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FIRST X-80 HSLA PIPELINE IN THE USA

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Abstract

The principals and executives of El Paso/Colorado Interstate Gas determined the viability of using X-80 HSLA linepipe for a 380 mile, 36 inch, high strength and high pressure natural gas pipeline. The cost of the pipeline was projected at $425 million and was 6 years in the making, from conception to completion. Construction was completed by two contractors employing 3 spreads within approximately 4 months of the construction start date.

A number of key elements had to be considered for the successful implementation of such a pipeline, these included the metallurgical design of the X-80 linepipe, bending tolerances, weldability issues, welding procedure qualifications, toughness testing, NDT techniques, welder and welding inspector training programs and hydrotesting.

Over 181,000 tons of linepipe was manufactured and delivered to the project. The pipe was manufactured at two different pipe mills – one in Canada (IPSCO, 80% of the entire order) and one in the USA (Napa the remaining, 20%). In addition to the 380 miles of 36 inch diameter mainline pipe, 4 miles of 30 inch X-80 pipe were manufactured and installed in a lateral pipeline near the Greenburg, KS, compressor station.

The project originated at the Cheyenne Compressor Station in Wyoming, and was aligned in a South-Easterly direction across Colorado, through Western Kansas and finishing at the Greensburg, Kansas Compressor Station. Over 32,000 additional HP of compression was added to the pipeline to deliver up to 1.7 billion cubic feet per day of natural gas to the marketplace.

This paper addresses several of the key materials, welding, NDT and construction issues associated with the use of X-80 HSLA linepipe, that allowed the project to be successfully completed ahead of schedule and under budget.

Introduction

During the summer and fall of 2004, the Cheyenne Plains Gas Pipeline Company (CIG, a subsidiary of El Paso) constructed a 380 mile long, high pressure natural gas pipeline through Colorado and Kansas. The pipeline became operational ahead of schedule in 2004 and was delivered under the initial approved budget. Two U.S.A. pipeline contractors completed the project. Associated Pipe Line Construction Inc. with one spread of equipment completed approximately 125 miles of the X-80, 36" dia. pipeline in Colorado. U.S. Pipeline Inc. completed the remainder of the 36" dia. pipeline in Colorado and Kansas and a 4 mile, X-80, 30" dia. lateral in Kansas with two equipment spreads.

Over 180,000 tons of linepipe was required for the project Napa Pipe mill manufactured approximately 80 miles. of X-80, 36"/30" dia. DSAW straight seam pipe. IPSCO pipe mill manufactured the remainder (~303 miles) of X-80, 36" dia. spiral seam welded. Wall thicknesses ranged from 0.464" to 0.667" for the X-80 linepipe. All pipe was shipped as 80 foot joints to minimize the amount of handling and the number of field welds.

The Cheyenne Plains Pipeline project represents the foresight and wisdom of the El Paso engineers and senior management to take advantage of new steel making, welding and non-destructive testing technologies to initiate the first X-80 pipeline project in the United States. As a result of the successful completion and implementation of the project, El Paso received the prestigious 'The Pipeline of the Year' award from the Pipeliners Association of Houston in June 2005.

The initiation of the project represented the move towards greater economical product throughput by increasing pressures and flow rates while ensuring reasonable construction costs. To accomplish this goal, significant consideration was paid to environmental, constructability, and safety issues for the long term reliable operation of the pipeline. At the root of the project success, was the metallurgical design and processing of the linepipe material, which included strength, toughness, weldability and fracture arrest properties. Such properties were optimized by a combination of microalloying element additions and thermo-mechanical processing of skelp during manufacture. These properties were considered in combination to meet weldability and constructability requirements, such as pipe handling (D/T ratios) and field bending.

The construction phase of the project was under the watchful eyes of the Department of Transportation (DoT) and the Office of Pipeline Safety (OPS) representatives from the Central and Western Region. Their representatives evaluated all of the construction elements to ensure compliance with Code and Regulatory requirements. CIG provided inspection for all of the required construction disciplines. Subcontractors EWI Microalloying International and Crantek Quality Services were chosen by CIG to provide additional quality assurance. Both groups evaluated and prepared metallurgical, welding and non-destructive testing (NDT) procedures, training of welding inspectors, provided technical support throughout the construction phase of the project and audits of radiographic film and automated ultrasonic inspection results.

