Chris Penniston, Welding & Materials Engineer, RMS Welding Systems, Canada, discusses mechanised welding of heavy wall pipe for the Alliance Pipeline Highway 43/32 Pipe Relocation Project.

The HIGHWAY TO SUCCESS

This discussion is focused on Alliance's Highway 43/32 Pipe Relocation Project, located near Whitecourt, Alberta, approximately 200 km northwest of Edmonton. The project was initiated because Canada's national pipeline regulator, the National Energy Board, directed Alliance to replace or relocate a short section of pipeline at the highway interchange, due to construction of a new commercial development adjacent to the pipeline right-of-way. Rather than just replace the section with heavier wall pipe, in keeping with its focus on pipeline safety, Alliance elected to deactivate that section of pipe, install new heavier-wall pipe and relocate the line further away from the commercial development.

The new pipe runs parallel to the old pipe, but is located a further distance from the outer edges of the commercial development (greater than 200 m). Figure 1 gives an overview of the project layout. The new pipe was certified as CSA Z245.1-07, 914 mm OD (NPS 36) × 22.8 mm (0.898 in.) WT grade 483, category II. The total installed length of the project was 831 m.

Contractual shipping obligations on the pipeline meant a limited outage timeframe of 96 hrs was established to tie-in the new section of pipe. This short outage time period, along with the swampy soil conditions in the area helped influence the choice of welding technology for the project. With traditional SMAW welding techniques and their associated non-destructive inspection delays, there would have been an increased need for ditch maintenance over longer periods of time, and the conditions would have been more challenging.

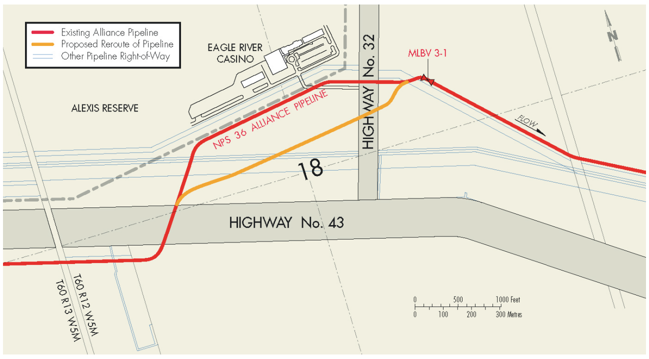

Figure 1. Overview of the Highway 43/32 Pipe Relocation Project.

Figure 2. RMS MOWII carriages welding FCAW-G in the upward progression during weld procedure development.

Figure 3. Metallographic cross-section of a weld produced during weld procedure development (pipe material is 22.8 mm thick).

Due to the potential impacts of an extended outage, Alliance technical management approved the approach to develop the necessary new welding procedure qualifications to mitigate the potential to hydrogen-induced cold cracking, provide a high level of consistent weld quality, and optimise productivity. As a result, mechanised (and semi-automated) gas metal arc welding (GMAW)/flux core arc welding (FCAW) was determined to be the best potential option along with the use of real-time phased array automated ultrasonic weld inspection. In addition, an option to use shielded metal arc welding (SMAW)/FCAW for the final tie-ins was also qualified. This aligned with the Alliance philosophy to optimise the qualification of welding procedures for future uses.

Welding process and equipment overview

Although other processes were used for the two final tie-in welds, this article focuses on the primary mainline process combination used on the project. This primary process combination utilised a modified waveform short circuit semi-automatic GMAW root pass, with mechanised gas shielded flux core arc welding (FCAW-G) remainder.

The chosen process for the root pass was that of modified waveform short circuit. Examples of this process include Lincoln Electric's surface tension transfer (STT) and Miller Electric's regulated metal deposition (RMD), which are well known in welding industries for their benefits in welding an externally applied root pass in gapped applications. Modified waveform short circuit cyclically modifies arc voltage and amperage characteristics, at different stages of the liquid weld metal transfer process. A reduction in heat input, lowered tendency of burn-through, enhancement of wetting and deposition, reduction of liquid weld metal turbulence and reduction of spatter are the main differences when compared to traditional dip transfer short circuit GMAW. Additional benefits of the modified waveform short circuit include greater tolerance to gap and offset/high-low variations, a desirable root bead profile with good penetration and fusion and lack of undercut, and high deposition, which prevents subsequent burn-through due to subsequent weld passes.

