Development of a Remote External Repair Tool for Damaged or Defective Polyethylene (PE) Gas Pipe

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ABSTRACT

Repair methods for polyethylene gas pipe are being investigated at Timberline Tool and Oregon State University under a cooperative agreement with the Department of Energy National Energy Technology Laboratory. Current repair procedures for polyethylene (PE) gas pipe require excavation, isolation, and removal of the damaged section of pipe followed by fusing a new section of pipe into place. The project will develop a method for repairing damaged PE pipe in situ, eliminating the need for large-scale excavation and replacement of pipe sections. The tool will incorporate heat fusion of a chemical patch to repair small nicks, gouges and punctures and will be operable through keyhole access, as well as more general application environments. The remote repair tool will enable the safe, rapid and cost-effective repair of damaged or defective PE gas pipes. This paper reviews the initial design and development of the mechanical device and two chemical processes for repairing damaged PE gas pipe.

BACKGROUND

The use of polyethylene (PE) pipe for natural gas transmission and distribution within the United States has been steadily growing over the past decade and currently accounts for a majority of America's natural gas distribution network. It is very important that the natural gas delivery system remain safe, reliable, and operate efficiently. The current delivery system consists of 650 thousand miles of underground plastic piping that has been in service for over 30 years. The AGA report, "Fueling the Future" [1], predicts that natural gas consumption will grow as much as 50 percent over the next 20 years. To meet this demand, the number of miles of distribution and transmission polyethylene (PE) pipe will increase (**See Figure 1**). According to Department of Energy reports [2], there exists a special need for improved

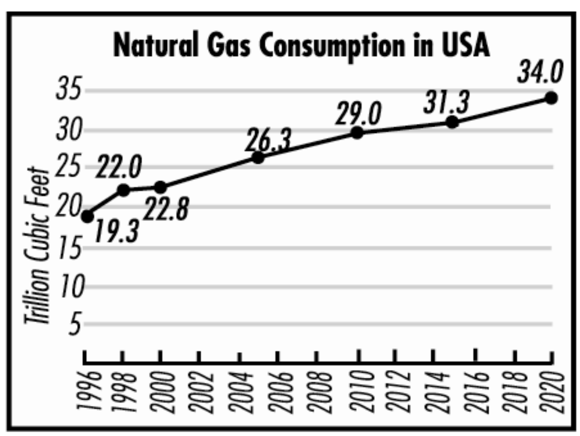

Figure 1

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tools for construction, maintenance, and repair of PE pipe to keep up with the expected growth.

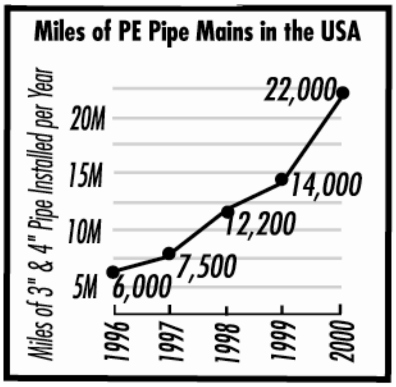

Figure 2

This project responds directly to this critical need. The project will develop a remote external repair tool to be utilized by the natural gas industry for repairing damaged or defective polyethylene (PE) pipe. The repair tool will be developed for 4-inch distribution size pipeline because it is commonly used in pipeline installations each year (**See Figure 2**). Only minor re-engineering will be required to adapt the tool concept for use on other pipe sizes.

The remote repair tool will allow the operator to repair the damaged or defective PE pipe externally without shutting off the flow of gas. The unique, curved jaw design perfectly matches the contour of the pipe, thereby encapsulating the outside wall. At the same time, the leak is stopped as the repair patch attached to the curved jaw is applied (**See Figure 3 & Figure 4**). The tool design allows the operator to deliver the repair patch (polyethylene gel or polyethylene adhesive) to the PE pipe and permanently repair the damaged area. The remote repair tool will keep the operator out of the trench and away from the escaping gas during the repair process, insuring the safety of the operator.

