DEVELOPMENT OF INTERNAL (TRENCHLESS) REPAIR TECHNOLOGY FOR GAS TRANSMISSION PIPELINES*

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ABSTRACT

The most common cause for repair of gas transmission pipelines is external, corrosion-caused loss of wall thickness. To prevent an area of corrosion damage from causing a pipeline to rupture, the area containing the corrosion damage must be reinforced. The most commonly used method for repair of gas transmission pipelines is the installation of welded full-encirclement steel repair sleeves.

Repair methods that can be applied from the inside of a gas transmission pipeline (i.e., trenchless methods) are an attractive alternative to conventional repair methods since the need to excavate the pipeline is precluded. This is particularly true for pipelines in environmentally sensitive and highly populated areas. Several repair methods that are commonly applied from the outside of the pipeline are, in theory, directly applicable from the inside. However, issues such as development of the required equipment to perform repairs remotely and mobilization of equipment through the pipeline to areas that require repair need to be addressed. Several additional repair methods that are commonly applied to other types of pipelines (e.g., gas distribution lines, water lines, etc.) also have potential applicability but require further development to meet the requirements for repair of gas transmission pipelines.

This paper describes an on-going project that is being sponsored by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) to develop internal repair technology for gas transmission pipelines.

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INTRODUCTION

A repair method that can be applied from the inside of a gas transmission pipeline (i.e., a trenchless repair) is an attractive alternative to conventional repair methods since the need to excavate the pipeline is precluded. This is particularly true for pipelines in environmentally sensitive and highly populated areas. Several repair methods that are commonly applied from the outside of the pipeline are, in theory, directly applicable from the inside. However, issues such as development of the required equipment to perform repairs remotely and mobilization of equipment through the pipeline to areas that require repair need to be addressed. Several additional repair methods that are commonly applied to other types of pipelines (gas distribution lines, water lines, etc.) also have potential applicability for internal repair of gas transmission pipelines. Many of these require further development to meet the requirements for repair of gas transmission pipelines.

To address this need, the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) is sponsoring a project to develop internal repair technology for gas transmission pipelines. The project team is being led by Edison Welding Institute (EWI) and includes Pacific Gas & Electric Company (PG&E) and Pipeline Research Council International, Inc. (PRCI).

BACKGROUND

The most common cause for repair of gas transmission pipelines is external, corrosion-caused loss of wall thickness. To prevent an area of corrosion damage from causing a pipeline to rupture, the area containing the corrosion damage must be reinforced. Other pipeline defects that commonly require repair include internal corrosion, original construction flaws, service-induced cracking, and mechanical damage. Defects oriented in the longitudinal direction that have a tendency to fail from hoop stress (due to pressure loading) must be reinforced in the circumferential direction, while defects oriented in the circumferential direction that have a tendency to fail from axial stresses (e.g., pipeline settlement) must be reinforced in the longitudinal direction. The most commonly used method for repair of gas transmission pipelines is the installation of welded full-encirclement steel repair sleeves (Figure 1). These sleeves resist hoop stress and, if the ends are welded to the pipeline, can resist axial stresses.

Current repair methods that are commonly applied from the outside of the pipeline are typically applied while the pipeline remains in service. While this is desirable for internal repair, many of the repair methods that are applicable to the inside of the pipeline would require that the pipeline be taken out of service. Most of the repair methods that are commonly applied to the inside of other types of pipelines, which typically operate at lower pressures, are done so to restore leak tightness. These repair methods would typically require further development to restore the strength of a gas transmission pipeline.

REVIEW AND ASSESSMENT OF CANDIDATE REPAIR METHODS

The first task of this project involved a review and an assessment of common external repair methods for gas transmission pipelines and of repair methods that are commonly applied to the inside of other types of pipelines.(1) This review resulted in the identification of two broad categories that are potentially applicable to repair of gas transmission pipelines from the inside; weld deposition repair and fiber-reinforced composite liner repair.

Figure 1 - Installation of a Welded Full-Encirclement Steel Repair Sleeve

Weld Deposition Repairs

Gas transmission pipeline repair by direct deposition of weld metal, or weld deposition repair, is a proven technology that can be applied directly to the area of wall loss (e.g., external repair of external wall loss) or to the side opposite the wall loss (e.g., external repair of internal wall loss).[2] There are no apparent technical limitations to applying this repair method to the inside of an out-of-service pipeline. Application of this repair method to the inside of an in-service pipeline would require that the methane gas be excluded from the welding environment. Weld repair is direct, relatively inexpensive to apply, and requires no additional materials beyond welding consumables.