For the second, fill and cap passes, mechanised FCAW-G was employed using a T-1 (rutile type) consumable welded in the upward progression. Similar to the GMAW process, FCAW-G uses an arc between a continuously fed consumable filler wire and the work piece. In the case of FCAW-G, the wire is of tubular construction and is filled with flux consisting of slag formers, deoxidisers, arc stabilisers, and alloying agents.[1] The welding current is carried through the tubular outer layer of the wire, resulting in a high current density there. This distribution of current results in high deposition, and it directs thermal energy to the outside of the wire, where it helps assure sidewall fusion. The arc is shielded by a gas of controlled composition, in this case consisting of 75% argon (Ar) and 25% carbon dioxide (CO_2). A CV power supply with DCEP cable layout is utilised along with a wire feeder that delivers wire at a continuous wire feed speed. The wire feed speed (WFS) and voltage are set on the machine and the welding power source outputs appropriate amperage to maintain the arc. The WFS and voltage settings are selected based on optimising arc stability and reducing spatter for the welding positions used, as well as to achieve the desired fusion and penetration characteristics, bead appearance, and lack of undercut. The use of T-1 type FCAW-G wire results in smooth spray-like molten metal transfer, characterised by small droplet size and low spatter

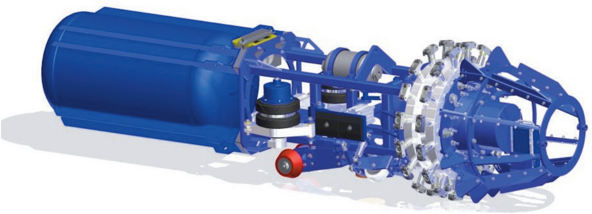

Figure 4. Schematic of RMS internal line-up clamp.

Figure 5. Front end of mainline welding, showing the RMS internal clamp at the end of the pipe.

Figure 6. Mainline equipment lineup.

levels, complete slag coverage of the weld puddle, proven minimum Charpy V-notch absorbed energy levels, and easy slag detachment prior to depositing subsequent passes.[1] In addition, the high melting point titanium oxide constituents contained in the formed slag have an elevated melting temperature. The high melting temperature results in a slag that solidifies more quickly than the weld puddle, resulting in the liquid weld metal being supported by a cohesive surrounding slag during weaved weld progression in the upward direction. By the use of an upward progression, sidewall fusion is assured and undercutting is reduced because of increased solidification time, resulting in excellent weld cohesion and low probability of lack of fusion defects.

Compared to SMAW using cellulosic electrodes (the process that would traditionally be chosen for a North American project of this type), FCAW-G offers higher weld metal deposition rates, lower fume levels, higher Charpy V-notch absorbed energy values, significantly lower hydrogen content, and because of the continuously fed wire, fewer stops and starts. This results in higher productivity and faster joint completion times, particularly for the heavy 22.8 mm wall thickness utilised on the project. On the downside, unlike SMAW, FCAW-G does require the use of a welding shelter in order to prevent the loss of shielding gas.

The RMS Mechanised Orbital Welder II (MOWII) system is a multi-micro-processor digitally controlled mechanised OD orbital welding system that has been used for second, fill and cap pass welding for tie-ins and mainline welding for various pipeline projects since 2006. It is versatile, with capability for single torch, dual torch (two-phased independently controlled torches separated by a significant distance), and tandem (two independently controlled arcs in a single puddle) welding, with FCAW-G, GMAW-S and GMAW-P process capability. The pendulum style weave of the MOWII system ensures a high rate of sidewall fusion because the arc makes contact with a large portion of the joint surface area. For this application of FCAW-G, through-the-arc automatic torch height/contact-tip-to-work-distance control was employed using amperage feedback ensuring consistent wire feed speed, amperage and voltage. Fine tuning of seam tracking, weave width and travel speed were accomplished by the welder controlling the MOWII through a control pendant, which contained process limits. These limits were set for the project based on CSA Z662 welding procedure specification 'essential changes' along with 'non-essential' variable limits set based on the experience of the RMS Welding Systems staff in implementing the FCAW-G process with the MOWII. Figure 2 shows a weld being completed in the company's shop during weld procedure development.