The success of the first high pressure X-80 gas pipeline project in the USA was a testimony to the organizational skills of CIG/El Paso and the focus on teamwork that evolved from the outset of the project.

Metallurgical Design

The use of X-80 Grade steel for long distance pipelines was contemplated as early as 1971/1972 for Arctic gas pipelines(1) which have yet to be built. However, the perceived benefits of using higher pressure, higher strength designs led to a fertile period of steel development. The metallurgical approaches that evolved were summarized in a circa 1989 review(2). A wide range of alloying and microalloying combinations are possible, with the exact choice dependent on prevailing alloying costs and available manufacturing equipment. In all cases, the steels are designed to optimize the strengthening and toughening benefits of niobium and to capitalize on their excellent field weldability when carbon contents are reduced to 0.06 percent and below.

Pipe Manufacturing

Pipe Specifications

The steel compositions used by the two manufacturers for the Cheyenne Plains project were selected on the basis of their compatibility with Steckel Mill processing regimes. IPSCO's traditional Nb-Mo steel(3) was used for the spiral seam feed stock, whereas a relatively new(4, 5) Nb-Cr approach was adopted by Oregon Steel Mills (OSM)/Napa Pipe for the longitudinally welded linepipe.

Typical chemical compositions for the two types of steel are shown in Table I which also incorporates details of the compositional restrictions from the CIG specification.

Table I. X-80 Chemical Compositions

PIPE TYPE	C	Mn	Si	Nb	Cr	Mo	Ni	Ti	N
Long Seam	0.04	1.58	0.13	0.098	0.24	-	0.15	0.011	0.004
Spiral Seam	0.03	1.68	0.27	0.095	0.03	0.30	0.02	0.019	0.009

Steelmaking, Rolling and Pipe Making

An overview of the two different manufacturing approaches is presented in Figure 1. The two producers achieved ostensibly similar strength and toughness results despite the different rolling and pipe making methods. Steckel Mill rolling at OSM was possibly facilitated by the significantly lower nitrogen content in the IMEXSA slab material which maximized niobium solubility.

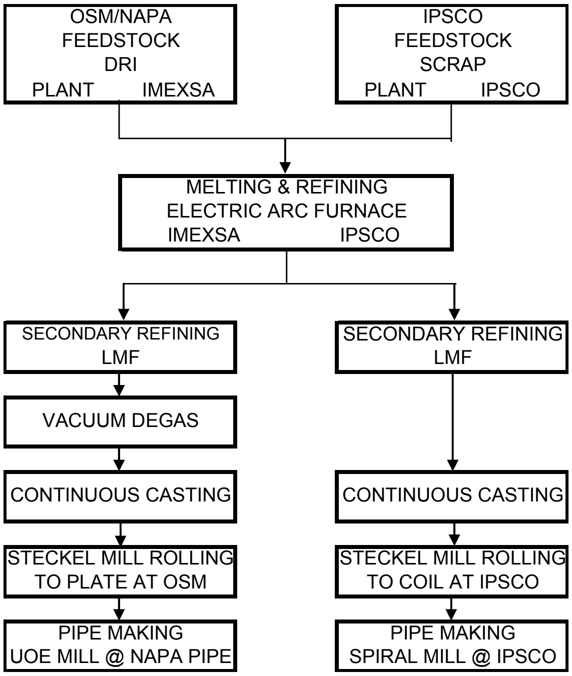

Figure 1. Manufacturing Approaches

Pipe making in both mills went smoothly with the exception that small engineering improvements were required at IPSCO to accommodate 0.667 inch wall X-80 skelp which was close to the design limits for the mill. IPSCO utilized a "single step" in-line welding process (rather than the offline two step approach which is being adopted elsewhere).

The DSAW welding consumables used by both manufacturers are shown in Table II. The weld metal was changed to a higher nickel content for the pipe used for hot bends to improve weld metal toughness in the tangents after induction bending and tempering. A typical hardness profile across a DSAW weld is presented in Figure 2.

Table II. Welding Consumables DSAW

BEAD	WIRE	FLUX
MAINLINE NAPA PIPE		
ID	Lincoln – L70	Lincoln NP 223
OD	Lincoln – LA90	Lincoln NP 223
HOT BENDS		
ID	Lincoln LA90	Lincoln NP 223
OD	Lincoln LA90	Lincoln NP 223
MAINLINE IPSCO		
ID	Bavaria S2Mo	Bavaria BF 6.5
OD	Bavaria S2Mo	Bavaria BF 6.5

A mechanical property summary for the helical seam linepipe is presented in Table III.