Remote welding has been developed primarily for the needs in the nuclear power industry, although working devices have been built for other applications. For example, beginning in 1985, Osaka Gas developed remote robotic equipment for repair of flaws in the root area of welds in gas transmission lines. The robot is self-propelled via wheels, uses an umbilical cable for control and power, and is able to perform work up to 500 ft from the pipeline entry point. The power supply for welding equipment is located at the entry point, which limits the working range. The working range is also limited by the ability of the robot to pull the umbilical cable. The robot is capable of working in 12- to 24-in.-diameter pipe with 90-degree bends. It does not remove the root flaws from the pipe prior to welding. Grinding of the pipe wall is used to remove impurities that can disrupt the welding arc. Welding is performed using the gas-metal arc welding (GMAW) process. The torch travel path is programmed prior to welding. Welding filler metal is carried onboard, while shielding gas is supplied via the umbilical. The robot incorporates features such as wire cutting and nozzle cleaning. Inspection of completed repairs is performed visually using video cameras located on the robot. Welding is controlled to avoid damage to pipeline coating. Approximately 4 hours are required to grind, weld, and inspect a 24-in.-diameter girth weld. Osaka Gas has been using the robots to perform field repairs since 1995. Current development work is believed to be focused on improving arc stability and robot range by placing the welding power supply on the robot.

Pacific Gas and Electric Company (PG&E) has developed the Internal Pipeline NDE System (IPNS) for internal inspection of gas pipelines (Figure 2). This system incorporates a variety of inspection technologies to characterize girth and long seam flaws, corrosion, and dents and gouges. A grinder is incorporated for preparation of areas of interest. The system has been in field use since 1996 and has a maximum range of 2,500 ft. The robot is self-propelled using tracks and is able to traverse 90-degree bends in 22- to 24-in.-diameter pipe. An umbilical is used to supply power and to control the device. Preliminary development work was performed for a companion system to perform machining and welding of defective welds. While not a welding system, IPNS demonstrates the practicality of performing work inside gas pipelines at extended distances from the entry point.

Figure 2 – Pacific Gas &Electric Internal Pipeline NDE System

The important characteristics of a useful internal weld deposition repair system include the ability to operate at long range from the pipe entry point (i.e., 2,000+ feet) and transverse bends and miters. The system should also incorporate machining/grinding capability to clean and prepare the weld joint and a high deposition, robust welding process. Although many of these features are incorporated in the existing systems, there is no single system that possesses all of the required characteristics. Further work is required to develop a system with all of these features. For in-service repair, further work is also required to develop the ability to exclude the methane gas from the welding environment.

Fiber-Reinforced Composite Repairs

Fiber-reinforced composite repairs are becoming widely used as an alternative to the installation of welded full-encirclement steel sleeves for repair of gas transmission pipelines. These repairs typically consist of glass fibers in a polymer matrix material bonded to the pipe using an adhesive (Figure 3). Adhesive filler is applied to the defect prior to installation to allow load transfer to the composite material. The primary advantage of these repair products over welded full-encirclement steel repair sleeves is that the need for welding is precluded.

Figure 3 - Installation of a Fiber-Reinforced Composite Repair Device

A variety of liners are commonly used for repair of other types of pipelines (e.g., gas distribution lines, sewers, water mains, etc.). Of these, the three that are potentially applicable to internal repair of gas transmission pipelines are sectional liners, cured-in-place liners, and fold-and-formed liners. Sectional liners are typically 3 to 15 ft in length and are installed only in areas that require repairs. Cured-in-place liners and fold-and-formed liners are typically applied to an entire pipeline segment. Cured-in-place liners are installed using the inversion process. Fold-and-formed liners are pulled into place and then inverted so that they fit tightly against the inside of the pipe. In addition to repair, continuously applied liners could be used to increase the operating pressure in (i.e., up-rate) an existing pipeline.

Composite-reinforced line pipe (CRLP) is also being considered for new construction of gas transmission pipelines. CRLP is a patented process that applies glass-resin reinforcement to steel pipe, which forms an outer protective barrier with additional hoop strength, prior to installation. In the winter of 2001, a 2-km section of 24-in.-diameter CRLP pipe was installed in northwestern Canada and is presently being tested by TransCanada Pipelines. Composite-reinforced pressure vessels are also being developed for gas transport modules (GTMs), which can be used to transport stranded gas to market areas. Composite materials are also being used for coiled tubing and offshore risers.

Further development of fiber-reinforced composite repairs/liners with sufficient strength is required prior to application to internal, local structural repair of gas transmission pipelines. Ideally, these products would combine the strength of currently used external repair products or CRLP with the installation process currently used for liners in other types of pipelines. Adhesion of the liner to the pipe surface, which is important for structural reinforcement but not restoration of leak tightness, also needs to be addressed. The required thickness of a repair for structural reinforcement and the potentially adverse effect on in-line inspection and flow restriction must also be determined.

SURVEY OF OPERATOR EXPERIENCE AND INDUSTRY NEEDS

A survey of operator experience and industry needs pertaining to internal repair of gas transmission pipelines was developed. The purpose of this survey was to better understand the needs and performance requirements of the industry regarding internal repair. The survey was sent to a wide range of gas transmission companies, including member companies of PRCI, and other companies within the industry. The survey consisted of six parts; currently used repair methods, use/potential use of internal repair, need for *in-service* internal repair, applicable types of damage, operational and performance requirements for internal repairs, and general comments.

