A. S. TAWENGI, A. SEDMAK, V. GRABULOV

ISSN 0543-5846
METABK 53(4) 624-626 (2014)
UDC – UDK 669.15:621.791.052:620.19=111

COLD WELD CRACKING SUSCEPTIBILITY OF HIGH STRENGTH LOW ALLOYED (HSLA) STEEL NIONIKRAL 70

Received – Prispjelo: 2014-01-07
Accepted – Prihvaćeno: 2014-05-20
Preliminary Note – Prethodno priopćenje

In view of the importance of high strength low alloy (HSLA) steels, particularly for critical applications such as off-shore platforms, pipeline and pressure vessels, this paper reports on an investigation of how to weld this type of steel without cold cracking. Using manual metal arc welding process and Tekken test (Y - Grove test) has been carried out both to observe the cold cracking phenomenon, and to investigate the influencing factors, such as preheating temperature and energy input, as well as electrode strength and diameter. However the results of the experiments show that there is a risk of cold cracking.

Key words: HSLA steel, weld metal, cold cracks, hardness, Heat Affected Zone (HAZ)

INTRODUCTION

High strength low alloy steels were originally developed in the 1960s for large-diameter oil and gas pipelines. Pipelines generally require steel of higher strength and toughness than mild carbon steel, and good weldability, [1], provided by relatively low content of carbon, C, and carbon equivalent (C_E). Therefore, remarkable progress have been seen in the development of High Strength Low Alloy (HSLA) steels for structural applications like pipelines, onshore/offshore structures and large ships. Further decreases in C_E became possible with the introduction of improved processing procedures such as controlled rolling quenching and tempering. Of course, other property requirements, in addition to weldability, have influenced HSLA steel development, e.g. the need to transport oil and gas safely and economically over long distances.

AVOIDANCE OF COLD CRACKING

Cold cracks (CC) are accounting for more than 90 % of weld cracks in actual steel structures, [2]. Hydrogen cracking is also known as cold cracking or delayed cracking. It generally occurs immediately after welding or a short time after, usually within 48 h. Moisture in consumable and/or material will transform into hydrogen gas (H_2) in the arc because of the high temperature. The hydrogen gas ends up as hydrogen porosity in weld metal or even diffuses into the HAZ. As hydrogen cracks are often very fine and/or sub-surface, they can be difficult to detect, [3]. Cold cracking in HAZ may cause serious damage to welded structures, and its prevention is an important subject. From a practical point of view, preheating is the most useful method to avoid cold cracking in HAZ, [3]. The cold cracking behavior is governed by the plate thickness, the hydrogen content of the weld metal, the heat input during the welding, the residual stress state in the weld region, and the chemical composition of parent metal and weld metal, [2,3]. Understanding hydrogen embrittlement is still an issue on a global scale, [4]. Factors determining the size and the transformed microstructure of the coarse-grained HAZ are critical. It is important to note that relationships between weld metal microstructure, composition and welding conditions are even more complex than in the HAZ. For these reasons research community has paid attention to reduce the susceptibility of steels to cold cracking by controlling welding parameters, preheating, and applying low hydrogen level consumables and welding processes. In this paper the HSLA steel NIONIKRAL 70 has been used for the weldability testing and for the analysis of influencing parameters. This steel has been developed in "Jesenice" steelworks, as the alternative for HY 100 steel, with the yield strength min. 700 MPa, [5]. Chemical compositions of steel Nionicral 70 are given in Table 1.

Table 1 **Chemical composition of the selected NIONIKRAL-70 steel**

Element	% Wt
C	0,106
Si	0,209
Cr	1,257
Ni	2,361
Cu	0,246
V	0,052
Mn	0,220
Mo	0,305
Al	0,007
S	0,017
P	0,005
Ti	0,002
Sn	0,014

A. S. Tawengi, A. Sedmak, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia
V. Grabulov, Institute for material testing, Beograd, Serbia

EXPERIMENTAL PROCEDURE

Cold cracking in a steel could be formed as a result of three factors: microstructure, content of hydrogen diffusion and welding stresses. There are many empirical formulas to calculate the sensitivity of a steel to cold cracking. Of many expressions, based on the carbon equivalent, C_E, the most often used are those by the International Institute of Welding (IIW) and by Ito and Bessyo, developed for this class of steel, [5, 6]:

$C_E = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15,$

$C_E = C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + Mo/15 + V/10 + 5B$, respectively.