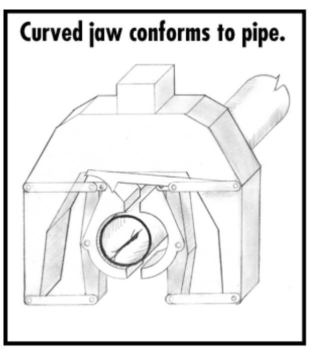

Figure 3

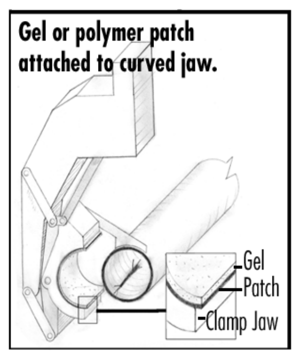

Figure 4

If a pipeline of greater than ¾-inch diameter is damaged more than 10% of the wall thickness, or if the pipe wall has been fully penetrated, current procedures for repairing buried natural gas pipe require excavations upstream and downstream from the rupture and isolation of the damaged section of pipe by “squeezing off” the flow of gas on both sides of the damage. Then the damaged section of pipe is excavated and cut out of the line, and replaced with a mechanical repair fitting or a new segment using either two couplings or a fusion joint and a coupling. These repair procedures are time consuming and expensive.

This new repair tool will operate remotely from the top-down, without the need to fasten the device under the pipe. This will dramatically improve the safety and repair procedures because only one operation and one excavation will be required. This will eliminate the need for additional excavations. The repair tool will be portable and lightweight, allowing for single person operation. It will operate in difficult and keyhole access situations without the need for squeeze-off. The repair tool technology being developed will operate remotely from the ground surface (**See Figure 5**) keeping the operator out of the trench, away from the danger of cave-in and flowing natural gas. The safety of the utility operator is the most important benefit of this repair tool. Another key benefit of the repair tool is the ability to operate the tool in "keyhole" excavations. These types of excavations minimize the impact to the surrounding environment and disruption to the neighborhood. Time and labor savings due to reduced excavation and ease of application are expected to be significant.

Maintenance and repair costs will be significantly lowered by the increased efficiency of the new tool during pipe repair operations. Current standard operating procedures for repairing natural gas pipelines require hours to accomplish. The proposed repair tool will allow the natural gas operator to repair the PE pipe at the site of the damage without additional excavation, and without shutting off the gas supply and interrupting the natural gas distribution to homes and businesses. By perfecting this repair process, thousands of pipe leaks can be repaired at a fraction of the current remediation cost that is estimated at $3.5 billion per year [3]. Recent advancements in excavation techniques using keyhole technology lessen the impact to the environment and society. Repair tools must now be developed to reduce costs associated with pipe repairs in these situations.

Figure 5

OBJECTIVES

The overall objective of this work is to develop a remote repair tool with unique chemical and mechanical processes to apply a permanent external repair patch to damaged or defective buried polyethylene (PE) natural gas pipe. This work will demonstrate the functionality and test the performance of a fully engineered prototype repair tool in laboratory and field tests.

SCOPE OF WORK

The research effort consists of experimental and analytical studies to develop a new technology to repair damaged PE pipe by using a mechanical tool to apply a repair patch (polyethylene gel or polyethylene adhesive) over the compromised area. Specific design goals for the tool include: lightweight construction; top-down application; hydraulic or manual operation from ground level; operable in confined space or keyhole opening; and effective operation on 4-inch diameter PE pipe.