A total of 56 surveys were sent out mostly to a single main point of contact at each company. A total of 20 completed surveys were returned, representing a 36% response rate, which is considered very good (a 10% response rate is typical for tailored surveys). The results of the survey are summarized below.(3)

Survey Results

The survey results indicate that the most common type of currently used repair is the installation of welded full-encirclement steel repair sleeves. Other currently used repair methods include "cut out and replace," fiber-reinforced composite wrap repairs (e.g., ClockSpring®), and grind-out repairs. One response summarized the company's perspective in the following fashion: cut out and replace cylinder (seldom), full encirclement steel sleeves (most common), direct deposition of weld metal (seldom, but frequency may increase), grinding to remove gouges (common), and welding a plugged fitting (e.g., a Threadolet®) over the damage.

Only one company indicated that they had attempted repair of a transmission line from inside the pipe. This involved the use of plastic tight liners, and for lower pressure lines (less than 100 psig), the use of slip-lined plastic liners. Both of these methods require the line to be out of service when the repair is made.

Nearly all of the companies that responded to the survey indicated that, if internal repair was to become a proven technology, they would use it. The survey results also indicated that the use of internal deposition repair is most attractive for applications where conventional excavated repairs are difficult, such as at river crossings, under other bodies of water (e.g., lakes and swamps), in difficult soil conditions, under highways or congested intersections, and under railway crossings. Internal repair offers a strong potential advantage when the only other alternative to rectify a leak or other problem in a water/river crossing is, for example, line replacement that requires high-cost horizontal direct drilling (HDD).

Survey responses pertaining to typical travel distances required for an internal repair system can be divided into three distinct groups: up to 1,000 ft, between 1,000 and 2,000 ft, and beyond 3,000 ft. All three of these groups require pig- or crawler-based systems. Despooled umbilical systems could be considered for the first two groups. For the last group, a self-propelled system with an onboard self-contained power system would be required. Pipe diameter requirements range from 2 to 48 in. The most common size range for 80 to 90% of the operators surveyed is 20- to 30-in. diameter, with 95% indicating that they use 22-in.-diameter pipe. The system should be able to negotiate obstructions such as elbows, bends, branches, etc. The survey responses indicate that the line should remain piggable and that the thickness of the repair should not interfere with future in-line inspection operations. One response referred to DOT Code 49 CFR 192.150.(4) The majority of survey respondents considered it very important for the pipeline to remain in service while the repair was conducted, especially if their system was not looped.

EVALUATION OF POTENTIAL REPAIR METHODS

The technology status assessment identified two broad categories of repair that are potentially applicable to gas transmission pipelines from the inside: weld deposition repair and fiber-reinforced composite liner repair. Various options exist for these two broad categories of repair, e.g., various welding processes for weld deposition repair. An evaluation exercise(5) was carried out to determine which specific repair options should be emphasized in the experimental portion of this project. This exercise included the review of not only the two broad categories, but additional novel repair technologies that might be applicable to internal repair. This exercise involved the creation of a matrix of potential repair methods that was used to compare and contrast the various attributes of each option. Five major feasibility categories were included in the matrix: technical feasibility, inspectability of completed repairs, technical feasibility of the process while the pipeline is in service, repair cost, and industry experience with the repair method.

Each feasibility category was then subdivided into capabilities or characteristics to rank. Each capability/characteristic was assigned a unique weight factor to distinguish its importance in the overall repair process feasibility. Weight factors for each capability/characteristic were based on the survey responses that were received, with the sum of all weight factors being 100%. For each potential repair process, individual feasibility capabilities were rated on a scale from (-1) to (5). Each rating was then multiplied by its unique weight factor. The weighted scores were totaled to determine a composite score for each repair option.

The matrix of potential repair methods was subdivided into three technology-specific groups: potential welding repair methods, potential liner repair methods, and potential surfacing repair methods. Potential welding repair methods included gas-tungsten arc welding (GTAW), GMAW, flux-cored arc welding (FCAW), submerged arc welding (SAW), laser welding, and explosive welding. Potential liner repair methods included plastic-reinforced, steel coil, shape memory alloy, fiber-reinforced reeled composite, and solid expandable tubulars. Potential surfacing repair methods included electroless nickel, thermal spray, carburation, and explosive surfacing.