Table III. Mechanical Properties: Helical Seam X-80

Description	**Yield (ksi)**	**UTS (ksi)**	**Y/T Ratio**	**Elongation (%)**
Min.	80	96	0.77	22
Max.	93.8	109.4	0.9	38
Std. Dev.	2.29	2.39	0.02	1.5
Average	84.8	102.5	0.83	33.6

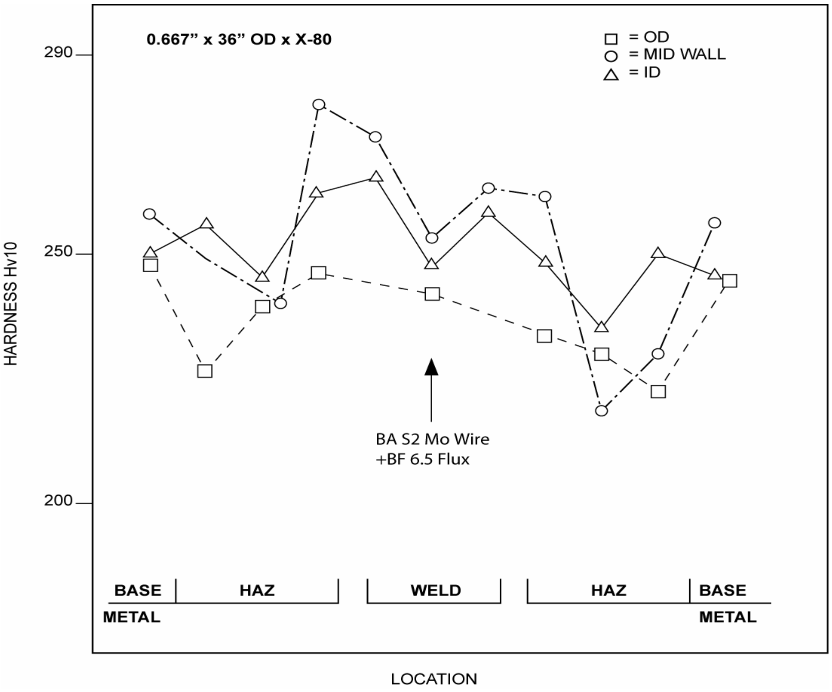

Figure 2

Weldability Testing

Prior to approval of the manufacturing procedure specification (MPS) for the X-80 linepipe, preliminary girth welding trials were carried out at the CRC-Evans facility in Houston, TX, using typical mechanized welding procedures, to assess field weldability in terms of expected HAZ hardness and toughness (CTOD) performance. On the basis of the results, the steelmaking practices were changed slightly and the aim levels for nitrogen and titanium were adjusted to lower levels.

Determination of Defect Acceptance Criteria

There are three well established procedures for conducting the Engineering Critical Assessment (ECA) for a pipeline to be constructed using mechanized welding and automated UT in North

America. These are BS 7910, a general purpose code, API 1104 Appendix A and CSA Z662 which are pipeline specific. The pipeline codes were considered more appropriate for this project and were employed for the ECA.

CTOD testing was carried out on procedure welds and the results were utilized to develop the correlations presented in Figure 3. Due to the non-conservative nature of API 1104 Appendix A for long defects, the acceptance criteria was selected from the different approaches and used to develop a blended defect tolerance diagram for the installation.

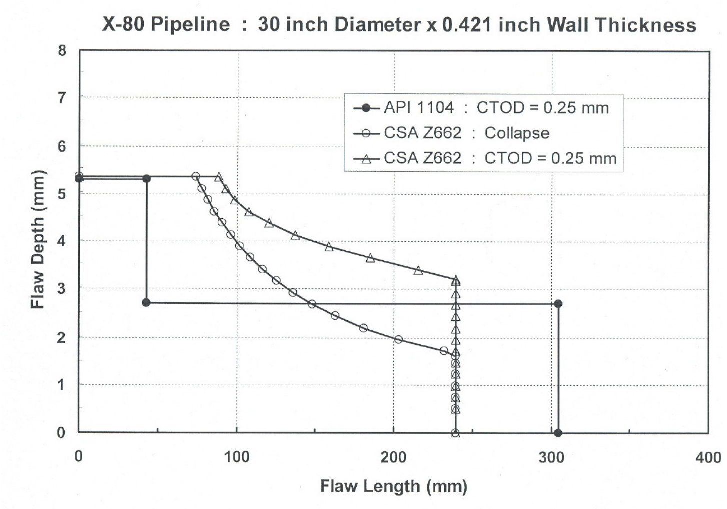

Figure 3.