Ito and Bessyo also introduced P_{cm} – the cracking parameter, which encompasses the influence of chemical composition (given by C_E value), the content of hydrogen diffusion and the coefficient of rigidity of welded joint:

$$P_{cm} = C_E + H / 60 + K / 40 \cdot 10^3$$

where H is hydrogen content (cm^3 / 100 g), K stiffness coefficient, for but joints K = 66 · S, S thickness (mm).

The chemical composition is shown in Table 1, leading to the following data:

$$C_E\,(IIW) = 0{,}67$$
$$C_E\,(Ito\ \&\ Bessyo) = 0{,}25$$
$$P_{cm} = 0{,}38.$$

where hydrogen diffusion content of 6 cm^3 / 100 g was used, and the stiffness coefficient is taken for the thickness of 18 mm.

Y-Groove test

Experiments were done with two batches of base material with two kinds of Mn, Ni, Cr and Mo alloyed basic electrodes with yield strength up to 685 N/mm^2 (T-75) and up to 785 N/mm^2 (T-80), both classified as E 69 2 Mn2NiCrMo B 42, after EN 757) and four preheating temperatures (20, 100, 150 and 200 ºC). Before welding, the electrodes were dried at 350 ºC for three hours. Figure 1 illustrates the Y - Groove assembly, [7].

Tables 2 and 3 show the basic data about welded test specimens, i.e. Y – Groove test, with the results of

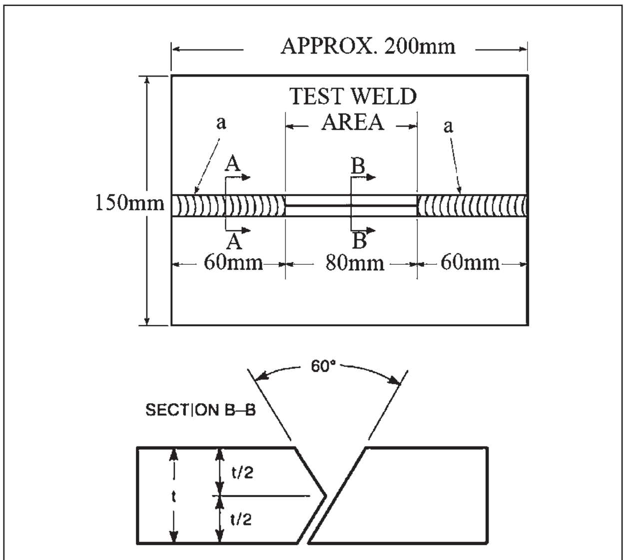

Figure 1 Oblique Y - groove test assembly, [7]

Table 2 **Results for Y- Groove test - batch 180079**

BM	Fill. mat.	Samp. code	Temp. / °C	Heat Input / KJ/cm	Metallo-graphic finding
180079	T - 75 (Ø 4 mm)	4	20	15,0	
		5		14,3	CC - HAZ
		6		13,7	CC - HAZ
		16	100	17,4	
		17		18,3	
		18		19,4	
		28	150	23,6	
		29		20,6	
		30		25,4	CC - HAZ
		40	200	20,6	
		41		22,0	CC - HAZ
		42		23,6	
	T - 80 (Ø 4 mm)	1	20	14,3	CC - Long
		2		15,7	-
		3		16,5	-
		13	100	18,3	-
		14		18,3	
		15		18,3	
		25	150	18,3	
		26		20,6	
		27		23,6	CC - HAZ
		37	200	17,4	
		38		19,4	
		39		20,6	
		49	200	17,4	CC - Long
		50		16,5	-
		51		20,6	-

Note: CC - cold crack, CC - Long - Longitudinal cold crack

Table 3 **Results for Y - Groove test - batch 180080**

BM	Fill. mat.	Samp. code	Temp. (°C)	Heat input KJ/cm	Metallo-graphic finding
180080	T - 75 (Ø 4 mm)	7	20	14,3	
		8		14,3	
		9		14,3	
		19	100	19,4	
		20		20,6	
		21		19,4	CC - HAZ
		34	150	20,6	
		35		23,6	CC - HAZ
		36		20,6	
		46	200	22,0	
		47		23,6	CC - HAZ
		48		19,4	
	T - 80 (Ø 4 mm)	10	20	15,0	
		11		15,0	
		12		13,7	
		22	100	18,3	
		23		19,4	CC - HAZ
		24		20,6	
		31	150	22,0	
		32		22,0	
		33		23,6	
		43	200	25,4	
		44		23,6	
		45		23,6	

