

3.1. Susceptibility of crack appearance

First group of tests estimated sensitivity of weld metal and heat affected zone to any type of cracking during or after welding.

Sensitivity to hot cracking was evaluated through calculation of Hot Cracks Sensitive (HCS) parameter and through FISCO technological test [3-6]. The value of HCS parameter for tested steel is 0.6. Since that value is less than 4, hot cracks are not probable to occur. The results of FISCO test showed that value of crack length percentage was 8 %. Since this value is less than 9%, hot cracks are not probable to occur.

Sensitivity to cold cracks was evaluated through calculation of carbon equivalent (CE) and cold crack - Pw parameter [3-6]. The value of carbon equivalent, calculated using IIW formula is 0.3. Since this value is less than 0.4, cold cracks should not occur in E380TM steel. Since the calculated value of e of Pw parameter is positive (0.24), the cold cracks are not probable to occure. Both results are in good agreement, indicating that tendency towards cold crack formation in weld joint is very small, i.e. cold cracks should not occur in steel E380TM. In other words, generally, this steel does not need preheating.

Sensitivity to cold cracks was evaluated through technological test too. For this purpose CTS test was used [3-6]. Results obtained in CTS tests showed no cracks in weldments.

Sensitivity to lamellar tearing was evaluated through classification of the steels. Steel E380TM was classified in category A (steel guaranteed without cracks) because of low content of sulphur. Also, one has to note that CaSi treatment resulted in sulphur shape technology, creating globular MnS and at the same time avoiding elongated MnS inclusions, responsible to lamellar tearing. This means that E380TM can be welded also using T type of joints, in which stress is in thickness direction. Sensitivity to lamellar tearing was evaluated through Window test [7, 8]. Results showed no lamellar tearing in cross section of tested plate, due to low content of sulphur.

Sensitivity to reheat cracking was evaluated through calculation of ΔG=Cr+3.3Mo+8.1V-2 and PSR=Cr+Cu+2Mo+7Nb+5Ti-2 parameters [3, 5, 9]. The values $\Delta G = -2$ and $P_{SR} = -1.64$, are both negative, indicating that reheating cracks are not probable to occur. This means that post weld heat treatment (PWHT) can be performed with one strong limitation: PWHT temperature must be lower than cooling temperature, to avoid precipitate coarsening, which will result in change of microstructure. Results of Tanaka technological test confirmed this conclusion [9].

3.2 Mechanical properties of welded joints

Specimens for testing tensile properties of weld metal and welded joint were performed in accordance to standard EN 895. Results of Tensile Testing of Butt Welding joint are summarized in Table 3.[10].

Table 3. Results of Hardness and Tensile Testing of butt Welding Joint

Hardness HAZ [HV10]	**Hardness weld metal** [HV10]	**Heat input** [KJ/cm]	**No. of passes**	**Measure of tensile strength**		
				Weld joint Rm [MPa]	Fracture position	Weld metal Rm [MPa]
190-220	220-280	5.2-7.8	6	570-590	Base met.	645
190-210	220-250	9.6-12.4	4 - 5	560-570	Base met.	620
190-200	210-240	19-21.6	3	560-580	Base met.	630

Mechanical testing of base metal (table 2) and butt welded joints (table 3) showed that higher level of strength is obtained in weld metal, due overmatching.

Vickers method was used for hardness measurements along the cross section of welded joints.

Measured values of hardness in HAZ and weld metal are shown in Table 3 [10]

Hardness measurement through welded joint (figures 1 and 2) showed the differences obtained for different heat inputs. Data from table 3 must be taken into consideration in that way that lower heat input (5-8 kJ/cm) was perform in 6 passes, while higher heat input (18-22 kJ/cm) in 3 passes. This fact influenced the values of UTS of weld joint, weld metal and probably toughness (table 3).

For each welded joint Charpy Absorbed Energy of Heat Affected Zone and weld metal were measured according to standard EN 875. The notches in weldment specimens were positioned in the WM and in the HAZ. Results of Testing Charpy Absorbed Energy are shown on Figures 1-2.