Bending

UOE longitudinally welded linepipe was used for the manufacture of hot induction bends at BendTec Inc., in Duluth, Minnesota. Mechanical property data for the 0.667 inch wt test bend are presented in Tables IV and V. On the basis of the final wall thickness and the project requirements, the bends were certified as Y-70 (70 ksi) fittings.

Table IV Qualification Induction Bend 0.667 wt
Toughness

Sample Location	**Energy ft/lbs (J)**			**% Shear**		
Tangent	107 (145)	108 (146)	120 (163)	100	100	100
Tangent weld	58 (79)	56 (76)	68 (92)	90	90	90
Intrados	213 (289)	19(267)	193 (262)	100	100	100
Extrados	188 (255)	187 (254)	150 (203)	100	100	100
Bottom	152 (206)	183 (247)	133 (180)	100	100	100
Bend Weld	78 (106)	70 (95)	121 (164)	70	70	100

Table V Qualification Induction Bend 0.667 wt Strength and Hardness

Sample Location	Yield Strength (ksi)	Yltimate Strength (ksi)	Y/T Ratio	Hardness (BHN)
Tangent	84.1	100.2	0.84	217
Tangent Weld		108.1		217
Extrados	78.7	95.8	0.822	217
Intrados	73.2	92.6	0.79	228
Bottom	78.6	95.8	0.821	228
Bend Weld		95.4	0	228

Cold Bending

The specified maximum bend radius used by the installation contractor for cold bending in the field was 0.5 degrees per pipe diameter. Because of industry apprehension concerning the cold bending performance of helical seam linepipe, it was considered prudent to carry out extensive full scale bending trials at CRC-Evans yard in Tulsa, Oklahoma.

Several test bends were made by the installation contractor's personnel to assess spring back, buckling resistance, behavior of the spiral seam and potential changes in mechanical properties due to cold deformation and strain ageing buckling.

Pipes were successfully bent to 0.8 degrees/pipe diameter without any measurable change in Charpy V-notch toughness, Figures 4 and 5. However, one test bend buckled when the bend radius exceeded 1 degree per pipe diameter. Charpy testing of the buckled area in the top quadrant of the bent pipe showed some deterioration of toughness in terms of absorbed energy and shear area percentage. However, the approximately +25°F upward shift in Charpy V-notch transition temperature still resulted in a 50 percent FATT at -40°F well below LAST for the project of 20°F.

