REPORT

December 14, 2005
EWI Project No. 47960GTH
DoT Transaction Agreement Number DTRS56-04-T-0011

Development of Best Practice Welding Guidelines for X80 Pipelines

Submitted to:

Office of Pipeline Safety (Research and Development)
Department of Transportation (DoT)

MATERIALS JOINING TECHNOLOGY

Report

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on

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Department of Transportation (DoT)

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1.0 Introduction

The use of X80 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 are summarized in a review from the late 1980s.[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 below 0.06%.

The focus of this report is to provide a summary of experiences associated with pipeline construction including the lessons learned and the factors that made the projects an overall success. To better demonstrate the development of welding technologies, the accounts of experiences are presented chronologically rather than geographically.

The report reviews the development and qualification of the pipe materials and welding procedures for the Cheyenne Plains Pipeline (Section 4) as required by the U.S. Department of Transportation (DoT) Office of Pipeline Safety (OPS) statement-of-work under Transaction Agreement DTRS56-04-T-0011. The Cheyenne Plains Pipeline, which was constructed in the Fall of 2004, is the first X80 cross-country gas pipeline constructed in the U.S. and the longest X80 gas pipeline in the world. The pipeline is 380 miles long commencing at the Colorado Interstate Gas Compressor Station near Cheyenne, Wyoming, and progressing in a southeasterly direction from Wyoming across Colorado and culminating at the Greensburg Compressor Station in Kansas. Sections 2 and 3 of the report also address some Canadian pipelines, namely NPS 48 Eastern/Western Alberta Mainlines (information on the Canadian pipelines was obtained in SI units; U.S. Customary Unit equivalents are provided, as appropriate).

In order to evaluate higher strength pipeline technology developed by TransCanada and its partners, two field installations of X100 have been performed on the TransCanada system within Alberta. These installations have evaluated both the summer and winter construction aspects of X100 (690-MPa) pipelines. The summer project was completed in October 2002 on the Saratoga Section of TransCanada's Western Alberta System Mainline Loop. The looping program included a 0.625-mile (1-km) section of NPS 48, X100 pipe. The mainline welding process used for this section was mechanized single-torch gas metal arc welding/pulse gas metal arc welding (GMAW/PGMAW). The winter project was completed during January and February of 2004 on TransCanada's North Central Corridor in Northern Alberta. The project included a 1.26-mile (2-km) loop of NPS 36 X100, known as the Godin Lake Section. The first field implementation of tandem PGMAW took place on this 1.26-mile (2-km) length of X100. Sections 5 and 6 include data on X100 pipeline welding in order to provide an idea of the best welding practices that have transitioned from the X80 projects.

2.0 NPS 48 Eastern Alberta System Mainline (X80)

Since 1994, TransCanada has laid close to 288 miles (460 km) of X80. The pipe has been provided primarily by IPSCO and NKK (now JFE Steel Corporation). The welding processes and procedures used were essentially the same as those used for X70. From the first construction project in 1994 to the most recent in 2002, only minor modifications have been made to welding processes and procedures.

Construction in 1994 of 20 miles (33 km) of TransCanada's NPS 48 Eastern Alberta System Main Line was the first North American long-distance, large-diameter pipeline project to use X80 steels. The mechanized GMAW spread used on the 0.47-in. (12-mm) wall pipe consisted of a CRC-Evans six-head internal welding machine, one unit with two CRC-Evans P200 tractors (one welding "shack") for the hot pass, four shacks for fill passes, and four shacks for the cap pass. A 0.035-in. (0.9-mm) diameter C-Mn-Si-Ti wire (ER70S-6) was used throughout with 75%Ar-25%CO_2 shielding gas for root and cap passes and 100% CO_2 for hot and fill passes. A 122°F (50°C) preheat was used. Welding productivity was at 110 joints/day with a repair rate of 6%.

Tie-ins were completed with a combination of cellulosic shielded metal arc welding (SMAW) using E8010G for the root and hot pass, with 212°F (100°C) preheat, followed by self-shielded flux-cored arc welding (FCAW) using E91T8-G for all remaining passes. The particular self-shielded consumable selected was optimized by the manufacturer in terms of deposit strength and toughness for application to X80 pipe, and the welds produced consistently met yield strength (YS) requirements and exceeded the toughness requirements at the 23°F (-5°C) design temperature. In addition, experience during construction demonstrated that the tie-in welds were completed approximately 40% faster with self-shielded FCAW welding than equivalent welds made using conventional cellulosic electrodes throughout. Low-hydrogen, vertical-down SMAW made with E10018G electrodes was used for any repairs carried out to the mechanized gas metal arc welds. The preheat temperature for the tie-in welding was 212 and 248°F (100 and 120°C) for repairs.

All mainline welds were inspected using automated ultrasonic testing (AUT) and assessed to an alternative weld acceptance standard developed in accordance with Appendix K (now Annex K) of Canadian Standards Association (CSA) Z662. Any repairs to mainline welds were inspected with handscan UT and assessed according to the workmanship requirements of the standard. Tie-in welds were inspected using radiography and also assessed in accordance with the workmanship requirements of the standard. It is TransCanada's practice to delay inspection for 24 hours on all welds in X80 and above that have been welded with SMAW.

3.0 NPS 48 Western Alberta System Mainline Loop (X80)

TransCanada's most recent X80 project was 42 miles (67 km) of NPS 48 [0.47-in. (12-mm) wall for mainline and 0.633-in. (16.1-mm) heavy wall for crossings] on the Western Alberta System Mainline Loop in 2002. The mainline welding spread consisted of one eight-head internal welding system, one hot-pass shack, four fill-pass shacks, and two cap-pass shacks and was easily capable of averaging 110 welds per day on the mainline pipe. The mechanized welding equipment was again provided by CRC-Evans. Over the years, some changes have been made to the mechanized welding procedures in that the 48-in. internal welding machine now has eight welding heads instead of six. Additionally, technology for dual-speed capping passes (faster on the sides than at the top and bottom) has been developed, which enables two crews to produce the cap passes rather than the four required on the previous project. Furthermore, computer control incorporated into the external welding bugs has made it possible for them to be used on any welding pass. On this particular project, the mechanized welding procedures qualified for the welding of the NPS 48 X80 pipe consisted of a narrower bevel geometry than previously used by TransCanada (work described in Section 2 of this report), requiring less weld metal to fill and offering the potential for an incremental improvement in welding productivity.