Compared to semi-automatic FCAW-G, the mechanisation of the FCAW-G process greatly improves productivity, weld quality and lowers weld defect rates. Factors influencing this include increased arc-on times, lowered operator fatigue, the ability to precisely control weave characteristics (including frequency, dwell and width) resulting in elimination of stopping and starting of welding during the deposition of a weld pass, the ability to implement automatic variable adjustments at different circumferential positions around the pipe, enhanced control of non-steady state welding characteristics and start and finish of a weld pass, pre-setting of aim weld variables with provisions for fine-tuning by the operator, as well as the ability to administratively adjust welding variables and set up across all the equipment in a quick manner to react to quality concerns (note, this was not required on this project).

With semi-automatic FCAW-G, inevitable changes in contact tip to work distance (CTWD) due to hand-held torch positioning during weld progression around the pipe circumference and during weaving in the joint preparation, result in variations in deposition and arc characteristics/stability and can potentially alter weld metal mechanical properties. This variation in CTWD results in a varying length of wire between the end of the contact tip and the arc, which affects the amount of resistive heating in that varying length. Because the MOWII system implemented automatic torch height control, the amperage, resulting heat input and weld metal deposition were maintained in a tightly controlled range. This enabled production of welds with assured and consistent Charpy V-notch absorbed energy values and strength in the weld metal and heat affected zone (HAZ).

Weld procedure qualification

A minimum preheat temperature of 120 °C was qualified. This elevated preheat temperature was employed to further ensure that no delayed hydrogen cracking would occur and to ensure consistent weld quality results during upset weather conditions.

For the Highway 43/32 Pipe Relocation Project, a welder using a semi-automatic hand-held torch accomplished the modified waveform short circuit root pass. The deposition of the root pass was sufficient to allow the second (hot) pass to be applied using the FCAW-G process without a risk of burn-through. The semi-automatic modified waveform short circuit root pass weld utilised a 1.0 mm diameter AWS A5.28 ER80S-G solid GMAW electrode with nominal heat input ranging from 0.5 - 0.9 kJ/mm, in the downward progression.

The mechanised FCAW-G second pass, fill and cap passes utilised a 1.2 mm diameter AWS A5.29 E111T1-K3MJ-H4 flux cored electrode with 75% Ar/25% CO_2 shielding gas. Heat inputs for these passes ranged from 0.8 - 1.6 kJ/mm. An overmatching consumable was chosen in order to ensure adequate strength, given the upward progression of the positional welds and expected dilution from the lean thermo-mechanically controlled processed (TMCP) pipe material. The consumable is rated for proven Charpy V-notch absorbed energy of greater than 27 J at -29 °C. The 'H4' hydrogen designation assured low hydrogen levels in the weld and HAZ, reducing concerns associated with delayed hydrogen cracking of the weld and/or HAZ, and removing the requirement for delayed non-destructive inspection of welds to check for delayed hydrogen cracking. While the design temperature for the pipeline was -5 °C, the opportunity was taken to validate the welding procedures for -45 °C potential future opportunities. Figure 3 shows a metallographic cross-section of a weld produced during weld procedure development.

Mechanical testing revealed excellent properties, with transverse to weld axis tensile tests displaying failure in the base material. Charpy V-notch testing of the weld metal centreline resulted in an absorbed energy range of 46 - 68 J at -45 °C and cross-weld tensile tests resulted in an ultimate tensile strength (UTS) of > 640 MPa.

Figure 7. A view from inside a fill pass shack during FCAW-G welding using the RMS MOWII.

Figure 8. A welding shack is lowered onto the pipe for tie-in welding.

Welding sequence

Counter bore and taper joints were needed at the final tie-in points to the existing line due to wall thickness mismatch with the new heavy wall pipe (22.8 - 14.2 mm wt). Therefore, end prep machines were used to face all pipe ends with a fresh factory configuration bevel of 30° with a 'land' of 1.6 mm. It is noted that there could be significant productivity gains from the use of a compound bevel utilising a steeper bevel angle toward the OD of the pipe, however, one of the goals of this project was to establish versatile and general procedures that can be used in future applications, and therefore, a compound bevel was not used.