Figure 4 is a bar chart that contains the composite scores for each potential repair option. It is apparent that, of the three broad categories of repair (welding, liners, and surfacing), repair methods that involve welding are generally the most feasible. Of the various welding processes, GMAW is the preferred method. The primary factors that make GMAW the most feasible are process technical feasibility and robustness, and industry familiarity with the process. The second most feasible of the three broad categories is repair methods that involve internal liners. Of these, fiber-reinforced composite liners are the most promising. The primary factors that make fiber-reinforced composite liner repairs the most feasible are the ability to match the strength of the pipe material and negotiate bends, and their corrosion resistance. The advantage of using a fiber-reinforced composite liner is somewhat offset by material cost, which is anticipated to be comparatively higher than that of a steel coil liner.

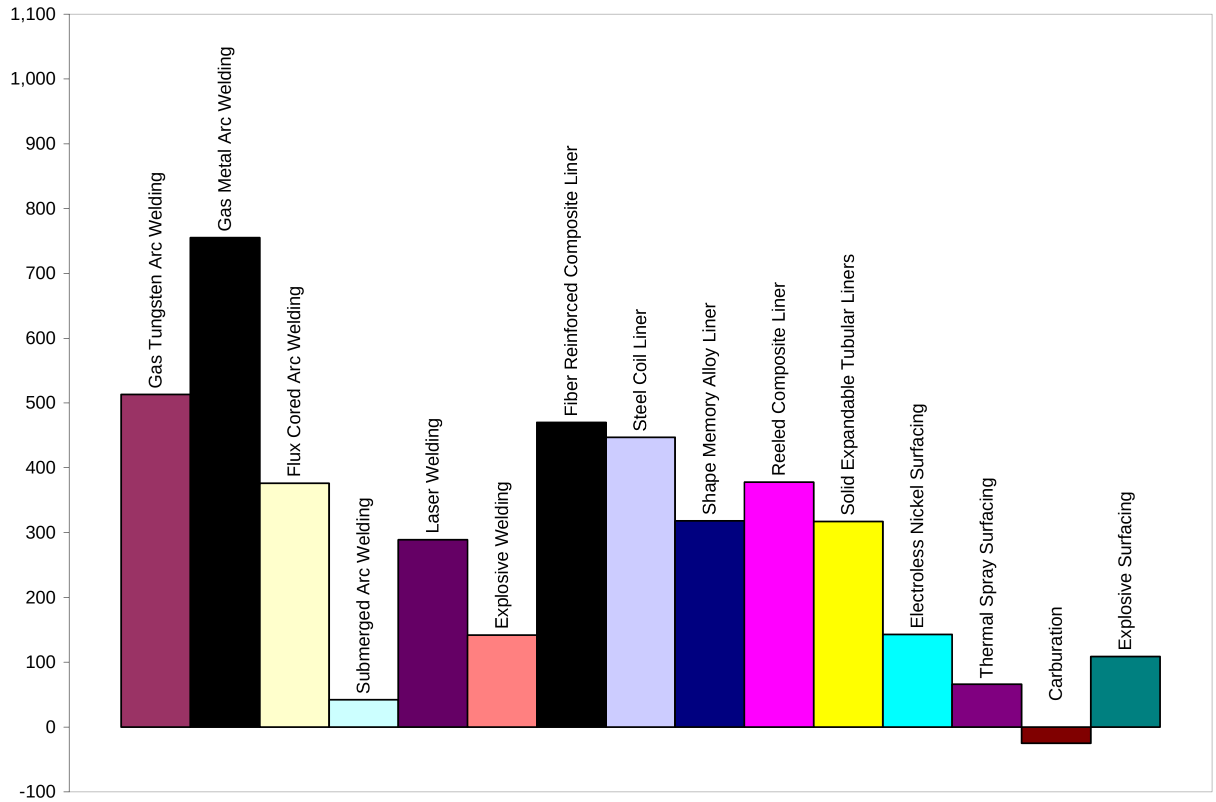

Figure 4 - Composite Score for Potential Repair Methods

Based on the results of this evaluation of potential repair methods, the experimental portion of the project is focusing on the development of repair processes that involves the use of GMAW welding and the use of fiber-reinforced composite liners.

FURTHER DEVELOPMENT OF CANDIDATE REPAIR METHODS

To date, experimental work has concentrated on the development of fiber-reinforced liners with the appropriate strength and stiffness and preliminary weld deposition parameters. This section describes the experimental program to further develop these methods for internal repair.(6)

Fiber-Reinforced Composite Liner Repairs

The initial test program for fiber-reinforced composite liner repair focused on the use of a modified version of an existing product manufactured by RolaTube, which was a bi-stable reeled composite material used to make strong, lightweight, composite pipe (Figure 5). When unreeled, it changes shape from a flat strip to an overlapping circular pipe that could be pulled into position. Following deployment, the longitudinal seam is welded with an adhesive that is activated and cured by induction heating. One example of this product is 4-in. diameter × 0.10-in. thick and is said to have a short-term burst pressure of 870 psi.