Tie-in and repair welding procedures remained unchanged.

All mainline and tie-in welds were inspected using AUT. Mainline welds were assessed to an alternative weld acceptance standard developed in accordance with Annex K of CSA Z662 and tie-in welds were in accordance with the workmanship requirements. Repairs were inspected with handscan UT and assessed according to the workmanship requirements of the standard.

One of the major accomplishments over the 8 years of welding X80 was the reduction in mainline repair rates. The overall repair rate on the Western Alberta System Mainline Loop was 1.9%. The improved repair rate was a direct result of ability of the contractor's welding foreman to make immediate adjustments based on the results of the AUT. This allowed him/her to react to any discontinuity in the weld before it reached a length requiring repair.

4.0 Cheyenne Plains Pipeline Project (X80)

4.1 Pipe Material

The main pipeline was constructed from 36-in.-diameter × 0.464-in.-wall X80 pipe. Road bore and river crossings were constructed using 36- × 0.667-in. wall X80 pipe. In addition to the 36-in. linepipe, approximately 5 miles of 30-in.-diameter × 0.386-in.-wall pipe was used to construct laterals near the Greensburg Compressor Station.

The 36-in.-diameter linepipe pipe was procured from the following pipe mills:

- IPSCO: 300 miles of spiral-welded linepipe (0.464- and 0.667-in. wall)
- NAPA: 60 miles of long-seam welded linepipe (0.464- and 0.667-in. wall)

The total weight of pipe provided to the project was ~181,000 tons, with IPSCO's order totaling ~143,000 tons and NAPA's order totaling ~38,000 tons. The IPSCO pipe was produced from plate from the IPSCO Regina, Saskatchewan, and Mobile, Alabama, plate mills. The NAPA pipe was produced from plate supplied by Oregon Steel Mill (OSM).

The 30-in.-diameter linepipe used for the laterals was supplied by NAPA.

The induction bends and the valve transition pieces, which were provided by Berg Pipe, were X70 36-in. diameter × 0.820-in. wall thickness.

4.2 Construction Spreads

The project was broken up into three spreads. Associated Pipe Line Construction Inc. completed the first ~125 miles of the X80 36-in. line, starting at the Cheyenne Compressor Station. The remainder was completed by U.S. Pipeline Inc. using two complete pipeline spreads. One of those spreads also completed ~5 miles of 30-in. X80 lateral near the Greensburg Compressor Station.

Associated Pipe Line (Spread 1) used one full spread of CRC-Evans Pipeline International (CRC-Evans) mechanized welding equipment, consisting of an internal welding system, two hot-pass shacks, four fill-pass shacks, and three capping shacks. Spread 1 used IPSCO spirally welded line pipe. Wind speeds of 15-20 mph were typical during construction. The effects of the wind were minimized by the shacks (Al buildings) which allowed the welding crew to achieve high production rates.

U.S. Pipeline used a modified full spread plus a mini-spread of mechanized welding equipment for each construction spread (Spreads 2 and 3). The mini-spread consisted of an internal clamp and welding system plus one hot-pass shack, two fill shacks, and one to two capping shacks. Spread 2 was exclusively IPSCO spirally welded line pipe. Spread 3 included some spirally welded line pipe plus the entire NAPA double submerged arc welded (DSAW) line pipe, including the 30-in. X80 lateral line pipe.

4.3 NDE Contractor

Weldsonix was selected as the NDE contractor for the entire project and provided AUT, manual UT (MUT), and radiographic inspection (RT).

One AUT system was provided for each mainline and mini-spread for each contractor for a total of five systems plus backup facilities. Each contractor spread had one MUT inspection operator. The RT rigs were added as required for fabrications, road, and river crossings and all transition welds.

The AUT inspection system was qualified during the Weld Procedure Qualification Test Program to determine detection capability and flaw sizing accuracy. The maximum undersizing error was less than 0.04 in. (1.0 mm).

Each UT system and each operator was required to provide a “prove-up” to ensure that the NDE requirements of the project could be achieved.

Weldsonix had a main center of operations in Burlington, Colorado, (Spread 2) and one office at the operation center for Spreads 1 and 3.

4.4 X80 Linepipe

4.4.1 Pipe Specifications

The steel compositions used by the two pipe manufacturers for the Cheyenne Plains Pipeline 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 feedstock; whereas, a relatively new(4,5) Nb-Cr approach was adopted by OSM/NAPA Pipe for the longitudinally welded linepipe.

Typical chemical compositions for the two types of steel are shown in Table 1 which also includes details of the compositional restrictions from the Colorado Interstate Gas (CIG) specification.

4.4.2 Steelmaking, Rolling, and Pipe Making

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 maximizes Nb solubility.

Pipe-making in both mills went smoothly with the exception that small engineering improvements were required at IPSCO to accommodate 0.667-in.-wall X80 skelp which is close to the design limits for the mill. IPSCO uses a “single-step” in-line welding process (rather than the off-line two-step approach which is being adopted elsewhere).

To assist in pipe handling and to minimize field welding, the mills were required to ship the pipe directly to seven pipe storage yards in 80-foot lengths. The DSAW welding consumables used by both manufacturers are shown in Table 2. The weld metal was changed to a higher Ni content for the pipe used for hot bends to improve weld metal toughness in the tangents after bending and tempering. A summary of the mechanical properties for the helical seam linepipe is presented in Table 3.