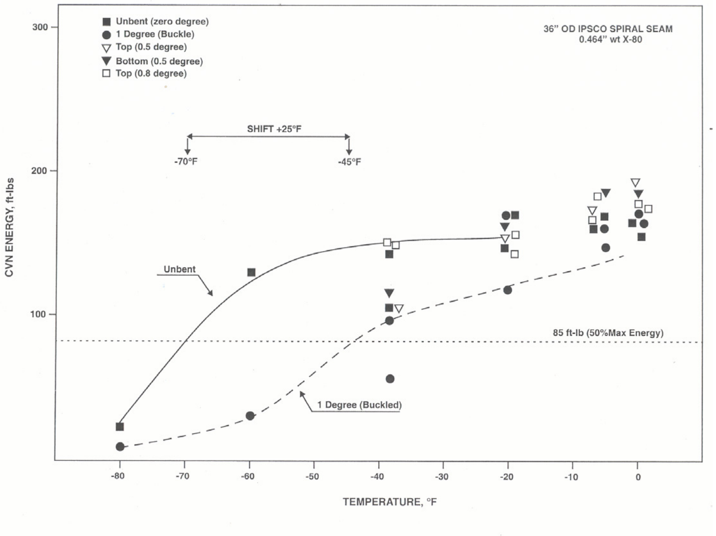

Figure 4

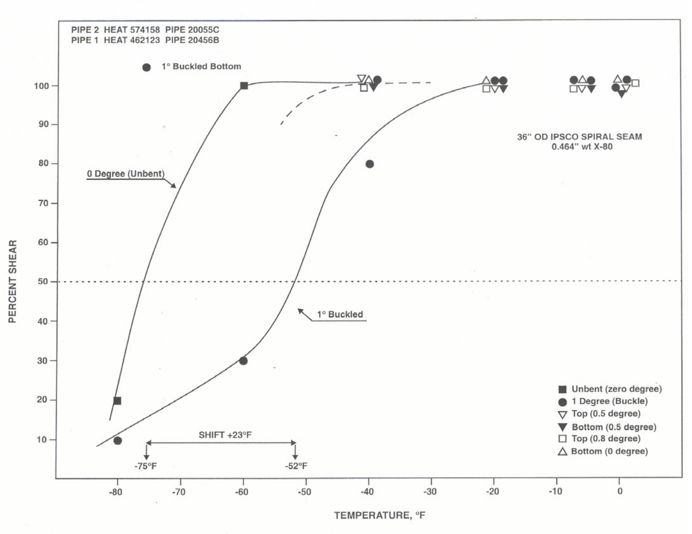

Figure 5

Welding Procedure Qualifications

It was determined from the outset that the CRC Mechanized Welding System would be used for the mainline construction for both contractors and all three spreads. This decision provided for a number of project advantages including consistency with welding procedure qualification tests, welding consumable specifications, reduced pre-fabrication costs and consistent inspection requirements.

Since the welding system had been used previously for the welding of X-80 pipeline steels in other countries, focus was centered around determining the requirements for welding road and river crossings and tie-in welds.

The preliminary welding procedure qualifications were carried out using some of the contractors' welders from Local 798 of the Pipeliners Union at the CRC Evans facilities in Houston in February, 2004, well ahead of any other construction activities, to evaluate the performance and weldability of the SMAW and FCAW welding processes to the field welding of the X-80 pipeline steel. North American pipeline welders are familiar with downhand cellulosic welding procedures. A change to welding with low hydrogen vertical up welding consumables required a significant commitment by the contractors to provide equipment and welder training for the project to be successful.

To ensure that a quality weld root would be achieved for the manual welding process, a key requirement was that cellulosic welding materials could be used only for the root and hot pass welds, with higher than usual preheat requirements employed to reduce the probability of hydrogen assisted cold cracking (HACC). A low hydrogen welding process, consumables and procedure would be required for the remainder of the weld. Such a requirement was made to mitigate the potential for HACC during production and tie-in welding while still maintaining the strength and toughness properties of the weld zone.

Since the wall thickness of the X-80 pipe was 0.464” for the mainline and 0.667” for the crossings, the amount of low hydrogen welding would be significant.

Weld metal and heat affected zone toughness properties were evaluated for a number of SMAW and FCAW welding procedure variations. In addition, the contractors were particularly interested in the welding speeds, deposition rates and other procedure requirements, such as tolerance to wind, welding techniques, etc. Variations included combinations of low hydrogen SMAW and FCAW welding consumables – types and multiple manufacturers, time delay considerations for root bead and hot pass, back welding and partial, thru-wall and multiple repairs. Welding procedures were developed in accordance with API 1104 and the additional project requirements.

Typical SMAW/FCAW Welding Procedure:

Root bead – E6010 (1/8 – 5/32” dia.)
Hot Pass – E9010-P1 (5/32 – 3/16” dia.)
Fill and Cap Passes – E9018M and/or E101T1-GM (0.045” dia., 75/25% Argon/CO_2)
Preheat - 150°F; Repair Preheat - 250°F
Interpass Temperature - 450°F (max.)

Two low hydrogen fill passes plus the cap pass was required for the 0.464” mainline pipe. Three to four low hydrogen passes plus a split (2 pass) cap was required for the 0.667” road bore and crossing pipe.

Summary of SMAW/FCAW Weld Properties:

Cross-weld Tensile Tests (UTS) : 99 – 110 ksi
Weld Metal Centerline CVN@23°F : 33 – 84 ft-lbs
HAZ CVN@23°F: 43 – 158 ft-lbs
VHN_{10kg}: 162 – 278 Parent Metal-HAZ-WM Traverses

Travel speeds for the low hydrogen welding processes were typically between 2 and 6 inches/min. FCAW provided the higher welding speeds with an additional advantage that the operating factor was two to four times that of SMAW, resulting in a considerable improvement in production speeds. The deposition rate, deposition efficiency and operating factor were considerably higher than for cellulosic welding techniques.