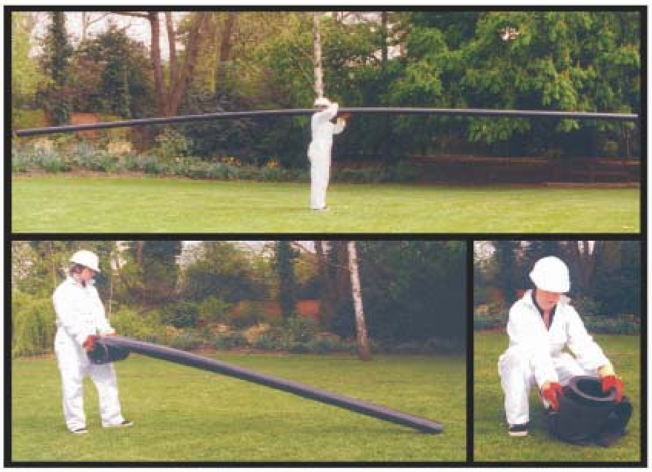

Figure 5 - RolaTube Bi-Stable-Reeled Composite Material

RolaTube developed a modified version of this product which uses nine plies of a glass-polypropylene material in the form of overlapping, pre-pregnated tapes of unidirectional glass and polymer. Glass-high density polyethylene (HDPE) material was also considered, but problems bonding the glass-HDPE material to steel were encountered. Heat and pressure were used to consolidate the plies of glass-polypropylene material into a liner. The resulting wall thickness of the liner is 0.11 in.

A supply of 4.5-in.-diameter × 0.156-in. wall thickness API 5L Grade B pipe material was procured and cut into four sections approximately 4-ft long. After the inside surface was degreased, lengths of lining were installed into two of the pipe sections. The installation process consisted of inserting a silicon rubber bag inside the liner and locating the liner inside the pipe. The silicon bag was then inflated to press the liner against the pipe wall. For these experiments, the entire pipe sections were then heated in an oven to approximately 400°F to fuse the liner to the pipe wall. Possible choices for liner installation in the field include infrared (IR) heaters on an expansion pig or a silicon bag inflated using hot air. An installed liner is shown in Figure 6.

Figure 6 - Liner Inserted into Center of 4.5-in.-Diameter Pipe

Using a ball end mill, long shallow damage representative of general corrosion was introduced into one pipe section lined with fiber-reinforced composite liner and one without. Using an end mill with rounded corners, short, deep damage representative of a deep, isolated corrosion pit was introduced into the second pair of pipe sections: one lined, one not lined. The dimensions of these areas were determined using the RSTRENG software(7), and represent a 30% reduction in burst pressure. Following the installation of end caps, all four pipe sections were hydrostatically pressurized to failure.

All four pipe sections failed in the areas of simulated corrosion damage. Both pipes with long shallow damage representative of general corrosion resulted in ruptures (Figure 7). The two pipes with short, deep damage representative of a deep isolated corrosion pit developed leaks. The failure pressures for the pipes with the liners were only marginally greater than the pipes without liners (i.e., 3472 vs. 3431 psi for the pipe samples containing long shallow damage and 4031 vs. 3750 psi for the pipe samples containing short, deep damage). This indicates that the liners were generally ineffective at restoring the pressure-containing capabilities of the pipes.

Figure 7 - Pipe Section with Liner Following Hydrostatic Pressure Test

A postmortem analysis was conducted on the four hydrostatic burst tests in pipe sections with simulated corrosion. To avoid damage the liner, water jet cutting was used to section the pipe sample containing the round-bottom longitudinal slot with the liner installed (Figure 8). The results indicated that the liner did rupture, and that disbonding was not an issue.

Figure 8 - Water-Jet Cut Section through Pipe Section with Liner

Further analysis indicated that the difference in modulus of elasticity between the steel and liner materials prevents the liner from carrying its share of the load. The modulus of elasticity for steel is approximately 30 x 10^6 psi. Tensile testing was carried out to determine the modulus of elasticity for the glass/polypropylene liner material that was used. The mean value for the modulus of elasticity for the liner material was measured to be approximately 2.2 x 10^6 psi. Because the liner material had a significantly lower modulus of elasticity than the steel pipe, as pressure in the lined pipe increases, the stiffness of the steel prevented the composite liner material from experiencing enough strain to share any significant portion of the load. Therefore, the mechanical properties of this line material were inadequate for internal pipe repair.

It is anticipated that a liner material with a modulus of elasticity that is closer to that for steel will be required for effective reinforcement of steel pipelines that have been weakened by wall loss defects (e.g., by eternal corrosion). A liner material with a modulus of elasticity that is just less than that of steel would allow the liner to carry its share of the load without putting the interface between the liner and the steel pipe in tension. If the modulus of elasticity for the liner material were greater than that of the steel pipe, as pressure in the pipe increases, the stiffness of the liner would prevent it from expanding with the steel pipe, putting the weak adhesively bonded interface in tension. If the adhesive layer between the pipe and the sleeve were to be broken, this would allow pressure into the annular space between the pipe and liner, allowing the pressure to act upon the defect-weakened area and rendering the liner useless.