4.4.3 Weldability Testing

Prior to approval of the manufacturing procedure specification (MPS) for the X80 linepipe, preliminary girth welding trials were carried out at CRC-Evans. Standard mechanized welding procedures were used to assess field weldability in terms of expected heat-affected zone (HAZ) hardness and toughness crack-tip-opening displacement (CTOD) performance. On the basis of the results the steelmaking practices were changed slightly and the aim levels for nitrogen and Ti were adjusted to lower levels.

4.4.4 Bending

UOE longitudinally welded linepipe was used for the manufacture of hot bends at BendTec Inc., in Duluth, Minnesota. Mechanical property data for the 0.667-in. wall thickness test bend are presented in Tables 4 and 5. Based on the final wall thickness and the project requirements, the bends were certified as Y-70 fittings.

The specified maximum bend radius to be used by the installation contractor 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 trials at the CRC-Evans facility 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 aging.

Pipes were successfully bent to 0.8 degrees/pipe diameter without incident, or any measurable change in Charpy V-notch (CVN) toughness. However, one test bend buckled when the bend radius exceeded 1 degree/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% fracture appearance transition temperature (FATT) at -40°F well below lowest anticipated service temperature (LAST) for the project of +20°F.

4.5 Weld Procedure Qualification

4.5.1 General

The main section of the pipeline was constructed using mechanized welding in combination with AUT. The mechanized GMAW procedures were qualified to API 1104 Appendix A to permit the development of alternative engineering critical assessment (ECA)-based flaw acceptance criteria. In addition to mechanized GMAW, SMAW, and FCAW procedures were qualified for tie-in welds, road and river crossings, and repair welds.

4.5.2 SMAW and FCAW Weld Procedure Qualification

The SMAW and FCAW preliminary weld procedure qualifications were carried at CRC Evans facilities in Houston in February 2004. The SMAW weld procedure specified a cellulosic root and hot pass followed by low-hydrogen vertical-up welding. The requirement for low-hydrogen vertical-up fill and cap passes was stipulated to reduce the potential for hydrogen-induced cold cracking during production and tie-in welding while still maintaining acceptable strength and toughness. The cellulosic root and hot pass welds were made with a higher-than-usual preheat temperature.

Since the wall thickness of the X80 pipe was 0.464 in. for the mainline and 0.667 in. for the crossings, the amount of low-hydrogen welding was significant. Generally, two low-hydrogen fill passes plus the cap pass were required for the 0.464-in. wall thickness and three- to four-fill passes plus a split cap were required for the 0.667-in. wall thickness material.

SMAW and FCAW welding trials were performed to evaluate a range of welding consumables from different consumable manufacturers. The welding trials assessed:

- Weld metal and HAZ toughness properties
- Welding speeds and welding productivity
- Process and procedure robustness (tolerance to wind, etc.)
- Time-delay considerations for root bead and hot passes
- Back welding and partial, through-wall and multiple repairs.

Welding procedures were developed in accordance with API 1104 and the project specifications.

Typical SMAW/FCAW weld procedures and properties are summarized below:

Typical SMAW/FCAW Welding Procedure

- Root bead: E6010 (1/8- to 5/32-in. diameter)
- Hot pass: E9010-P1 (5/32- to 3/16-in. diameter)
- Fill and cap passes: E9018M or E101T1-GM (0.045-in. diameter, 75/25% Ar/CO_2)
    - Tie-in/road crossing/transition weld preheat: 150°F
    - Repair preheat: 250°F
    - Maximum interpass temperature: 450°F (max.)

Summary SMAW/FCAW Weld Properties

- Cross-weld tensile tests: 99-110 ksi
- Weld metal centerline CVN at 23°F: 33-84 ft-lb
- HAZ CVN at 23°F: 43-158 ft-lb
- $VHN_{10\ kg}$: 162-278 (parent pipe-HAZ-WM traverse)

Welding Consumables Used on the Project

- Root bead: Lincoln Fleetweld 5P+ (E6010)
- Hot pass: Hobart Pipemaster 90 (E9010-G)
- Fill and cap – SMAW: ESAB Atom Arc 9018M (E9018-M)
- Fill and cap – FCAW: Lincoln Pipeliner G80M (E101T1-GM) and Hobart Fabco 101K2 (E101T1-GM)

Travel speeds for the low-hydrogen welding processes were typically between 2 and 6 in./min FCAW provided higher welding speeds with an additional advantage that the operating factor was 2-4 times that of SMAW, resulting in a considerable improvement in productivity. The deposition rate, deposition efficiency and operating factors were also considerably higher using the FCAW process than for cellulosic welding techniques.

A major concern regarding low-hydrogen welding processes is protection from the wind. Unfortunately, due to the relative high wind speeds in the flat lands of Colorado and Kansas, porosity was a continual issue. Once the welders realized that the use of wind protection was a necessity, the repair rate for these processes was substantially reduced. Since the root weld and hot pass were made with cellulosic electrodes, wind protection was not as critical of a requirement.

4.5.3 Mechanized GMAW Procedure Qualification

The mechanized weld procedure qualification was performed at CRC Evans facilities in Houston in February 2004. The following welding procedures were qualified to API 1104 Appendix A:

WPS1: 36- × 0.464-in. Wall

- WPS1-I-B: IPSCO Pipe
- WPS1-N-C: NAPA Pipe
- WPS1-I-M: IPSCO (Mobile) Pipe

WPS2: 36- × 0.667-in. Wall

- WPS2-N-E: NAPA Pipe
- WPS2-I-AL: IPSCO (Mobile) Pipe

3WPS3: 30- × 0.386-in. Wall

- WPS3-N-AJ: NAPA

The main mechanized welding parameters are summarized in Table 7. The certificates for the GMAW wires are summarized in Table 8.

