Development of a Keyhole Squeeze-off Tool to Enable the Repair of Large (4 and 6-inch) Polyethylene Gas Pipe

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ABSTRACT

Due to the expanding use and progressive aging of natural gas polyethylene (PE) pipelines in the United States, there is a critical need for safe, reliable and cost effective repair. The natural gas industry is moving to "keyhole" repair methods to maintain these pipelines because current repair procedures are time consuming and expensive. The critical first step in gas line maintenance and repair is to stop the flow of natural gas using PE pipe squeeze-off tools.

Through research and development with the Department of Energy (DOE) Small Business Innovation Research, Timberline Tool has successfully developed and tested a new squeeze-off tool that provides natural gas utility operators with the means to squeeze-off large (4 and 6-inch) PE pipe in "keyhole" situations. The use of keyhole excavations in place of open trench excavations improves utility worker safety by reducing exposure to trench wall collapse. Timberline's new keyhole squeeze-off tool increases worker safety and speeds the repair of pipeline breaks thus reducing the cost and time required to repair these large pipelines.

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EXECUTIVE SUMMARY

With more than a million miles of natural gas transmission and distribution pipes traversing the United States, the Department of Energy has placed a high priority on developing technologies and tools that contribute to safer, more efficient maintenance. The natural gas industry is currently moving toward keyhole technology for maintaining this vast infrastructure. Similar to arthroscopic surgery, keyhole technology allows the buried natural gas pipe to be accessed or repaired through a small (18-inch diameter) keyhole above the pipe. It eliminates the need for extensive and disruptive excavation with a backhoe or other large equipment at the repair site. Specialized tools are necessary for operators to access the buried pipe and make repairs through small "keyhole" openings.

Timely repair of a leaking natural gas pipeline is of critical importance to the safety, reliability and cost effectiveness of the United States' natural gas pipeline system. The first step in repairing polyethylene (PE) gas pipe is to squeeze off the flow of gas. Squeeze-off tools are available for use on smaller natural gas pipe (between ½" and 2") for conventional and keyhole excavations. However, squeeze-off tools for repair of larger gas pipe (4" and 6") are not available. The primary objective of the work described in this report was to develop, test and construct an engineered prototype tool to safely squeeze-off 4" and 6" gas pipe in keyhole situations. Initial research focused on determining the optimum squeeze bar configuration for the new tool and the amount of force required to bring the pipe to different degrees of compression with varying parameters such as temperature, squeeze rate and jaw size. Based on the results, various mechanical designs suitable for keyhole applications were studied by Timberline Tool engineers.

The double-actuated design using a top-down approach was selected and an engineered prototype was constructed. All components for the construction of the tool were designed and subsequently modeled in a stress analysis program prior to machining with a CNC vertical mill. Functionality tests on the engineered prototype tool as well as integrity tests on squeezed pipe sections were conducted according to ASTM standards for the safe squeeze-off of polyethylene pipe.

Field evaluations of Timberline's new tool at seven natural gas companies operating in the United States demonstrated significant advantages over conventional methods used to squeeze-off large diameter natural gas pipe. The new tool's design is lightweight, a single operator can manage it, and it keeps workers out of the trench. Excavations are kept to a minimum (the tool can reach into a hole as small as 18" in diameter) which lessens the monetary and environmental impacts of pipeline repair. Timberline's new squeeze-off tool is a significant breakthrough for the natural gas industry because it reduces the cost and time required for repair of pipelines and increases the safety of pipeline operators.

INTRODUCTION

Background

With more than a million miles of natural gas transmission and distribution pipes traversing the United States, the Department of Energy has placed a high priority on developing technologies and tools that contribute to safer, more efficient pipeline maintenance. The natural gas industry is currently moving toward keyhole technology for maintaining this vast infrastructure.

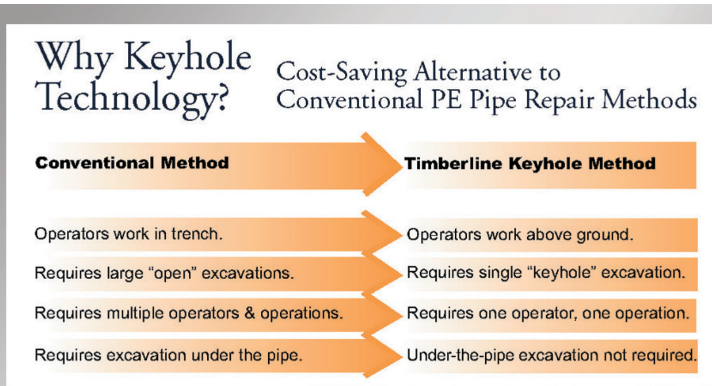


Figure 1: Advantages of keyhole excavation over conventional excavation to access and perform repairs on buried pipe

Figure 2: Timberline's Keyhole Solution

Keyhole technology uses small "keyhole" excavations to access and perform repairs on natural gas pipe providing significant advantages (Figure 1) over conventional open-trench excavations, which typically cover an area about three feet by five feet. Open-trench excavations are expensive, especially in urban areas when the pavement must be cut and restored. These excavations require several large pieces of equipment and can account for 80% of the total cost of a repair job. Similar to arthroscopic surgery, keyhole technology enables crews to remain above ground while working on buried natural gas pipe through an 18" hole. Specialized tools are required to allow operators to access the buried pipe and subsequently make repairs through these small "keyhole" openings (Figure 2).