Carbon fiber-based composite materials have a much higher modulus of elasticity than glass-based composite materials. The modulus of elasticity for commercial grade raw carbon fiber material is in the 30- $\times$ 10^6-psi range, but this is reduced significantly when a matrix material is introduced. High-grade, raw carbon fiber materials can have a modulus of elasticity that is in the 50- to 60- $\times$ 10^6-psi range. These high-grade, raw carbon fiber materials are expensive and scarce. Nonetheless, it may be possible to design a liner material that has a modulus of elasticity that is closer to that for steel even after the matrix material is introduced.

In spite of the high cost, the results of the survey of pipeline operators suggests that such a repair may still be useful for river crossings, under other bodies of water (e.g., lakes and swamps), in difficult soil conditions, under highways, under congested intersections, and under railway crossings.

Finite-element analyses are being carried out to determine the required properties of the liner material. Plans for the continued development of fiber-reinforced composite liner repairs include identifying a carbon fiber-based material that can be made into a suitable liner and repeating the experimental program described above. Following this, provided that the redesigned liner material is effective at restoring pressure-containing capability, an experimental program involving larger diameter pipe (e.g., 20 in.) will be undertaken.

Weld Deposition Repairs

The initial test program for weld deposition repairs focused on evaluating various commercially available systems for internal weld deposition using GMAW. These evaluation trials were also used to develop baseline welding parameters. A length of 20-in.-diameter $\times$ 0.312-in.-wall thickness API 5LX-52 pipe material was procured for these evaluation trials and positioned with the axis in the 5G (horizontal-fixed) position.

As welding progresses around the inside diameter of a pipe, the welding position transitions between flat, vertical, and overhead. The types of repairs that are envisioned are ring deposits to perhaps reinforce a defective girth weld, spiral deposits to repair an entire pipeline section, and patches to repair local corrosion damage. Torch travel for the former two types would best be achieved using orbital-type welding procedures where welding progresses continually around the circumference of the pipe. Patch repairs could be accomplished using a torch travel path that is either orbital or axial. Torch weaving, a technique that improves out-of-position weld bead shape, is also required. Weaving is commonly used in vertical-up welding to provide an intermediate shelf on which to progressively build up the weld deposit. For this application, the preferred metal transfer mode for GMAW was short-circuit transfer. This mode assures droplet transfer in all welding positions. Open arc droplet transfer that is provided by spray, pulse spray, and globular transfer are not suitable for orbital overhead welding where gravity promotes spatter instead of metal transfer.

Three welding systems were evaluated for use in the development of welding parameters for internal repair: an internal bore cladding system (Bortech), a six-axis robot capable of complex motion control (OTC Daihen), and an orbital welding tractor configured for inside welding (Magnatech Pipeliner). Each system has motion-control limitations and individually would not be appropriate candidates for an internal repair welding system. For example, the Bortech system was designed for spiral cladding the inside of a pipe that is preferable in the vertical position.

The Bortech system was selected initially because it is affordable, uses simple motors for motion, and has simple controls for operating constant voltage (CV) power supplies (Figure 9). It was necessary to purchase and install a counterbalance to offset the weight of the opposing torch.

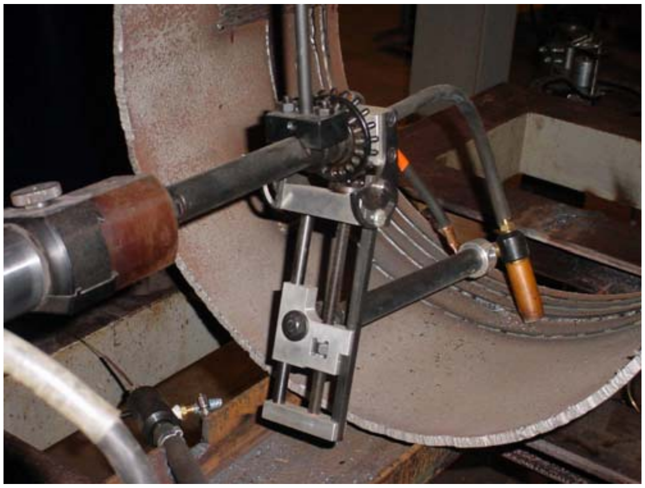

Figure 9 - Bortech Internal Bore Cladding System

Preliminary weld trials with the Bortech system using an 0.035-in.-diameter ER70S-6 filler metal (i.e., electrode) produced marginal results. Only stringer beads could be deposited using short-circuit transfer in the spiral-clad mode. With stringer beads, the deposition rate was low since only narrow beads could be deposited. The bead shape suffered the most in the overhead position when starting downhill. The Bortech system does not allow torch weaving, which is required to improve weld bead profile thus allowing higher deposition rates and improved fusion. In principle, the Bortech system could be made suitable for an internal repair system. Anti-backlash servo-motors and gears, and programmable controls would be required, as well as an additional motor drive to permit control of the torch and work angle.