The results of the weld procedure qualification tests are summarized in Tables 9 through 14 as follows:

Table No.	Weld Procedure	Pipe Diameter (in.)	Pipe Wall (in.)	Pipe Mill
9	WPS1-I-B	36	0.464	IPSCO
10	WPS1-N-C	36	0.464	NAPA
11	WPS1-I-M	36	0.464	IPSCO (Mobile)
12	WPS2-N-E	36	0.667	NAPA
13	WPS2-I-AL	36	0.667	ISPCO (Mobile)
14	WPS3-N-AJ	30	0.386	NAPA

The major findings from the weld procedure qualification CTOD test program can be summarized as follows:

WPS1

- The weld metal CTOD results all exhibited Type “m” results at 23°F with CTOD values ranging from 0.27 to 0.50 mm.

- The IPSCO HAZ CTOD results exhibited Type “u” and “m” results at 23°F with CTOD values ranging from 0.23 to 0.66 mm.

- The NAPA HAZ results IPSO pipe exhibited Type “m” results with CTOD values ranging from 0.50 to 0.54 mm

WPS2

- The weld metal CTOD results all exhibited Type “m” results at 23°F with CTOD values ranging from 0.25 to 0.40 mm.

- The IPSCO (Mobile) HAZ CTOD results all exhibited Type “m” results at 23°F with CTOD values ranging from 0.33 to 0.59 mm.

- The NAPA HAZ CTOD results exhibited Type “u” and “m” results with CTOD values ranging from 0.27 to 0.56 mm

<u>WPS3</u>

- The weld metal CTOD results all exhibited Type “m” results at 23°F with CTOD values ranging from 0.27 to 0.45 mm.

- The NAPA HAZ CTOD results all exhibited Type “m” results at 23°F with CTOD values ranging from 0.41 to 0.76 mm.

In summary, the PGMAW weld metal exhibited excellent toughness. Although the HAZ toughness results were excellent, preliminary welding trials with heavy-wall IPSCO pipe failed to satisfy the minimum CTOD toughness requirement specified in API 1104 Appendix A. The Charpy impact tests exhibited nominally identical trends to the CTOD results with typical HAZ absorbed energies of 150 J.

Since weld metal toughness is primarily dependent on the welding consumables (including shielding gas) and welding parameters, the high CTOD toughness exhibited by the PGMAW weld metal validates the selection of the welding consumables and welding parameters used in the Cheyenne Plains project. HAZ toughness is primarily a function of parent pipe chemistry and microstructure in combination with the thermal cycles produced by welding. The excellent weld metal and HAZ toughness results permitted the use of alternative ECA-based flaw acceptance criteria on all main pipeline mechanized procedures.

The low toughness HAZ results obtained from the preliminary welding trials on the heavy-wall X80 pipe highlights the need to perform CTOD testing to characterize toughness and also indicates the potential benefit of pre-qualifying X80 pipe for major pipeline projects prior to weld procedure development and qualification to ensure good HAZ toughness.

4.6 Welder Training and Qualifications

4.6.1 SMAW/FCAW Welder Training and Qualifications

Local 798 in Tulsa, Oklahoma, provided facilities and a complete range of equipment for welders to pre-train on the low-hydrogen welding processes and equipment before their arrival at the jobsite. However, most welders appeared onsite to undertake the training program provided by the contractors. Local 798 trainers, Miller Electric and Lincoln Electric technical representatives provided the training on behalf of the contractors. To meet the minimum job requirements as imposed by Local 798, all welders were required to complete a 12-in. 5G butt weld at the jobsite, to API 1104 requirements.

Since the number of welds on the 0.667-in. wall thickness for river, road, and railway crossings were significant but sporadic, they were left for the tie-in (SMAW/FCAW) welders. The tie-in welders trained and qualified on X80, 36-in.-diameter, 0.464-in.-wall thickness linepipe. 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, internal back welds, and multiple qualifications (including the 12-in.-on-12-in. branch test and additional processes). A total of 142 welders underwent training and were qualified for the project.

The welding procedures for tie-in welds, fabrications, transition welds, and repair welds were designed in such a way as to minimize the number of required welding procedures. Although this meant that additional welds were required to validate the procedures, those procedures were consolidated, similar to an ASME (using multiple PQRs) approach. These procedures were reviewed and accepted by the DoT representatives.

A total of 13 welding procedures were developed to address all of the qualification parameter requirements, including multiple repairs. The 13 welding procedures were distilled down to 3, including the 0.464-/0.667-in. X80 to the 0.820-in. X-70 transition welds.

Note: Spread three qualified additional welders by the NPS 12 branch test as they had additional small diameter laterals, fabrications, and meter stations to build which required the use of lower strength materials. Those cellulosic welding procedures were provided by the owning company.

4.6.2 Mechanized PGMAW Welder Training and Qualifications

A number of welders appeared onsite with previous experience in welding using the CRC automatic welding equipment, including the internal lineup and internal root welding machine, the P200 hot-pass machine, and the PGMAW P600 dual-torch welding system. 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 AUT and mechanical testing to API 1104 defect acceptance criteria. Operators qualified on X80, 36-in.-diameter, 0.464-in. wall thickness.

4.7 Field Construction Experience

4.7.1 Mainline Mechanized Welding

As always, the start of welding construction depends 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 nondestructive evaluation (NDE) contractor and welding inspectors. It usually takes the first week of welding construction to get the welding program properly lined out. During this time, both the production and repair rates tend to be poor. These results, statistically, hurt the 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 of 10 to 60 welds per day with repair rates up to 25%. These repairs can be 3 in. or 30 in. in length, or may be cut-outs. However, as the spread develops its production pattern, a full spread can achieve up to 150 welds per day. A mini-spread will usually achieve 40-60 welds per day. Steady state is usually on the order of 120-150 welds per day for a full spread and approximately 50 welds per day for the mini-spread. For a modified and mini-spread configuration, a total production of 180-200 welds is achievable.

Again, a number of factors enter into the 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 results. Usually, the construction contractor is focused on productivity at the risk of enduring a “reasonable” repair rate. For long-length projects in relatively remote areas, travel time from the contractor’s yard to the construction site can significantly impact the productivity results.

To ensure the integrity of the pipeline, it was hydrostatically tested by filling a completed section with water and pumping it up to a pressure significantly higher than that encountered during operation.

