

Improved Girth Welding on Seamless Linepipe for High H₂S Partial Pressure Condition

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ABSTRACT

O&G industry is more and more cautious about the risk of Sulfide Stress Cracking when low alloyed steels are in contact with aqueous environments saturated by high partial pressures of H₂S. According to NACE MR0175 / ISO 15156 part 2, material tested in NACE TM0177 Solution A saturated by 1 bar H₂S above 80% Actual Yield Strength is qualified for all regions of NACE environmental severity diagram. Basically, this lab test condition is considered severe enough for widening the admissible field exposure conditions up to 10 bar H₂S partial pressure. However, recent works highlighted the existence of a threshold partial pressure of H₂S below 10 bar for TMCP seam welded pipes. In the present work, similar situation has been observed for girth welds on X65 seamless pipes: acceptable welds based on hardness data passed at 1 bar H₂S NACE Solution A but failed in a fit-for-purpose condition of 6.8 bar H₂S. Improved welding procedure has been defined for reaching the appropriate SSC resistance at this H₂S partial pressure. It is recommended to evaluate the SSC resistance of girth welds at the field H₂S partial pressure when superior to 1 bar.

Key words: Girth weld, Seamless Pipe, High H₂S Partial Pressure, SSC

INTRODUCTION

NACE MR0175 / ISO 15156 document part 2 provides material requirements for selecting cast irons and low-alloy steels for sour environments.¹ Figure 1 is reproduced from this standard and describes different regions of environmental severity for Sulfide Stress Cracking (SSC): service in region 0 being the least susceptible to cracking, even for very sensitive materials, and region 3 being the worst. This diagram is built from two chemical parameters related to the environment: pH in the y-axis and partial pressure of H₂S in the x-axis. Lower pH and higher partial pressure of H₂S results in higher environmental severity for H₂S cracking. More specifically, NACE TM0177 defines NACE Solution A,² which presents a pH below 4, saturated by 1 bar of H₂S, as a reference environment for assessing the susceptibility of steels to cracking. According to Annex B of NACE MR0175 / ISO 15156,¹ a material can be qualified as SSC resistant in all regions of Figure 1, meaning up to 10 bar of H₂S, if it presents a threshold stress higher than 80% Actual Yield Strength (AYS) in this reference environment, as evaluated by uniaxial tensile, C-ring or four-point bend test. However, recent failure experience on Kashagan oilfield in Kazakhstan has created a concern for the SSC resistance when the partial pressure of H₂S exceeds 1 bar.³ Even though the root cause of the failure was the formation of local hard layers on Thermo-mechanically Controlled Process (TMCP) pipes,⁴ it has been demonstrated by Marchebois et al. that a X65 TMCP material free from any local hard layer can be SSC resistant at 1 bar H₂S but failing at 5 bar H₂S and above.⁵ Still, for X65 TMCP grade and based on a considerable laboratory test matrix, ExxonMobil company recommended to split region 3 in two sub-regions 3a and 3b, highlighting the detrimental impact of high H₂S partial pressures on the SSC resistance.⁶ Present authors acknowledge that the problematic of local hard layers is restricted to TMCP linepipe grades because of very different manufacturing processes. Nevertheless, Vallourec and Serimax companies took actions for confirming the appropriate SSC resistance of X60 and X65 seamless pipes and semi-automatic girth welds for sour environments up to 15 bar H₂S. After corrosion tests, all specimens were free of any observable SSC in longitudinal micrographic cross-sections, even when Inner Diameter (ID) skins and welds toots were kept intact for the tests, which is the most representative configuration of pipes in service.⁷ The present work pursues investigations of the SSC resistance in high H₂S partial pressures of X65 girth but for manual welds that are required on less accessible zones of a pipeline where semi-automatic welding is not possible.