For mainline welds, after preheating, initial fit-up of the joints was accomplished using an RMS Welding Systems internal clamp (Figure 4) utilising outward clamping force to align the pipe, minimise high/low, and control gap. The system is similar

Figure 9. PAUT equipment scanning a girth weld.

to the RMS Internal Welding Machine (IWM), except without provisions for internal root bead welding. With the internal clamp engaged, the root/hot pass welding shack was lowered onto the joint. The root pass was applied using a hand-held semi-automatic GMAW torch, using a modified short circuit process around 100% of the circumference prior to releasing the internal clamp to advance to the next joint. An RMS MOWII mechanised OD welding system was then attached to a tracking band and welding of the second pass proceeded. After this, the root/hot pass welding shack was advanced to the next joint, following completion of fit-up of the next joint using the internal clamp. Figures 5 and 6 provide a view of the mainline equipment lineup.

Once the first shack was removed from the joints, one of the three fill/cap pass welding shacks would be lowered onto the joint in order to complete the joint using the RMS MOWII mechanised OD welding system. Mainline weld completion times were typically just over two hours up to three hours per weld. Figure 7 shows a view from inside a fill pass shack during welding.

For all tie-in welds, pipe ends were cut and prepared for welding, then preheating was applied and an OD clamp was used to ensure good fit-up. A welding shack was lowered onto the tie-in joint, and the root pass was applied to accessible areas of the joint, after which the clamp was removed and the root pass completed over the entire circumference. The rest of the weld was then completed the same as a mainline weld, except that only one shack would be used to weld the entire joint. Although the use of a shack for tie-ins may seem at first glance to be cumbersome, in the case of this project, where muddy soils were encountered, the shack provided dry solid ground for the welders, and also controlled their proximity to the pipe. Mainline weld completion times were typically around 2.5 hrs, with some joints taking up to 3.5 hrs, depending on the logistic challenges on a particular weld joint. Figure 8 shows a weld shack being lowered onto the pipe for tie-in welding.

Final tie-in welding

Due to the safety requirements of the project, air movers were utilised during the final tie-ins to ensure that any natural gas that may be present in the line would be neutralised. However, this would have created a major problem for the use of GMAW root welds. As a consequence, a final tie-in procedure was developed and qualified using SMAW (E6010) root weld with a low hydrogen hot pass (E8018-C3) prior to completion of the welding using the mechanised FCAW welding system and procedure. No repairs were required on the final tie-ins.

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In order to evaluate the integrity of the mainline and tie-in welds, and the one and only weld repair, phased array automated ultrasonic testing (PAUT) was utilised. Weld defect acceptance criteria was per CSA Z662-11 'workmanship' criteria. In order to verify the effectiveness of the PAUT set-up used, PAUT inspection procedures were developed and seeded defect welds were produced during the weld procedure development process. The scans were verified by radiographic testing (RT) to confirm that the PAUT detected defects reliably. Figure 8 shows the PAUT equipment set-up used.

The weld reject rate for the project was very low, with only one repair required, as a result of slag entrapment near the midwall. With a total of 84 welds performed on the project, this corresponds to a 1.2% repair rate.

Conclusions

The Alliance Pipeline Highway 43/32 Pipe Relocation Project presented many challenges, including a limited outage time window; cold, wet and windy weather conditions; working from mats, and difficult soil conditions. In response to these challenges, a versatile and productive, highly controlled mechanised welding process and techniques were qualified and implemented to ensure a consistent high level of weld quality.

This procedure utilised a modified waveform short circuit gas metal arc weld root pass with mechanised gas shielded flux core arc weld remainder. This choice mitigated risks of delayed hydrogen cracking, and shortened non-destructive inspection delay time requirements. The inherent benefits of the process and consumables, along with the use of the RMS MOWII mechanised welding equipment, ensured consistent welds, high productivity, a low repair rate and assured mechanical properties.

Acknowledgements

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Reference

1. 'Welding, Brazing and Soldering', ASM Handbook, Volume 6, ASM International, (USA, 1993).