4.7.2 Tie-in, Crossing, and Repair Welds

Production rates were dependent on the location of the welds and the amount of time required for fit-up. Once the 36-in. pipe was fitted up and the bead and hot pass installed, it required about 1 hr to complete the weld with two welders using the FCAW semi-automatic welding process for fill and cap welds. AUT was used on the SMAW/FCAW welds wherever possible and where the joining wall thicknesses were the same. This minimized the time the tie-in crew needed to spend at a location waiting for the NDE repair results.

The weld repairs primarily included slag inclusions and porosity. Attention to detail is very important when welding X80 using the low-hydrogen welding process. Equipment selection, maintenance procedures and responsibilities, and welder training are critical for the use of low-hydrogen welding processes on X80 pipe. Repair rates on the order of 25% initially were not unusual. By the end of the project, the repair rates for low-hydrogen welds were less than 10%. Considering that this was the contractors' and owning company's first X80 project, as well as the use of the FCAW welding process, the results were reasonable.

4.7.3 Lessons Learned

The factors that made the overall project a success included:

- Contractor willingness to support the new welding and NDE processes required for the X80 construction program.

- Welding procedure qualifications at Local 798, Tulsa, worked well and were well supported.

- Preliminary presentations to the contractors and owning company construction personnel to provide an overview of the X80 welding and NDE requirements and issues.

- High level technical oversight throughout the project to resolve welding issues and problems and ensure a consistent basis for the evaluation of visual and NDE defects.

- Responsive auditing program provided by the QA team for AUT and RT-inspected welds prevented several welds that would have had to have been excavated for repairs, or cut-outs.

- Efforts of the CRC technicians to make the first X80 U.S. project a success.

- The QA team was fully supported by the owning company management and project managers.

- A training program was implemented for each contractor to address welding and NDE overview and issues to welding foremen, senior and welding inspectors, chief inspectors, project supervision, and DoT representatives. Numerous issues were addressed and a level of confidence was developed with the regulatory officials.

5.0 NPS 48 Western Alberta System Mainline Loop (X100)

5.1 Production Welding Procedure Development and Qualification

The emphasis to date at TransCanada with respect to technology development for the welding of X100 has been on developing mainline mechanized girth welding procedures and manual tie-in welding procedures. The joining technology has also focused on developing procedures that would meet strain-based design requirements for frost heave and for severe winter service. For single-wire mechanized GMAW systems, early work on the welding of X100 steels demonstrated that conventional dip-transfer or short-arc welding with 100% CO_2 shielding gas will not provide the appropriate combination of weld metal strength and toughness and that Ar-rich shielding gas mixtures and controlled-dip or pulsed welding conditions will be required. Procedures have now been developed for mechanized welding using PGMAW and standard wires with various gas mixtures. Developments also include higher productivity applications such as tandem PGMAW. A low-hydrogen vertical-down manual metal arc procedure is available for tie-in welds.

For the 1 km of X100 on the Saratoga Section of the Western Alberta System Mainline Loop, a combination of mechanized GMAW and PGMAW was used for all mainline welds as follows:

- Internal root beads using short circuit metal transfer with 75%Ar-25%CO_2 shielding gas mixture and 0.9-mm (0.035-in.) C-Mn-Si-Ti (ER70S-6) wire.

- External weld passes using PGMAW with 85%Ar-15%CO_2 shielding gas mixture and 1.0-mm (0.040-in.) 1.0%Ni 0.3%Mo (ER100S-G) wire.

- External cap pass using short-circuit metal arc welding with 85%Ar-15%CO_2 shielding gas mixture and 1.0-mm (0.040-in.) 1.0%Ni 0.3%Mo (ER100S-G) wire.

- 100°C (212°F) minimum preheat was maintained throughout.

Tie-in welds were completed using the SMAW process as follows:

- Root beads completed with E8010-G, minimum preheat 100°C (212°F) maintained throughout.

- Hot, fill, and cap passes completed with 4.0-mm (5/32-in.) E11018-G low-hydrogen, vertical-down electrodes.

- There was a 24-hour delay prior to inspection for all shielded metal arc welds.

Typical results from the procedure qualifications gave average yield strengths of 698 MPa (101 ksi) and ultimate strengths of 815 MPa (118 ksi) for the mechanized girth welds. The respective cross weld tensile test results all failed in the pipe material and gave corresponding pipe longitudinal yield strength properties of 675 MPa (98 ksi) and ultimate strengths of 811 MPa (118 ksi). Note these longitudinal properties are slightly higher than those reported for the pipe qualification of 623-MPa (90-ksi) yield and 801-MPa (116-ksi) ultimate; however, that is not unusual when performing cross weld tests. In either case, however, the girth weld properties overmatched those of the pipe longitudinal properties and that was one of the main criteria.

5.2 Welder Training and Qualification

The 1 km of X100 was welded after the X80 construction on the Western Alberta System Mainline Loop, discussed earlier, was completed. An extra 2 days of training took place just prior to welding the X100 to familiarize the welders with the PGMAW process and to qualify them to use the X100 welding procedures.

5.3 Production Welding

Production welding was conducted with a small welding spread of one internal welding system and five external welding “shacks” or workstations.

All mainline and tie-in welds were inspected using AUT. Mainline welds were assessed to an alternative weld acceptance standard developed in accordance with Annex K of CSA Z662 and tie-in welds in accordance with the workmanship requirements. Repairs were inspected with handscan UT and assessed according to the workmanship requirements of the standard.

Eighty-four mechanized welds were completed in the X100 pipe in 2 days. Twenty-three of the welds required repair, nearly all of them for sidewall lack-of-fusion at the location between the hot pass and the first-fill pass between the 2 and 4 o'clock locations on one side of the pipe, and most of them on the first day of welding. Maintaining contact tip-to-work distance in the first-fill pass is critical for avoiding this defect in the compound bevel which was used. Welders need time to become familiar with the peculiarities of PGMAW, as the manual, hands-on response required with respect to contact tip-to-work can be the exact opposite to that required for short-arc mechanized GMAW.