This project will be performed in two Phases – Phase 1 will be completed in March 2005 and Phase 2 will be completed in March 2006. During Phase 1, the project team will design, fabricate and perform in-house and field tests on one or more repair tool configurations to determine the functionality, safety and reliability. Laboratory tests (quick-burst tests and sustained pressure tests) will be performed on repaired PE pipe sections to determine the overall performance of the test tools, and the quality and adequacy of the repair. During Phase 2, the project team will use information gained in Phase 1 to guide the construction of one or more engineered prototype repair tools. In-house and field tests will be performed on the engineered prototypes and laboratory tests will be performed on repaired PE pipe sections using the same testing protocol and procedures as Phase 1. This work will be conducted at Timberline Tool's facilities in Kalispell, Montana, Oregon State University Chemical Engineering Department in Corvallis, Oregon and KeySpan Energy Delivery facilities in Long Island, New York. The project team is currently examining two concepts for repairing PE pipe. Both concepts apply an external patch to the damaged pipe using a mechanical device.

The first concept, polyethylene gel bonding, uses a gel containing a bonding agent attached to a PE patch (thickness depends on application) to join the surfaces of the PE patch material and the damaged PE pipe. This phase of the research is being conducted to fulfill the project objectives to find a polyethylene gel to bond polyethylene-to-polyethylene natural gas pipe. Further, the bond will able to withstand at least 500 psi in shear strength. Although many different gels were considered, the investigation focused on two solvents for use in the polyethylene gel. Several HDPE samples were successfully bonded using HDPE gel, and subsequently tested for shear strength in an Instron machine. **Figure 6** shows the results from two samples prepared and pulled using two non-relaxed samples. The samples in **Figure 6** were prepared at 110 deg C with a cure time of two hours.

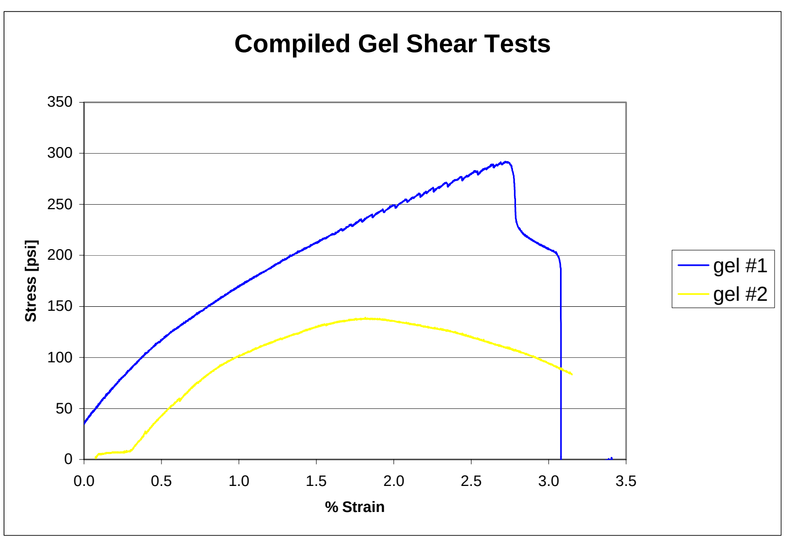

Figure 6: Early Shear Test Results

Photos were also taken of the cross-section of the bond joint, as well as the surface of the fractured bond surface. **Figure 7** shows the cross section of the bond joint. This photo shows that the gel creates a relatively seamless joint with the sample. An ideal bond joint would be difficult to differentiate from the sample itself.