Based on the results experienced with the Bortech system, it was decided to develop preliminary welding procedures using a robotic GMAW system. The use of a six-axis coordinated motion OTC robotic welding system (Figure 10) permitted the application of weave beads for spiral cladding, or for stringer beads, in either direction. The system did not have a commutater for welding torch current that would permit continuous spiral welding. The robot was interfaced to an advanced short-circuit power supply, the Kobelco PC-350, which uses fuzzy-logic pulse waveforms to minimize spatter during metal transfer and permits the application of variable polarity waveforms. Variable polarity combines the rapid, low heat input melting of a negatively charged electrode with the metal transfer stability of electrode positive.

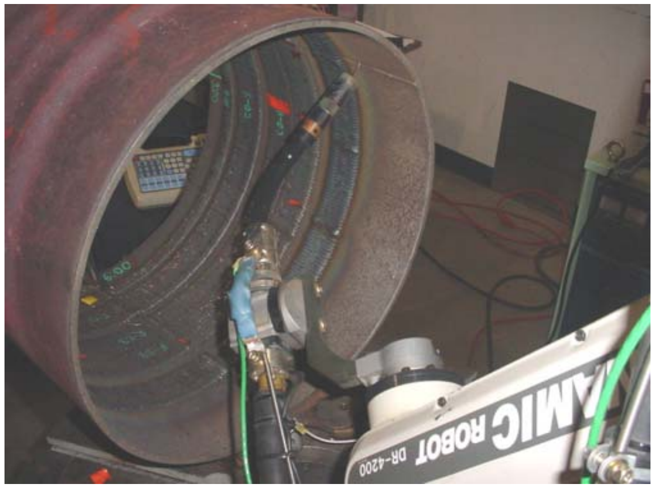

Figure 10 - OTC Robotic Welding System

The OTC robot welding system was used to develop preliminary repair welding procedures with the intent that they would be transferred to a different system for pipeline repair demonstrations. A range of orbital weave parameters were developed to establish an operating window, and to determine deposit quality and deposition rate. The ideal weld bead shape would have uniform thickness across the weld section except near the weld toes which should taper smoothly into the base material. Smooth toes promote good tie-ins with subsequent weld beads. The fusion boundary should be uniform and free from defects. Preliminary tests were also performed to evaluate bead overlap and tie-in parameters that would be required to make high quality repairs. All the welding tests were performed with a 95% argon-5% carbon dioxide shielding gas mixture using an 0.035-in.-diameter ER70S-6 electrode.

Using the robot welding system, orbital welding parameters using weaving were developed for several bead widths (Figure 11). The pipe is near room temperature when welding is initiated. In general, most weld starts appeared more convex because of this. The weld bead profile slowly changes as steady-state temperatures are achieved in the pipe wall. The development of welding parameters was based on optimizing the bead shape in the steady-state condition. In practice, a programmable weld controller could be used to increase the welding heat input at the weld start. This would provide better weld bead start quality. As steady-state temperatures are achieved, the start parameters could be transitioned to steady-state parameters to provide uniform bead shape.

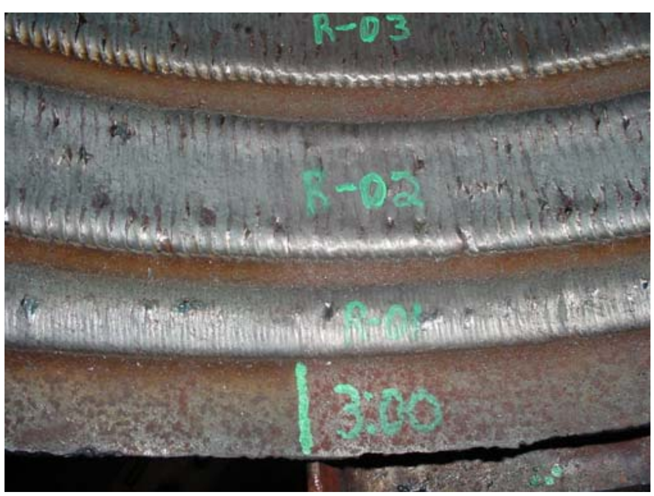

Figure 11 - Typical Bead Shapes in Steady-State Condition

Several years ago, PG&E purchased a welding tractor from Magnatech for internal weld deposition repair procedure development (Figure 12). Since the robot welding system is not portable, the Magnatech system was sent to EWI so it could be used for further parameter development and demonstrations. The Magnatech welding tractor has orbital motion with controls for torch oscillation. The system is limited to a finite number of revolutions that can be made before cables need to be unwound. The controls are analog and do not have high accuracy; however, they are sufficient for preliminary parameter development and demonstration welding.