A major concern for the use of the low hydrogen welding processes was from the wind and its effect on shielding efficiency. Due to relatively high and continuous winds throughout the project, the prevention of porosity defects was a major issue. Once the contractors realized that the use of wind protection was necessary, the repair rate for these processes was substantially reduced. Since the root pass and hot pass were made with cellulosic electrodes, wind protection was not a major requirement. The contractors provided different approaches to the wind protection shelters. The quality of commercially-available wind protection shelters was poor.

Welder Training & Qualifications

The Local 798 welders union shop in Tulsa, OK provided facilities and a complete range of equipment for welders to pre-train on the low hydrogen welding processes before their arrival at the jobsite. However, most welders appeared at the construction site to undertake the training program provided by the contractors. CRC-Evans welding technicians, Local 798 trainers and FCAW equipment suppliers, provided the training on behalf of the contractors. To meet the minimum project requirements, all welders were required to complete a manual 12 inch, 5G butt weld at the jobsite, in accordance with API 1104 requirements.

A number of welders appeared at the construction site with previous experience welding with the CRC-Evans Automatic Welding equipment, including the internal lineup and internal root welding machines, the P200 hot pass machine, and the pulsed GMAW P600 dual torch fill and cap welding system. It was important that, regardless of previous experience, each welder underwent a training session with each of the welding systems. Welders qualified on either the internal welding system or the external welding systems, by making a complete weld that was evaluated by automatic ultrasonic testing and mechanical testing to API 1104 defect acceptance criteria. Operators qualified on X-80, 36" dia., 0.464" wall thickness project pipe material.

As the number of welds on the 0.667" wall thickness pipe material for river, road and railway crossings were significant but sporadic, they were left for the tie-in (SMAW/FCAW) welders who were better equipped to set up for a small number of welds. The tie-in welders trained and qualified on X-80, 36" dia., 0.464" wall thickness project linepipe material. Training was provided by the contractors' foremen and equipment manufacturers' representatives. The completed welds were evaluated by mechanical methods to API 1104 acceptance criteria.

In addition, a number of welders were required to complete additional training and qualification for repair welds, back welds, etc. A total of 142 welders underwent training and were qualified for the project. A total of 235 weld qualification tests were performed.

Non-Destructive Evaluations

A project specific specification was developed for guidance to ensure that all of the welds were evaluated in accordance with API 1104 and the additional project requirements. A separate NDE specification was developed and implemented for automated ultrasonic inspection.

NDT Process Selection & Qualification Tests

The automated ultrasonic inspection process was selected to evaluate all mainline production welds, except for transition welds which were evaluated by conventional radiographic testing (RT) techniques. After an evaluation of the technical, and commercial aspects of the NDE contractors bids, Weldsonix was selected as the contractor for all NDE on the project. The automated ultrasonic testing (AUT) process was selected for all mainline production GMAW welds. A limited amount of equipment was available to provide AUT for the SMAW/FCAW process welds. The AUT procedures were evaluated against production test welds with seeded defects of differing types, including undercut, lack of fusion, lack of cross-penetration, etc.

The mainline AUT inspection system had to be capable of evaluating up to 150 welds per day, per spread with a high degree of reliability. The primary advantage of AUT is that it can be safely used in the same pipeline section as that being welded and provides real time feedback to the welding supervisors as to any quality issues that may require corrective actions. In addition, manual ultrasonic testing (MUT) procedures were developed for evaluation of any weld repairs.

To meet the stringent requirements of the project, Weldsonix had to qualify additional AUT procedures to address pipe temperatures, consistency test (forward and backward), weld geometry, tracking band offset, and time of flight (TOFD) markers. For each pipe manufacturer, specific mill and wall thickness, a separate calibration block was manufactured, assessed and supplied to every AUT rig on the project.

It was also necessary to section, metallographically examine and characterize preliminary defects by physical measurement to determine the accuracy of the AUT system and to determine the ‘allowance for inspection error’ as required by API 1104, Appendix A when using the Engineering Critical Assessment (ECA) techniques for weld defect assessment.

The Crantek auditor evaluated the process, procedures and system reliability prior to allowing the AUT contractor to proceed with production evaluations.

Each operator had to be qualified to the production AUT, MUT and RT procedure requirements for the project.

Welding Inspector Training

Prior to the start of welding construction, the project team provided a training program for the welding inspection personnel involved with each of the mainline welding contractors. The primary objectives were to ensure that the inspectors were conversant with the project welding procedure requirements, welding specifications, weld defect assessment criteria, NDE techniques, code and regulatory requirements and also that there was a uniformity in visual weld inspection for defects, such as undercut, weld shape, misalignment, and any other relevant surface defects.