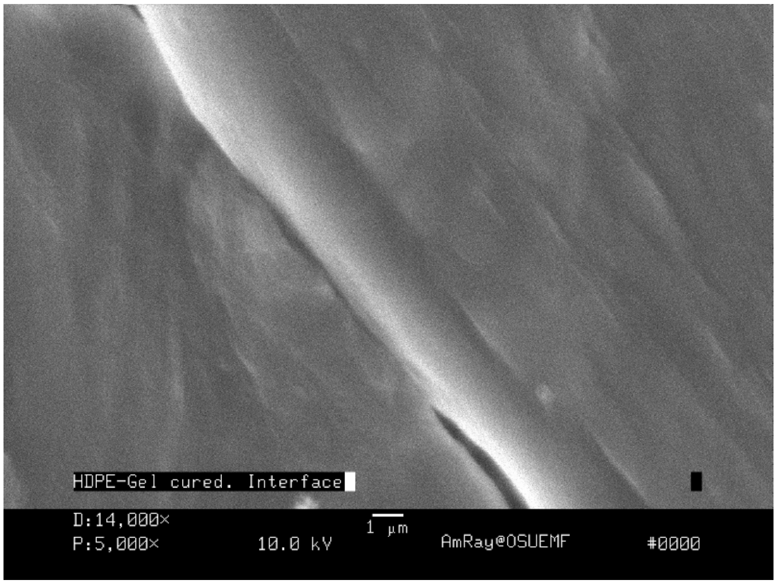

Figure 7: SEM Bonded Cross Section

As the design for the gel progresses, the two fixed parameters (pressure and gel composition) may be varied. Gel composition includes choice of solvents, choice of polyethylene density, and relative constituent concentrations.

The second concept, polyethylene adhesives, utilizes structural plastic glues to join the surfaces of the PE patch and the damaged PE pipe. This phase of the research is being conducted to fulfill the project objectives to find an adhesive that will bond polyethylene-to-polyethylene natural gas pipe. Further, the bond will be able to withstand at least 500 psi in shear strength. Although many different adhesives were considered, the investigation focused on three structural plastic glues.

For each of the three glues the strength of the bonds was tested with an overlap shear test. This is a generic test, often used in industry and research, because the geometry of the joint is simple. In the test, the sample is held and pulled at a constant rate to cause shear stress in the overlap joint. The joint may be capable of either cohesive or adhesive failure. **Figure 8** shows the results of these shear tests.

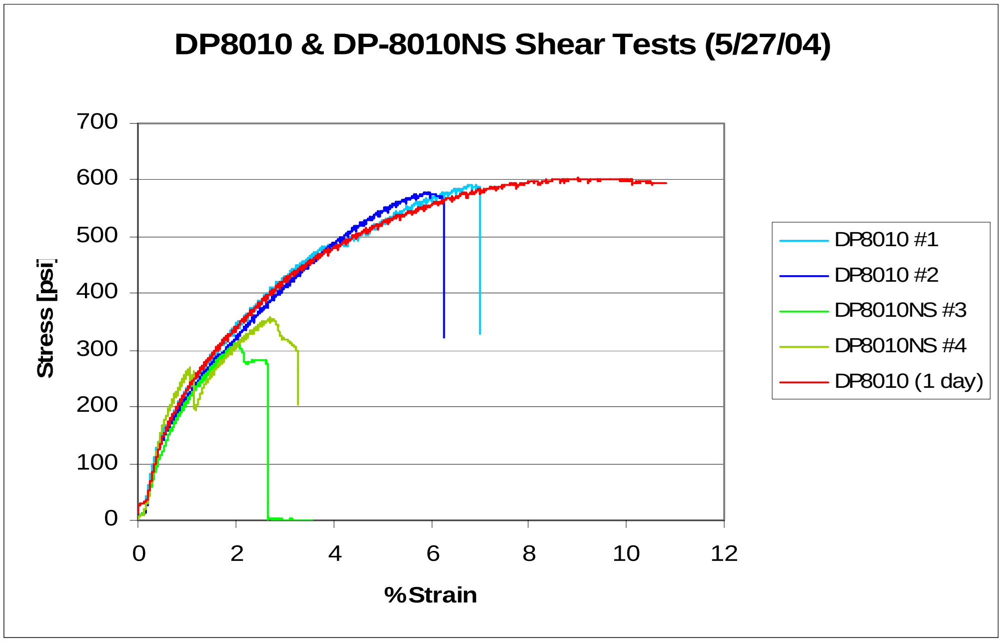

Figure 8: ***DP-8010 and DP-8010NS cured at*** $80°C$ ***for 90 minutes in the Carver Press. One DP-8010 sample cured at*** $80°C$ ***for 24 hours in the Carver Press (this sample did not break).***

The best adhesive results occurred when some pressure was applied during curing. Further experiments will be conducted to narrow the range of pressure necessary for the best strength in the adhesive joint.