6.0 NPS 36 North Central Corridor (X100)

6.1 Production Welding Procedure Development and Qualification

An extensive amount of welding development occurred immediately prior to the Godin Lake project. The welding development had two main thrusts. The first was to modify slightly the conventional, single-wire PGMAW procedure that was used on the earlier, summer X100 construction project. The aim of the modification was to eliminate the minor lack-of-fusion imperfections that were occurring in the hot pass/first-fill pass region. This was achieved through the implementation of voltage sensing to control the contact-tip-to-work distance (CTWD) around the circumference of the pipe. The single-wire procedure was fully qualified, primarily as a back-up procedure, for use on Godin Lake. The second major thrust, which was a key objective, was to implement the higher-productivity tandem welding. The procedure qualified and used on the project was a hybrid combination of single-wire GMAW, PGMAW, and tandem PGMAW, as follows:

- Internal root bead using short-circuit metal transfer with 75%Ar/25%CO_2 shielding gas mixture and 0.9-mm (0.035-in.) C-Mn-Si-Ti ER70S-6 wire.

- External hot and first-fill weld passes using single-wire PGMAW with an 85%Ar-15%CO_2 shielding gas mixture and 1.0-mm (0.040-in.) 1.0%Ni 0.3%Mo wire (to field test single-wire PGMAW for the welding of X100 under winter conditions and to provide CRC-Evans with the opportunity to implement and field test its new P260 automated pipeline welding platform with automatic torch-to-work height control).

- External second- and third-fill and cap pass using tandem PGMAW with an 85%Ar-15%CO_2 shielding gas mixture and 1.0-mm (0.040-in.) 1.0%Ni 0.3%Mo wire. The welding platform used for the tandem PGMAW systems was CRC-Evans' P600, and the second- and third-fill passes used both automatic torch-to-work distance and seam-tracking capabilities.

The two all-weld-metal tensile tests from the tandem hybrid welding-procedure qualification resulted in an average yield strength of 818 MPa, and weld metal centerline (Bx2B) CTOD test results were 0.20, 0.23, and 0.26 mm at -10°C; therefore, this procedure meets the tensile requirements for a high-strain design with X100 pipe for a northern pipeline project.

6.2 Welder Training and Qualification

Production welding was conducted with a small welding spread of one internal welding system and four external welding "shacks" or workstations. Welder training and qualification was completed for the single-wire PGMAW procedure in 3 days. Four welders from the 11 qualified were then selected for training on the tandem PGMAW process. Tandem PGMAW welder training and qualification was completed in 4 days.

Some minor problems with the behavior of the shielding gas in the very low temperatures (-40°C), as well as inconsistencies in wire feed with the tandem PGMAW equipment, were resolved during this time. Dealing with these issues during training assisted the welders and technicians to identify those items of equipment requiring close surveillance and regular maintenance during production welding.

6.3 Production Welding

The welding crew moved on to the X100 in the afternoon of January 31, 2004. Refamiliarization with mechanized welding and three production welds were completed initially. The first full day of welding was February 2, when 25 welds were inspected without repair. In the authors' recollection, this is the first mechanized welding kickoff (not to mention one with new welding technologies) with no repairs in the first day of welding. The number of welds completed by the end of the week, on February 6, was 174, and there were a total of seven repairs for lack-of-sidewall fusion in mechanized PGMAW passes and a final repair rate of 5%. Positive feedback was received from the welding crews, and the only challenges were persistent inconsistencies in wire feed and minor arc instabilities that could not be totally resolved but were minimized by frequent tip and liner maintenance.

Considerable work is still underway at TransCanada, and primarily related to additional work on higher productivity welding processes and the continued development of consumables and procedures for mainline, tie-in, and double jointing.

Further development of tandem PGMAW is now in the hands of the pipeline-welding-equipment suppliers.

7.0 Summary

This report reviews the development and qualification of the pipe materials and welding procedures for the Cheyenne Plains Pipeline. The Cheyenne Plains Pipeline, which was constructed in the Fall of 2004, is the first X80 cross country gas pipeline constructed in the U.S. and the longest X80 gas pipeline in the world. The report also summarizes the experiences associated with pipeline construction including the lessons learned and the factors that made the project an overall success.

8.0 References

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Table 1. Target Chemistries for Long Seam and Spiral Seam X80 Linepipe

PIPE TYPE	C	Mn	Si	S	P	Nb	V	Cr	Mo	Cu	Ni	Ti	N	Ca
Long Seam	0.04	1.58	0.13	0.003	0.01	0.098	0.002	0.24	-	0.23	0.15	0.011	0.004	0.002
Spiral Seam	0.03	1.68	0.27	0.002	0.011	0.095	-	0.03	0.3	0.27	0.02	0.019	0.009	0.003

Table 2. Welding Consumables for X80 Linepipe and Bends

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

Table 3. Summary of Tensile Properties of X80 Spiral Pipe (651 Heats)

Description	Yield Strength (ksi)	Tensile Strength (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

Table 4. Qualification Bend (0.667-in. Wall) Bent at 1850°F at 1.2 in./min

Sample Location	Yield Strength (ksi)	Tensile Strength (ksi)	Y/T Ratio	Hardness (BHN)
Tangent	84.1	100.2	0.84	217
Tangent Weld		108.1	0	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

Table 5. Hot Bend (0.667-in. Wall) Procedure Qualification

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 6. Summary of Welding Specifications WPS 1, WPS2, and WPS3