Quality Control/Quality Assurance

It cannot be understated that the attitudes of all personnel involved, including construction supervision, welders, inspectors, NDE and construction contractors personnel and regulatory officials involved in the project were part of the teamwork fabric that contributed to a successful project. A major catalyst in making this happen was a competent QA team, as was provided by the EWIMicroalloying/Crantek personnel. A positive attitude and focused objectives and the willingness to help all construction personnel with respect to welding and NDE issues had an intrinsically beneficial effect on this successful result.

The well integrated, qualified and experienced QA field team consisted of a lead QA/welding engineer, 2 welding technologists, 1 RT auditor and 1 AUT auditor for the 380 miles of pipe construction which provided a construction direct cost benefit to the project. Each welding technologist travelled across 190 miles of pipeline construction, including mainline construction and supplemental visits to road bores, river crossings, fabrication locations and valve sites.

Production Welding

Repair rates and difficulties during the start of welding construction occur frequently on this type of project and depend on many factors, including the weather, terrain, preparation of the welding systems, preparation and quality of welders and welding technicians, the attitude of the welder foremen and preparation of the NDE contractor and welding inspectors. It usually takes 10 days of welding construction to get the welding program properly lined out. However, during this time, both the production and repair rates tend to be poor. These initial results affect the overall project statistics as they are usually not representative of the overall project results.

During the first week, it is not unusual to have welding production rates as low as 10 to 60 welds per day with repair rates up to 25%. Such repairs can be 3” or 30” in length, or complete cut-outs. However, as the spread develops its production pattern, a full spread can achieve 150 welds or more per day. For a modified and mini-spread configuration, a total production of 180 – 200 or more welds is achievable.

A number of factors enter into the achieved production rates, including terrain, weather, and welder skills. In addition, the ability of the mechanized welding technicians to evaluate and resolve equipment problems on a timely basis can significantly affect the production and repair rate statistics. Usually, the construction contractor is focused on productivity at the risk of enduring a ‘reasonable’ repair rate. This situation can be the source of constant aggravation for the project management, welding inspectors and contractor supervision and management team. At the root of this issue is an unclear expectation on the part of all parties with regard to the specification requirements. For long length projects in relatively remote areas, travel time from the contractor’s yard to the construction site can also significantly impact productivity results.

Tie-in, Crossing and Repair Welds

Production rates for these such welds are dependant on the physical location of the welds and the amount of time required for the fit-up, etc. Once the 36” pipe was fitted and the bead and hot pass installed, 1 hour or more was required to complete the weld with 2 welders using the FCAW semi-automatic welding process. AUT was used on the SMAW/FCAW welds wherever possible and where the wall thicknesses of the adjoining pipes were the same. This allowed for the minimum amount of time the tie-in crew needed to spend at a location waiting for the acceptable NDE repair results.

Primarily, weld defects included slag inclusions and porosity where welding techniques and protection from the wind were not adequate. Attention to detail is a very important feature for successfully welding X-80 using low hydrogen manual and semi-automatic welding processes. Equipment selection, maintenance procedures and welder training are critical for the successful use of low hydrogen welding process on X-80 pipe. Repair rates in the order of 25% initially are not unusual. By the end of the Cheyenne Plains project, the repair rates for low hydrogen welds were less than 10%. Considering that it was the contractors and owning company’s first X-80 project and the use of the FCAW welding process, the results were acceptable but could have been substantially better with a little more attention to detail.

Conclusions

By selecting higher grade, X-80 and above, HSLA linepipe, it is necessary to provide a metallurgical design for the linepipe that can provide the fracture toughness and weldability characteristics that allow for a project to be a technical and commercial success.

In addition, it is critical that attention is paid to the detail necessary for the upfront training and qualification of welding procedures, welding operators and welders. The development and qualification of appropriate automated ultrasonic testing procedures and personnel is critical to ensure that all welds are evaluated in accordance with the required codes and specifications thus maintaining initial pipeline integrity. It is critical that the pipeline contractors and their personnel are willing to try new welding processes and techniques to ensure that contract specifications and welding integrity are met. Technical support and teamwork in all aspects of the construction program is necessary to ensure that a project can be delivered ahead of schedule and under budget.

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