Figure 12 - Magnatech ID Welding Tractor Capable of Spiral and Ring Motion with Oscillation

The Magnatech tractor was interfaced to a Panasonic AE 350 power supply, which provides pulse waveforms and can be operated in a short-circuit mode where artificial intelligence is used to minimize spatter. The current pulsing and short circuiting helps lower heat input and improve deposition rate in out-of-position welds. Pre-programmed current waveforms are provided by algorithms for steel electrodes and many other materials.

PG&E purchased this system specifically for repair welding of 22-in.-diameter pipe. For this project, a supply of 22-in.-diameter pipe was procured for further parameter development and demonstrations. The 22-in.-diameter pipe was made in the 1930s and has an asphalt coating. Plans for the continued development of weld deposition repair include transferring the successful welding parameters developed using the OTC robotic welding system to the Magnatech system. Trials will be undertaken that involve repair of simulated corrosion damage that will be introduced into the outside of the 22-in.-diameter pipe. Lengths of the 22-in.-diameter pipe will be placed in a soil box so that the transfer of heat from the welding process to the surrounding soil can be evaluated. Various types of soil will be included. The effect of internal weld deposition repair on coating integrity will also be evaluated. Completed repairs will then be subjected to hydrostatic pressure testing to evaluate the ability of weld metal deposited on the inside of the pipe to reinforce damage on the outside of the pipe.

Additional experiments will also be carried out to investigate the effect of methane in the welding environment on the integrity of completed repairs. The results of survey indicate that operators have a strong preference for the development of internal repair methods that can be applied while the pipeline remains in service. During any arc welding operation, the material being welded is exposed to temperatures that range from ambient to well above the melting temperature (2736°F). When steel at high temperature is exposed to a hydrocarbon gas (such as methane), carburization can occur. When steel at temperatures above 2066°F is exposed to methane, eutectic iron can form as the result of diffusion of carbon from the methane into the steel. In previous work at EWI,[(8)] in which welds were made on the outside of thin-wall pipe containing pressurized methane gas, carburization and the formation of thin layer of eutectic iron occurred (Figure 13). This phenomenon was previously reported by Battelle during experiments with liquid propane.[9] There were also small cracks associated with the eutectic iron layer, which were attributed to the limited ductility of eutectic iron.

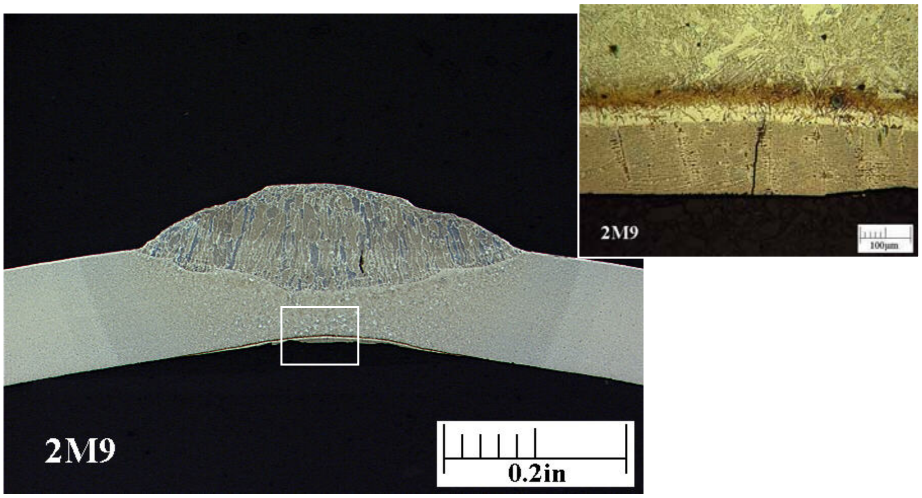

Figure 13 – Metallographic Section through Weld with Eutectic Iron Layer

SUMMARY AND CONCLUSIONS

Repair methods that can be applied from the inside of a gas transmission pipeline (i.e., trenchless methods) are an attractive alternative to conventional repair methods since the need to excavate the pipeline is precluded. The results of an industry survey and an evaluation of repair methods that are potentially applicable to gas transmission pipelines from the inside indicate that both weld deposition repair and fiber-reinforced composite liner repair are attractive options.

Initial development of reinforced composite liner repairs focused on the use of a glass-polypropylene composite material. Experimental results indicate that a liner material with a modulus of elasticity that is closer to that for steel will be required for effective reinforcement of pipelines that have been weakened by wall loss defects (e.g., by eternal corrosion). Initial development of weld deposition repairs has focused on determining system requirements for internal weld deposition using GMAW and on developing baseline welding parameters. A programmable weld controller will be required to provide adequate weld quality at the weld start and at tie-in location, and to achieve uniform steady-state bead shape. Activities to further develop both of these repair methods that are potentially applicable to gas transmission pipelines from the inside are planned.

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