Description		WPS1	WPS2	WPS3
Pipe Details	Grade	X80	X80	X80
	Diameter (inch)	36	36	30
	Wall Thickness (inch)	0.464	0.667	0.386
Welding Parameters	Preheat (F)	125	125	125
	Max Interpass (F)	450	450	450
Root Pass	AWS Specification	A5.18	A5.18	A5.18
	AWS Classification	ER70S-G	ER70S-G	ER70S-G
	Manufacturer	Thyssen	Thyssen	Thyssen
	Trade Name	TS-6	TS-6	TS-6
	Size (inch)	0.035	0.035	0.035
	Weld Process	GMAW	GMAW	GMAW
	Direction	Downhill	Downhill	Downhill
	Shielding Gas	75% Argon / 25% CO_2	75% Argon / 25% CO_2	75% Argon / 25% CO_2
	Heat Input (kJ/inch)	6.6 - 12	6.5 - 12	7.0 - 11.0
Hot Pass	AWS Specification	A5.18	A5.18	A5.18
	AWS Classification	ER70S-G	ER70S-G	ER70S-G
	Manufacturer	Thyssen	Thyssen	Thyssen
	Trade Name	TS-6	TS-6	TS-6
	Size (inch)	0.035	0.035	0.035
	Weld Process	GMAW	GMAW	GMAW
	Direction	Downhill	Downhill	Downhill
	Shielding Gas	100% CO_2	100% CO_2	100% CO_2
	Heat Input (kJ/inch)	6.3 - 8.6	6.5 - 8.7	6.0 - 8.5
Fill & Cap Passs	AWS Specification	A5.18	A5.18	A5.18
	AWS Classification	ER70S-6	ER70S-6	ER70S-6
	Manufacturer	Lincoln	Lincoln	Lincoln
	Trade Name	Super Arc L-56	Super Arc L-56	Super Arc L-56
	Size (inch)	0.04	0.04	0.04
	Weld Process	PGMAW	PGMAW	PGMAW
	Direction	Downhill	Downhill	Downhill
	Shielding Gas	85% Argon / 15% CO_2	85% Argon / 15% CO_2	85% Argon / 15% CO_2
	Heat Input (kJ/inch)	11.2 - 18.7	12.0 - 23.9	10.0 - 25.5

Table 7. Chemical Analysis of GMAW Wires (Test Certificates)

Description	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Ti	V
Thyssen	0.06	0.71	1.53	0.013	0.011	0.05	0.01	0.02	0.15	0.05	-
Lincoln	0.09	0.83	1.46	0.015	0.009	0.02	0.01	0.02	0.24	-	<0.01

Table 8. Weld Metal Mechanical Properties (Test Certificates) – 100% CO_2 Shielding Gas

Description	Thyssen	Lincoln
Yield Strength (ksi)	70.8	71.0
Tensile Strength (ksi)	84.0	88.0
Elongation (%)	26.1	27.0

Description	Thyssen	Lincoln
Cv at 32F (ftlb)	-	77
	-	88
	-	86
Average	-	84
Cv at -20F (ft lb)	27	54
	25	46
	39	52
Average	30	51

Table 9. Weld Procedure Qualification WPS1-I-B (36- × 0.464-in. IPSCO)

Tensile Test Results

Description	Area (sq inch)	Gage Length (inch)	0.2% YS (ksi)	TS (ksi)	Elong (%)	Comments
All Weld	0.0196	0.64	95.2	104	27	Nil

Charpy Impact Results

Description	Position	Notch Location	Temp (F)	Cv Energy (ft.lb.)	Average (ft lb)
Weld C/L	Q1	WCL	23	130, 104, 119	118
Weld C/L	Q3	WCL	23	94, 116, 96	102
HAZ	Q1	FL + 0.4 mm	23	160, 124, 155	146
HAZ	Q3	FL + 0.4 mm	23	155, 162, 157	158
HAZ	Q1	FL + 2.0 mm	23	159, 164, 152	158
HAZ	Q3	FL + 2.0 mm	23	164, 164, 176	168
HAZ	Q1	FL + 5.0 mm	23	156, 134, 134	141
HAZ	Q3	FL + 5.0 mm	23	154, 152, 167	158

CTOD Results

Specimen Number	Location (o'clock)	Notch Position	Temp (F)	CTOD (mm)	Type of Result	Comments
1	12	Weld	23	0.27	m	Nil
2	3	Weld	23	0.40	m	Nil
3	6	Weld	23	0.34	m	Nil
4	12	HAZ	23	0.59	m	Nil
5	3	HAZ	23	0.37	m	Nil
6	6	HAZ	23	0.23	u	Nil

Table 10. Weld Procedure Qualification WPS1-N-C (36- × 0.464- in. NAPA)

Tensile Test Results

Description	Area (sq inch)	Gage Length (inch)	0.2% YS (ksi)	TS (ksi)	Elong (%)	Comments
All Weld	0.0201	0.64	94.7	103.8	23	Nil

Charpy Impact Results

Description	Position	Notch Location	Temp (F)	Cv Energy (ft.lb.)	Average (ft lb)
Weld C/L	Q1	WCL	23	126, 114, 100	113
Weld C/L	Q3	WCL	23	102, 94, 96	97
HAZ	Q1	FL + 0.4 mm	23	146, 159, 158	154
HAZ	Q3	FL + 0.4 mm	23	156, 152, 164	157
HAZ	Q1	FL + 2.0 mm	23	174, 173, 170	172
HAZ	Q3	FL + 2.0 mm	23	182, 188, 174	181
HAZ	Q1	FL + 5.0 mm	23	180, 181, 146	169
HAZ	Q3	FL + 5.0 mm	23	183, 166, 150	166

CTOD Results

Specimen Number	Location (o'clock)	Notch Position	Temp (F)	CTOD (mm)	Type of Result	Comments
1	12	Weld	23	0.38	m	Nil
2	3	Weld	23	0.50	m	Nil
3	6	Weld	23	0.50	m	Nil
4	12	HAZ	23	0.53	m	Nil
5	3	HAZ	23	0.50	m	Nil
6	6	HAZ	23	0.54	m	Nil

Table 11. Weld Procedure Qualification WPS1-I-M (36- × 0.464-in. IPSCO Mobile)

Tensile Test Results

Description	Area (sq inch)	Gage Length (inch)	0.2% YS (ksi)	TS (ksi)	Elong (%)	Comments
All Weld	0.0161	0.0204	95.1	103.9	30	Nil