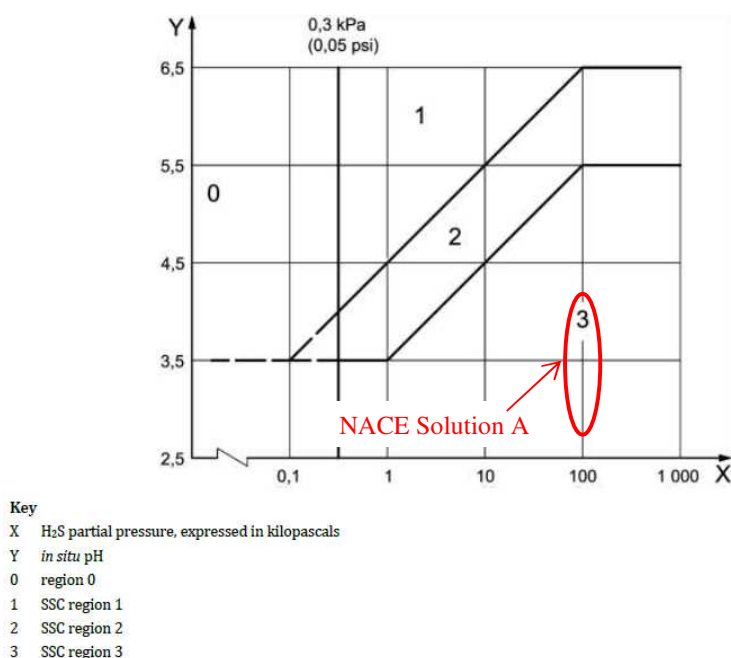


Figure 1: Regions of environmental severity with respect to the SSC of carbon and low-alloy steels; from [1]. Domain of NACE TM0177 Solution A is added (red shape).

EXPERIMENTAL PROCEDURE

Materials

Parent material is a seamless pipe, quenched and tempered X65QS PSL 2 in 219.1 mm outer diameter and 15.09 mm thick. Actual Yield Strength (AYS) is 510 MPa. Pipe used in this project came from a manufacturing lot that passed a SSC resistance quality control test consisting of Four-Point Bend (FPB) test at 85% SMYS in NACE TM0177 Solution A saturated by 1 bar H₂S.

Manual welds were prepared in a laboratory according to parameters given in Table 1.

Table 1: Welding parameters of manual welds.

MGW1	MGW2
Welding position: 5G Welding process: - GTAW for root & hot passes - SMAW from fill to cap Welding wire: - ER80S-NiMo1 Ø2.4mm for GTAW - E8018-G-H4R Ø3.2mm for SMAW Preheat temperature: 150°C Heat Input range for root pass: 6-14 kJ/cm	Welding position: 5G Welding process: - Manual STT for root - GTAW for hot to cap Welding wire: - ER70S-6 Ø1mm for STT - ER90S-G Ø2.4mm for GTAW Preheat temperature: 50°C Heat Input range for hot: 6-9 kJ/cm Heat Input range for fill: < 15 kJ/cm

SSC test at 1 bar H₂S or high partial pressure

The four-point bend (FPB) tests were performed in accordance with the NACE TM0316-2016 standard.⁸ The bend specimens were sampled close to the inner diameter (ID) of pipes. The tensile stressed surface was on the ID side (root face for the welded samples) and was grounded (removing the root bead profile for the welded samples) then mechanically polished to a 600 or 1200 SiC grit finish. Specimens were cleaned with ethanol in ultrasonic bath then rinsed with acetone before to be exposed to the sour environment. For the stress application on parent materials, unidirectional strain gauges were fixed at the center of specimens, on the tensile stressed surface. For girth welds, two unidirectional strain gauges were fixed, on each side of the weld. The bend deflection was controlled by the first strain gauge that reached the target. Strain gauges were positioned on parent materials, at least 5 mm distant from the Heat Affected Zone (HAZ). For the proper positioning of strain gauges, the HAZ was revealed on one lateral side of the bend specimen by light etching with 1% nitric acid solution. The Young's Modulus was assumed to be 207 GPa for the conversion of the local deformation into stress. Applied stresses were 90% AYS. The size of the specimens was 115 mm long by 15 mm width and 5 mm thick. The distance between the two inner rollers of the bending jig, which defines the length of specimen stressed at the target, was 40 mm.

Test solution was NACE TM0177-2016 Solution A² for atmospheric pressure tests and EFC 16⁹ pH 3.58 for high pressure tests (50 g/L NaCl plus 4 g/L sodium acetate, initial pH adjusted with concentrated hydrochloric acid). Atmospheric FPB tests were performed at 1 bar H₂S while high pressures tests were performed at 13.68 bar total pressure (50% H₂S and 50% CO₂). Initial pH 3.58 has been determined by OLI Studio version 9.6.1 (AQ and MSE database) so that pH 3.5 be reached after saturation with high pressure acid gases. Test solutions and vessels were deaerated to less than 10 ppb residual oxygen. All tests were performed at 24°C +/- 3°C during 720 h.

For autoclave tests, the partial pressures of acid gases are susceptible to change over time due to their consumption by corrosion processes. In addition, all cathodic reactions contributing to the corrosion of steel produce hydrogen gas as a by-product, leading to a risk of overestimation of the true H₂S partial pressure in a sealed vessel.¹⁰ Consequently, for all autoclave tests the gas phase was regularly replenished at the test temperature as follow: decrease of the total pressure down to 6.84 bar, bubbling of H₂S gas at 6.84 bar for 1 h, addition of 6.84 bar of CO₂.

