Fractography study of experimental CTOD measurements on Friction Stir Welded specimen on API X80 steel

J.A. Avila[1-2], A.J. Ramirez[1-]2, P.R. Mei[2]

[1] University of Campinas (Unicamp), Campinas–SP, Brazil

[2] Brazilian Nanotechnology National Lab. (LNNano), Campinas-SP, Brazil

ABSTRACT

Different fracture surfaces of crack tip opening displacement (CTOD) specimens of FSW weld plates of API X80 steel were investigated, using optical and electron microscopy. The changes in the CTOD results regarding the decreasing in temperature of the test were the motivation of this study. High-strength low-alloy steels (HSLA) are widely used for on-shore and off-shore pipelines construction within the oil & gas industry. These materials chemical composition and processing parameters are tailor designed to provide the needed combination of mechanical strength, toughness, and resistance to the not uncommon severe environmental working conditions.

Key words: CTOD, HSLA, FSW, fracture surface

Introduction

Nowadays the welding fusion process are still used in the pipeline weld joints, however, new welding process such as friction stir welding proved feasibility and advantages of its use to join high melting temperature alloys (Gibson et al., 2013; Santos et al., 2010; Santos, Ramirez, Paes, & Marinho, 2013; Wei & Nelson, 2012), the use of such technology to deploy pipelines may soon become a reality. Thick API 5L steels plates and tubes had been welded by FSW (Kumar et al., 2010; Santos et al., 2010) proving its competence to performed sounds welds. Also, this kind of weld presented acceptable CTOD values within the critical zones of the weld as presented (Kumar et al., 2010; Santos et al., 2010). However, there are important still challenges to be addressed and among them, the joints fracture toughness evaluation and deep understandings are tasks that need to be addressed.

Experimental procedure

After CTOD test the lowest surface specimens were analyzed using optical and electron microscopy. Plates of X80 API-5L steel 100x400x12 mm were used to produce butt FSW joints. Both chemical composition and mechanical properties presented at Table 1 and 2 were provided by a Brazilian steel producer. No bevel preparation was made on the plates, just as machined straight edges were used. Regarding the effect of the FSW weld parameters, in this study the FSW welds were produced using the same welding parameters on a previous study (Santos et al., 2010). The fracture toughness was assessed with CTOD parameter according to the ASTM E 1290-08 (2010) standard. The three-point bending specimen (SENB) was selected. A fatigue pre-crack length-to-width ratio (a_0/W) of approximately 0.6 was used. The notches in the CTOD specimens were oriented along the through-thickness (L–T) direction. There were three different notch locations regarding the first weld pass. The first one was located on the advancing side heat affected zone (HAZ/AS), the second on the retreating side heat affected zone (HAZ/RS), and finally on the stir zone (SZ).

Table 1. Chemical composition [Wt %], X80 API 5L Steel

C	Si	Mn	Cu	Cr	Al	Mo	Nb	Ni	P	Ti	V	N*	B*	S*
0,07	0,25	1,79	0,02	0,14	0,03	0,19	0,07	0,02	0,01	0,01	0,03	50	2	13

* ppm

Table 2. Mechanical properties of X80 API 5L steel.

Property	MPa	Ksi
Yield strength (YS)	531	77
Tensile strength (TS)	710	103
YS/TS (%)	75	
Average hardness (HV0.2) by microindentation	235 HV	

Results and discussion

At first the BM fracture surfaces were characterized, after that the fracture surface who presented the least CTOD values on the weld specimens were analyzed. The base material presented in the majority of the specimens a ductile behavior, and also presented a delamination on the central region of the specimen, this region in API steels could present microstructural textures and some elongate inclusions composed with S, P or Al (Joo, Suh, Bae, & Bhadeshia, 2012). In the case of weld specimens the least CTOD values were found on -40 ºC for all the notches, and the notch located on the stirring zone presented the lowest CTOD values, around 0.15 mm. Its fracture surface appearance presented a long Stretch zone wide (SZW) and short region with presence of dimples, it could mean that the majority of the energy was spent blunting the crack tip instead stable crack growing.

The tunneling made during fatigue precrack produced the invalidation according of the test result according to standards requirements, besides this crack tunnel front provided the mixture of a plane stress state in almost all the cracks fronts. However, the center of the specimen presented a high triaxial state, producing a plane strain state. This argument could explain the presence of some delamination in the specimens with notches locate in presence of different microestrutural regions. The crack growth more in the second pass than the first one, It may occurred because the heat produced by the second pass affected the first one, causing annealing on the first weld pass, likewise, the second pass presented a hardness zones within the weld (Horschel, 2008).

References

Gibson, B. T., Lammlein, D. H., Prater, T. J., Longhurst, W. R., Cox, C. D., Ballun, M. C., … Strauss, A. M. (2013). Friction stir welding: Process, automation, and control. *Journal of Manufacturing Processes*, *In press*, 1–18.

Horschel, J. D. (2008). *Mode I Fracture Toughness Testing of Friction Stir Processed HSLA-65*. Brigham Young University.

Joo, M. S., Suh, D.-W., Bae, J. H., & Bhadeshia, H. K. D. H. (2012). Role of delamination and crystallography on anisotropy of Charpy toughness in API-X80 steel. *Materials Science and Engineering: A*, *546*, 314–322.

Kumar, A., Fairchild, D. P., Anderson, T. D., Jin, H. W., Ayer, R., Macia, M. L., … Ozekcin, N. (2010). Research Progress on Friction Stir Welding of Pipeline Steels. *IPC2010*, *IPC2010-31*, 1–9.

Santos, T. F., Hermenegildo, T. F., Afonso, C. R. M., Marinho, R. R., Paes, M. T. P., & Ramirez, A. J. (2010). Fracture toughness of ISO 3183 X80M (API 5L X80) steel friction stir welds. *Engineering Fracture Mechanics*, *77*(15), 2937–2945.

Santos, T. F., Ramirez, A. J., Paes, M. T. P., & Marinho, R. R. (2013). Microstructure evaluation of UNS S32205 duplex stainless steel friction stir welds. *Metallurgy and materials inox 2010*, *66*(2), 187–191.

Wei, L., & Nelson, T. W. (2012). Influence of heat input on post weld microstructure and mechanical properties of friction stir welded HSLA-65 steel. *Materials Science and Engineering: A*, *556*, 51–59.

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a. Name: Julián Arnaldo Ávila Diaz
b. University: University of Campinas
c. Class: PhD Student
d. Mailing Address: Rua Giuseppe Máximo Scolfaro, 10.000, Polo de Alta Tecnologia. CEP 13083-970, PO Box 6192, Campinas, Brazil.
e. Telephone : +55-19-35183116
f. Fax (if available): 19-35183104
g. Email: ja123407@fem.unicamp.br
h. Research Advisor with his/her email (if applicable): Paulo Mei (pmei@fem.unicamp.br) and Antonio Ramirez (antonio.ramirez@lnnano.cnpem.br)
i. Title of proposed poster/paper: Fractography study of experimental CTOD measurements on Friction Stir Welded specimen on API X80 steel.