EVALUATION OF HYDROGEN EMBRITTLEMENT SUSCEPTIBILITY OF DUPLEX STAINLESS STEEL WELDING BY FRICTION STIR PROCESS

RESEARCHER RESPONSIBLE: Antonio Jose Ramirez

UNIT: Materials Characterization and Processing Lab.

LABORATORY: Brazilian Nanotechnology National Laboratory - LNNano/CNPEM

ABSTRACT

Pipelines of high strength steel are widely used in oil and gas industry for the exploration, production, processing and transport of natural gas, refined oil-based products, crude oil, and liquefied petroleum gas. Nowadays, the field welding joints are performed mostly by using Shielded Metal Arc Welding (SMAW), gas metal arc welding (GMAW) and fluxed-cored arc welding (FCAW) processes. SMAW the most used process is a physically demanding activity with very low productivity and elevated cost.

The use of fusion welding processes, especially the ones that use filler metals filler metal has are subject to the hydrogen embrittlement which results on hydrogen induced cracking, one of the main problems associated today to the joining of high strength steel pipelines. The Friction Stir Welding technology deployment will permit the partial replacement of welding fusion process, which will allowed productivity improvements, cost reduction, and most important should provide better mechanical performance.

In this work, duplex stainless steel will be joined by Friction Stir Welding to evaluate their effects on the joint performance to several environmental conditions (welding in air and water at low temperature (0 °C – 4 °C/deep sea). The microstructure characterization of the welded joints will be performed using optical, scanning electron microscopy and X-ray diffraction. The joints mechanical behavior will be evaluated using microhardness, fracture toughness, and conventional blending and tensile test. The results from this study will be used to evaluate the safe deployment of this welding technology to joint high strength steel pipelines.

Key words: Friction Stir Welding, High Strength Steels, Pipelines, Welding

1 INTRODUCTION AND MOTIVATION

Development of high strength steels pipelines has enabled the energy industry to improve the efficiency and to reduce the cost of long distance oil/gas transmission in view of the pipeline wall thickness and operating pressure. The increasing steel yield strength reduces the wall thickness required for internal and external pressures and hence the overall quantity of steel required. Further savings have been identified for transportation, welding equipment, welding consumables and overall lay time. Higher strength pipe allow higher pipeline pressures, and hence permits transporting more quantities of material per hour [Dong et al, 2009].

The use of SMAW for welding the pipeline steels has several disadvantages. This process has very lower productivity, higher defect rate, and higher cost when compared to automatic joining process. In general, hydrogen induced cracking (HIC) is always a concern. In order to reduce the HIC risk, the welded part is preheating, in this case torches or electric blankets in combination with the use of special welding consumables are necessary. The use of so-called low hydrogen practices is necessary, too. When high strength steels need to be welded, specially designed welding consumables are required to provide low levels of diffusible hydrogen and therefore low HIC susceptibility.

HIC is one of the predominant failures occurring in high strength steels. This results from the entry of atomic hydrogen into the steels. The hydrogen atoms diffuse towards the stress zones, and are trapped and precipitated at sensitive metallurgical defects, such as hardening phases, nonmetallic inclusions or microcracks to reduce the local ductility, resulting in HIC. The susceptibility of the steel to this phenomena increases when the strength of steel is higher [Briottet et al, 2012; Dong et al, 2009; Nanninga et al, 2012].

In the last years, great effort in the research and development related to the implementation of semiautomatic and automatic pipe welding machines are made, which should significantly increase welding deposition rate and improve pipeline production.

Friction Stir Welding (FSW) is a solid state, joining process with widespread use in the aerospace, shipbuilding automotive and railway industries, to join light metallic alloys, as Al and Mg alloys. The understanding of the welding process, and the structure and properties of welded joints has been useful in reducing defects and improving uniformity of weld properties, expanding the applicability of FSW to new engineering alloys [Coehlo et al, 2012; Santos et al, 2010].

The weld joint properties obtained by this process are not very clear. The welded joint is considered as the weakest place of steel pipe. To prevent unexpected fracture, superior low temperature toughness is required in this part. Therefore, it is necessary to study the microstructure and properties of the welded joint of the pipeline steel [Rutao et al, 2009; Zhang et al, 2010].

2 OBJECTIVE

To establish the influences of welding parameters and environmental conditions on microstructure evolution and mechanical properties of the high strength steel FSWs.

3 METHODOLOGY

The development of this work involves the evaluation of welding joints with several parameters of operation (rotational and welding speed, and heat input), environmental conditions (welding in water at 25 °C and around 0 °C), and hydrogen contents (electrolytically charged samples with hydrogen). The other parameters such as tool (Polycrystalline Cubic Boron Nitride, PCBN) and work piece (duplex stainless steel) will be constant during this project. This evaluation will be made by welding quality inspection, microstructural characterization and mechanical behavior (hardness measurements, tension test, fracture toughness critical crack tip opening displacement, CTOD).

The statistical experimental design 2^k will be employed for the evaluation of independent and interaction effects of heat input, environmental conditions, and hydrogen content on fracture toughness. The table 1 shows the combinations of factors and levels of this experimental design, with three factors and two levels (high and low) for each one. The main effects will be determined by ANOVA analysis and Yates algorithm. Additionally, a continuous bibliographic revision will be made on the application of FSW process on steels.

Table 1. Factors and levels of experimental design 2^3.

Environmental conditions	Heat input	Hydrogen content	
		Low level H_0	High level H_1
Low level T_0	Low level Q_0	$K(T_0, Q_0, H_0)$	$K(T_0, Q_0, H_1)$
	High level Q_1	$K(T_0, Q_1, H_0)$	$K(T_0, Q_1, H_1)$
High level T_1	Low level Q_0	$K(T_1, Q_0, H_0)$	$K(T_1, Q_0, H_1)$
	High level Q_1	$K(T_1, Q_1, H_0)$	$K(T_1, Q_1, H_1)$

The Brazilian Nanotechnology National Laboratory - LNNano/CNPEM has all the equipment necessary for the execution of this project: welding equipment FSW, optical and electronic microscopies, universal testing machines, and automatic micro-hardness system.

4 GENERAL LINES OF THE SCHEDULE TO BE COMPLETED

Activity Plan												
Activity	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1. Bibliografic revision												
2. Experimental Development												
2.1 Elaboration and evaluation of welding joints than were joined at 25°C												
2.2 Elaboration and evaluation of welding joints than were joined at water at 0°C												
2.3 Elaboration and evaluation of welding joints than were joined at water at -4°C												
3. Results analysis and discussion												
4. Project Close												

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Campus: Rua Giuseppe Máximo Scolfaro, 10.000 - Polo II de Alta Tecnologia - Caixa Postal 6192 - 13083-970 - Campinas/SP
Fone: +55.19.3512.1010 | Fax: +55.19.3512.1004 | www.lnnano.cnpem.br