After 720 h of exposure to the sour environment, the tensile stressed surface of specimens was carefully examined to detect any trace of SSC: 10x magnification followed by magnetic particle inspection (MPI) and finally at 100x magnification on longitudinal cross-sections at mid-width, 1/3-2/3 or on suspect areas.

RESULTS

SSC Resistance of Parent Pipe

Two parent pipes from the same manufacturing lot, presenting yield strengths at 493 and 496 MPa, were tested with the four-point bend test at 90% AYS in the modified EFC 16 environment described above at 13.68 bar (50% H₂S balance by CO₂). After 720 h of immersion, the 6 test specimens were visually inspected, followed by MPI and finally by longitudinal micrographic cuts (Figure 2). No SSC has been detected and parent material has been claimed SSC resistant in this specific sour environment.

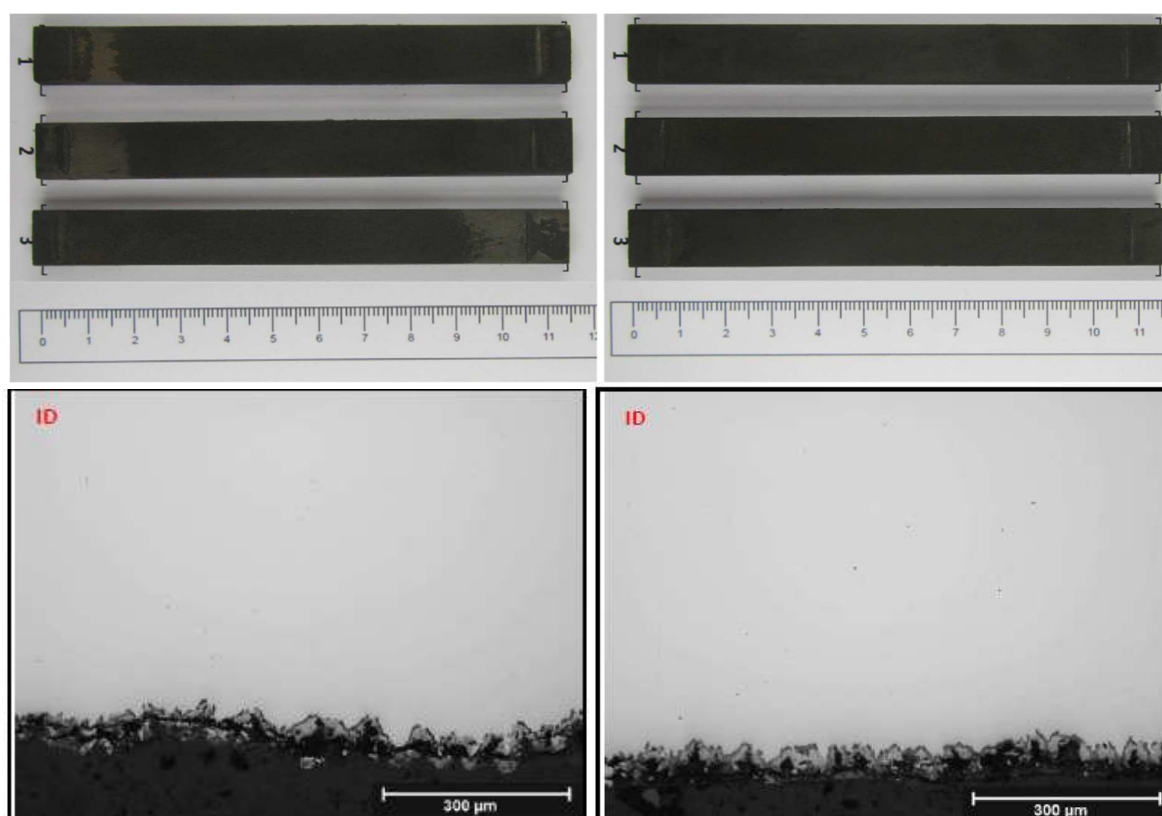


Figure 2: (Top) Macrographs of FPB specimens (tensile stressed face) sampled on parent material after exposure in high pressure sour environment; (Bottom) representative micrographs at magnification 100x.

Mechanical Tests on Manual Girth Welds

Cross weld tensile tests and bend tests were performed according to API 1104. Results of tensile tests are in Table 2: tensile properties are above the requirements of 535 MPa. Side bend specimens were sampled at 135 and 315° and acceptable results were obtained with a bend angle of 180°. Toughness tests were performed according to ASTM E23 on welds, at different locations at -10°C (Table 3). Average energy values are between 159 and 285 J, consistent with tough and ductile welds.