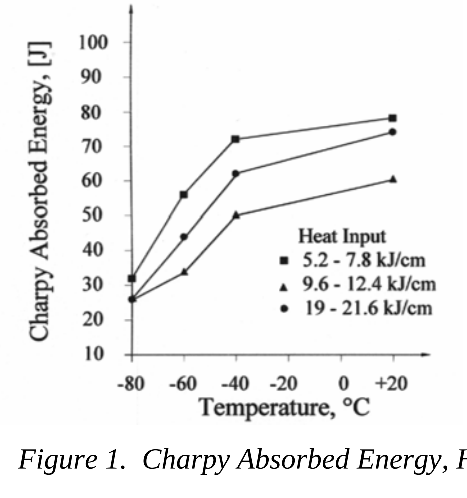

Figure 1. Charpy Absorbed Energy, HAZ

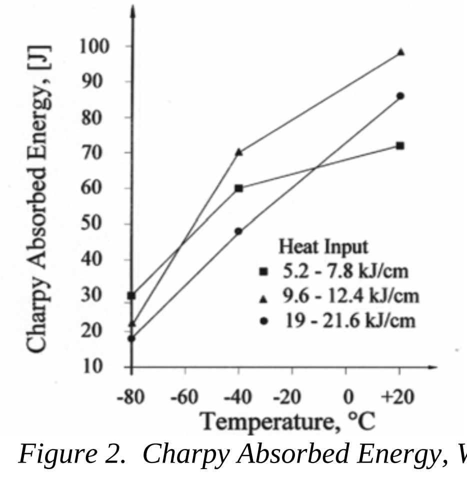

Figure 2. Charpy Absorbed Energy, WM

3.3. Behaviour related to brittle fracture

Behaviour related to brittle fracture was estimated by transition temperatures i.e. 50% Charpy impact energy [11]. The results, obtained for BM, WM and HAZ are analyzed and compared.

Transition temperature has significant part in the brittle fracture resistence. The major engineering use of the Charpy test in material selecting regarding brittle resistance is determination of transition temperatures. Transition temperatures i.e. 50% upper shelf Charpy impact energy were obtained from diagrams in Figures 1 and 2. The results are shown in Table 4. These results show that HAZ and WM have satisfactory resistance against brittle fracture. The highest value of transition temperatures in weld metal deposit was expected due to the highest values of hardness.

Table 4. Values of transition temperatures

	Heat Input kJ/cm	**Temperature, °C**		
		HAZ	WM	BM
50% Charpy V impact energy	5.2 – 7.8	-72	-70	- 85
	19 – 21.6	-66	-48	

4. CONCLUSIONS

- Weldability testing confirmed that steel grade E380 TM has improved toughness, yield stress and ultimate tensile strength up to -60°C. This was possible to obtain using an optimisation of chemical composition, (optimal level of carbon and microalloying elements and small amount of impurities) and thermomechanical processing (optimal rolling schedule - temperatures, strain rates and reductions for each stand).
- -In this paper, a complete procedure for complex weldability testing has been implemented, with aim to reveal susceptibility towards technological cracks formation that can be introduced during welding. Also, methods for evaluation of the changes in base metal and in the heat affected zone, (especially degradation of mechanical properties and structure) are studied, in purpose to get ability to identify critical segments in welded joint. Finally, behaviour related to brittle fracture was tested for all parts of the weldments (WM, HAZ and BM).
- Test results have shown that welded joints obtained by prescribed welding technology, have satisfactory quality regarding mechanical properties, but also regarding crack occurrence and growth.
- All results, unambiguously, indicate that microalloyed steel E380TM, has very good mechanical properties and weldability, and can be strongly recommended for fabrication of welded constructions.

5. REFERENCES

[1] Baker R.G., Dolby R.E. and Watkinson F.: The assessment of cracking problems. Weldability of Structural and Pressure Vessel Steels, Welding Institute Conference, London, 1970

[2] Radović A.: Metallurgic-Technological problems of materials weldability, Proceedings Int.Symposium, Weldability of materials and testing methods, Vranje, 1985, 1-8 (in Serbian)

[3] Hrivnjak I.: Relations between steel developments and welding technology, WELDER-Journal of YU welding association, 1978, 24 (3), 145-152

[4] Grabulov V.: Experimental testing of welded joints, Monography, International Fracture mechanics summer school, Arandjelovac, 1984, 405-420, (in Serbian)

[5] Linnert G.E.: Welding metallurgy of carbon and alloy steels, AWS, New York, 1997

[6] Radovic A.,Bajic N., Grabulov V.: Advanced approach of wedability testing of steels producting in SARTID, Proceedings, Third symposium of Yugoslav metallurgists, Bor, 1997, 54-59 (in Serbian)

[7] Kanazava S.: Lamellar tearing resisting steels and the direction for use of them, Doc-IIW-IX-1974

[8] Bajic N., Radovic A.,Grabulov V.: Lamellar tearing resistance assessment of microalloying steels using Window test, Proceedings, Fourth symposium of Yugoslav metallurgists, Zlatibor, 1999, 23-26

[9] Tanaka J.: Decrease in residual stress, change in mechanical properties and cracking due to stress relieving heat treatment of HT80 steel, Doc-IIW-IX

[10] Halap A.A.: A contribution to wedability study of microalloyed steels, Mr.Sc. degree thesis, Belgrade, 2000.

[11] Dieter E.G.: Mechanical Metallurgy, Third Edition, Mc Graw Hill, 1986