Our initial investigation indicates that one of the structural plastic glues will be suitable for use in patching natural gas pipes. **Figure 9** shows the bond we are attaining. This figure shows the glue interface under 1650X SEM magnification.

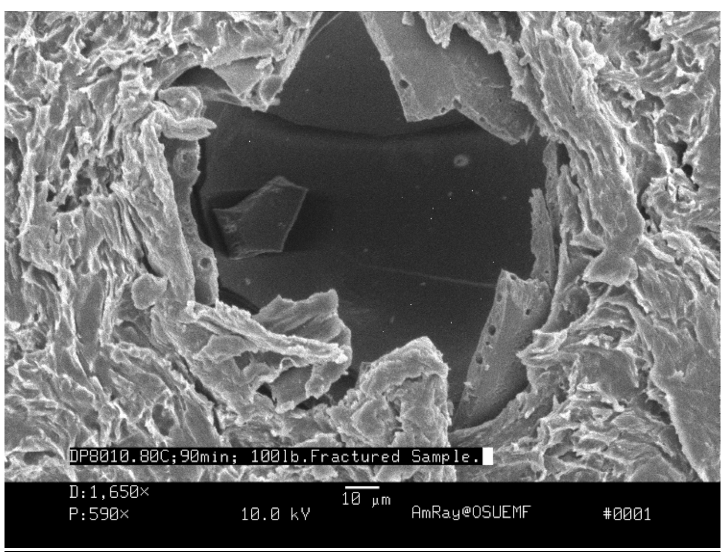

Figure 9: ***Sample 1 cured at 80°C for 90 minutes in Carver Press with 50 lbs pressure. Glass sphere broken during shear test. 1650x magnification.***

Further experiments will involve applying the patch to a damaged section of pipe. Subsequent burst tests will be performed on the repaired pipe sample to determine how much pressure the patch can withstand. Additionally, contact angle analysis will be conducted on the sanded surface of both HDPE and MDPE to determine the extent of surface modification necessary for an optimum bond. Based on the outcome of this research, the sample preparation may need to be modified.

Various conceptual designs were developed for the mechanical tool to apply the chemical patch to the compromised area on the PE pipe (**See Figure 10**). The next step involved 3D modeling of the optimum design to meet the project objectives for remote operation, keyhole application, and to ensure compliance with natural gas industry operating practices. The optimum design included a mechanical aluminum tool with jaws open on the end to allow for top-down application; a curved jaw configuration for encapsulation of the pipe at the area of damage; jaws capable of heating the patch; and a closing mechanism on the tool for applying slight pressure (approximately 10 psi) to the pipe being repaired.

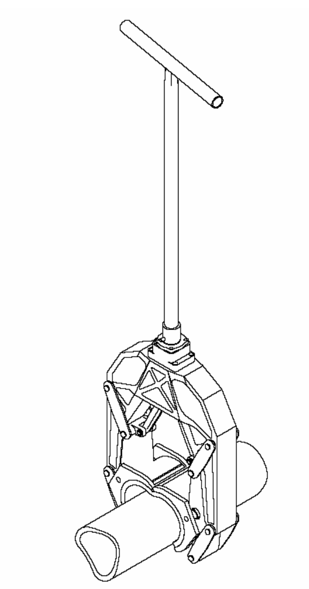

Figure 10

The completion of the project will involve construction of an engineered prototype. Laboratory and field tests will be performed on the prototype and repaired pipe samples under well defined testing and operating procedures of natural gas distribution systems. The effectiveness of the design will be reviewed and modifications made to improve performance as necessary for the safe, rapid, cost effective repair of damaged or defective PE gas pipe. The tool will incorporate heat fusion of a chemical patch to repair small nicks, gouges and punctures and will be operable through keyhole access, as well as more general application environments.

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