Note: CC - cold crack, CC - Long - Longitudinal cold crack

Figure 2 Detected cold cracks in Y-probe (magnification 200 X)

metallographic analysis, indicating eventual presence of cod cracking. The metallographic indication of a crack, as an example, is shown in Figure 2, whereas results of hardness measurements through the welded joint (Y - Groove test) for different preheating temperatures are given in Figure 3.

RESULTS AND DISCUSSION

Susceptibility of NIONIKRAL 70 welded joints to cold cracking has been assessed by the experiments presented here. This study indicates some (minimal) differences in behavior of testing batches 180 080 and 180 079, but no decisive effect of any of input parameters. Compared to the results of other probes (CTS, Chabelka, etc, as presented in [5]), Y – Groove test proved to be more selective, indicating more cold cracking for the same experimental conditions. Anyhow, results provided by Y – Groove test, and presented here, are not conclusive. Namely, one can hardly point out the effect of preheating temperature, input energy and electrode strength level. It looks like as if the cold cracking is stochastic process, and the same holds for the other weldability testing shown in [5]. Therefore, one can conclude that another parameter should be taken as the relevant for weldability assessment. Several possibilities emerge, related either to the fracture toughness or to the Charpy toughness, with separation of energies [8]. In the first case couple of parameters would be possible to use, either static ones, like J_{Ic} or K_{Ic}, or dynamic one, J_{Id}, or fatigue crack growth rate, [9, 10]. In the case of Charpy energy, separated into the crack initiation and propagation energy, the initiation energy would be more relevant parameter, because it is more likely to indicate weldability, than the crack propagation would do. Therefore, further investigation following this reasoning is recommended, [9, 10].

CONCLUSION

Taking into account the values obtained for C_E (IIW and Ito - Bessyo) and P_{cm}, and the results obtained by the Y - Groove test, it can be concluded that there is a risk of cold cracking when welding NIONIKRAL 70, as a typical representative of HSLA steels with the yield strength over 700 MPa. No decisive relations could be establish between the input parameters (preheating temperature, input energy, electrode strength) and weldability, based on cold cracking appearance. Therefore, it is recommended to use parameters like initiation and propagation energy obtained by instrumented Charpy pendulum, and/or different measures of fracture toughness, instead of, or together with weldability testing.

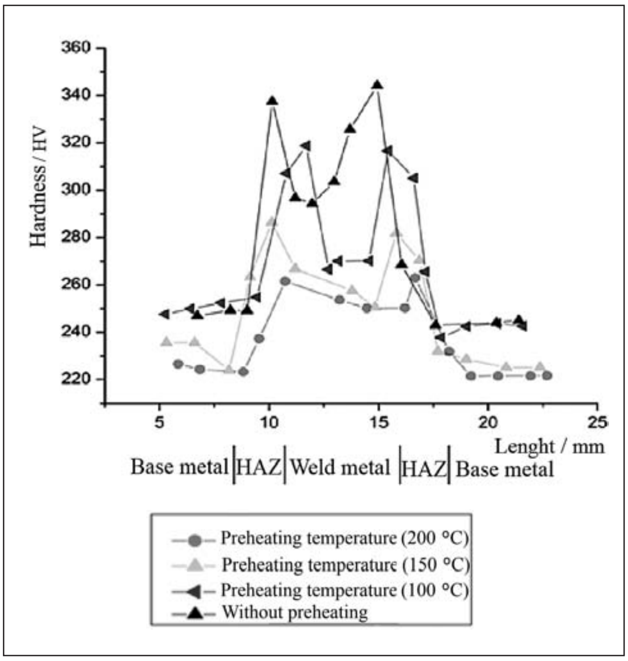

Figure 3 Hardness distribution for Y-probe (batch 180079, electrode T-80, Ø 4 mm)

Acknowledgements

The authors acknowledge financial support by the Ministry for education, science and technology development, Republic of Serbia, projects 174004 and 35002.

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Note: For English language translation and editing responsible is the lecturer from Faculty of Mechanical Engineering, University of Belgrade, Serbia