Charpy Impact Results

Description	Position	Notch Location	Temp (F)	Cv Energy (ft.lb.)	Average (ft lb)
Weld C/L	Q1	WCL	23	132, 114, 100	115
Weld C/L	Q3	WCL	23	120, 122, 119	120
HAZ	Q1	FL + 0.4 mm	23	116, 148, 160	141
HAZ	Q3	FL + 0.4 mm	23	172, 170, 173	172
HAZ	Q1	FL + 2.0 mm	23	175, 178, 171	175
HAZ	Q3	FL + 2.0 mm	23	181, 170, 174	175
HAZ	Q1	FL + 5.0 mm	23	174, 180, 184	179
HAZ	Q3	FL + 5.0 mm	23	184, 172, 184	180

CTOD Results

Specimen Number	Location (o'clock)	Notch Position	Temp (F)	CTOD (mm)	Type of Result	Comments
1	12	Weld	23	0.33	m	Nil
2	3	Weld	23	0.33	m	Nil
3	6	Weld	23	0.36	m	Nil
4	12	HAZ	23	0.25	u	Nil
5	3	HAZ	23	0.66	m	Nil
6	6	HAZ	23	0.48	m	Nil

Table 12. Results of Weld Procedure Qualification WPS2-N-E (36- × 0.667-in. NAPA)

Tensile Test Results

Description	Area (sq inch)	Gage Length (inch)	0.2% YS (ksi)	TS (ksi)	Elong (%)	Comments
All Weld	0.0194	0.64	94.7	103.3	23	Nil

Charpy Impact Results

Description	Position	Notch Location	Temp (F)	Cv Energy (ft.lb.)	Average (ft lb)
Weld C/L	Q1	WCL	23	121, 116, 126	121
Weld C/L	Q3	WCL	23	112, 115, 118	115
HAZ	Q1	FL + 0.4 mm	23	188, 182, 190	187
HAZ	Q3	FL + 0.4 mm	23	178, 166, 173	172
HAZ	Q1	FL + 2.0 mm	23	176, 178, 182	179
HAZ	Q3	FL + 2.0 mm	23	160, 174, 180	171
HAZ	Q1	FL + 5.0 mm	23	192, 198, 195	195
HAZ	Q3	FL + 5.0 mm	23	181, 180, 185	182

CTOD Results

Specimen Number	Location (o'clock)	Notch Position	Temp (F)	CTOD (mm)	Type of Result	Comments
1	12	Weld	23	0.30	m	Nil
2	3	Weld	23	0.34	m	Nil
3	6	Weld	23	0.38	m	Nil
4	12	HAZ	23	0.56	m	Nil
5	3	HAZ	23	0.27	u	Nil
6	6	HAZ	23	0.33	m	Nil

Table 13. Results of Weld Procedure Qualification WPS2-I-AL (36- × 0.667-in. NAPA)

Tensile Test Results

Description	Area (sq inch)	Gage Length (inch)	0.2% YS (ksi)	TS (ksi)	Elong (%)	Comments
All Weld	0.0196	0.64	100.1	107.1	28	Nil

Charpy Impact Results

Description	Position	Notch Location	Temp (F)	Cv Energy (ft.lb.)	Average (ft lb)
Weld C/L	Q1	WCL	23	102, 108, 108	106
Weld C/L	Q3	WCL	23	114, 102, 106	107
HAZ	Q1	FL + 0.4 mm	23	62, 97, 150	103
HAZ	Q3	FL + 0.4 mm	23	164, 144, 166	158
HAZ	Q1	FL + 2.0 mm	23	170, 164, 174	169
HAZ	Q3	FL + 2.0 mm	23	166, 176, 182	175
HAZ	Q1	FL + 5.0 mm	23	186, 184, 186	185
HAZ	Q3	FL + 5.0 mm	23	144, 176, 142	154

CTOD Results

Specimen Number	Location (o'clock)	Notch Position	Temp (F)	CTOD (mm)	Type of Result	Comments
1	12	Weld	23	0.28	m	Nil
2	3	Weld	23	0.28	m	Nil
3	6	Weld	23	0.25	m	Nil
4	12	HAZ	23	0.59	m	Nil
5	3	HAZ	23	0.39	m	Nil
6	6	HAZ	23	0.25	u	Invaid
7	6	HAZ	23	0.33	m	Re-test

Table 14. Results of Weld Procedure Qualification WPS3-N-AJ (30- × 0.384-in. NAPA)

Tensile Test Results

Description	Area (sq inch)	Gage Length (inch)	0.2% YS (ksi)	TS (ksi)	Elong (%)	Comments
All Weld	0.0199	0.64	93.1	102.3	31	Nil

Charpy Impact Results

Description	Position	Notch Location	Temp (F)	Cv Energy (ft.lb.)	Average (ft lb)
Weld C/L	Q1	WCL	23	72, 68, 73	71
Weld C/L	Q3	WCL	23	75, 83, 73	77
HAZ	Q1	FL + 0.4 mm	23	120, 126, 114	120
HAZ	Q3	FL + 0.4 mm	23	118, 136, 122	125
HAZ	Q1	FL + 2.0 mm	23	138, 146, 154	146
HAZ	Q3	FL + 2.0 mm	23	140, 144, 142	142
HAZ	Q1	FL + 5.0 mm	23	156, 172, 154	161
HAZ	Q3	FL + 5.0 mm	23	154, 148, 155	152

CTOD Results

Specimen Number	Location (o'clock)	Notch Position	Temp (F)	CTOD (mm)	Type of Result	Comments
1	12	Weld	23	0.16	u	Invalid
7	12	Weld	23	0.30	m	Re-test
2	3	Weld	23	0.27	m	Nil
3	6	Weld	23	0.45	m	Nil
4	12	HAZ	23	0.72	m	Nil
5	3	HAZ	23	0.41	m	Nil
6	6	HAZ	23	0.76	m	Nil