Advances in Geographic Information System mapping, Global Positioning System locating, ground probing radar, electromagnetic detection and acoustic technologies make it possible to accurately locate PE pipe without open trench excavations. After locating the pipe, new keyhole excavation techniques make use of vacuum equipment to dig a precise hole 18 inches in diameter. These systems remove a reusable “plug” of pavement, sod or topsoil using a special hole saw and then continue excavating down to the depth of the buried pipe by loosening the soil with an air lance or water jet. The loosened soil is evacuated and held for return after work on the pipe is completed. This type of excavation is found to be less expensive and faster while removing minimal material from the site. The keyhole excavation method provides economic benefits to society by reducing the direct cost of repair as well as the indirect cost of loss of natural gas service due to pipeline damage.

The need for PE pipe squeeze-off tools in keyhole access situations

Once keyhole excavation is complete, a squeeze tool is required to completely stop the flow of natural gas. Proper squeeze-off of PE gas pipe is the critical first step in the repair process. After repair of the pipe, squeeze-off is released, allowing the flow of natural gas to resume. When squeezed with a well designed tool made to specifications determined by the pipe size and wall thickness, the pipe retains its structural integrity. As a result, large natural gas grids need not be interrupted and service can remain intact for all customers except those in the immediate area.

The squeeze-off technique is now routinely used by the natural gas industry for repair of PE pipe and is the first and most important step in any repair situation. Over one half-million PE pipe squeeze-offs are performed annually according to the *User’s Guide on Squeeze-Off of Polyethylene Pipe*.

The adoption of keyhole excavation technology brings with it the need for specialized tools to correctly squeeze-off PE pipe from ground level and operate in a small 18-inch diameter hole. A vital need for the natural gas industry is a tool that has the capacity to squeeze-off 4 and 6-inch diameter PE transmission and distribution lines in keyhole access situations.

EXPERIMENTAL

Project Objectives

The goal of this effort was to develop a tool to squeeze-off 4 and 6-inch polyethylene (PE) gas pipe in keyhole situations. The design of the new keyhole squeeze-off tool was based upon previously published research by the Gas Technology Institute that suggested increased squeeze bar radius more effectively and safely stops the flow of natural gas in PE pipe. The design also included a

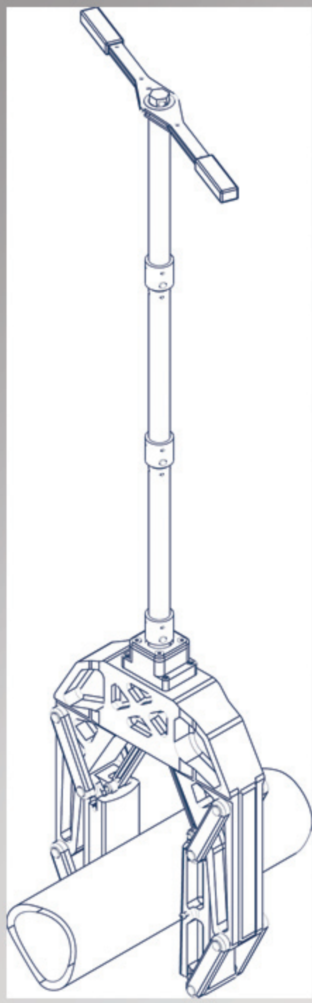


Figure 3: Top-down approach to squeeze-off PE pipe

top-down approach for squeezing off the PE pipe (Figure 3). Structural analysis of the engineered prototype with different jaw curvatures, computer modeling, and testing in laboratory and field environments resulted in development of a new mechanical design capable of providing the forces required to accomplish safe, reliable and cost effective squeeze-off of 4 and 6 inch PE pipe. The approach included detailed engineering analyses, rigorous and carefully controlled laboratory tests and a field-testing program with natural gas partners.

Summary of Task Descriptions

Task 1: Polyethylene Materials & Compression Testing and Analysis: This task determined the forces required to squeeze-off pressurized PE pipe using large diameter jaws.

Task 2: Design the Engineered Prototype Squeeze-off Tool: An engineered prototype was developed based on results from Phase 1 laboratory and field evaluations and the results from Task 1 above.

Task 3: Design and Engineering of Prototype Parts: The engineered prototype tool was completely designed using 3D solid CAD (computer aided drafting) and CAM (computer aided machining) software packages. Representations of the components were virtually machined to produce a program specifically designed for this squeeze-off tool. Utilization of these engineering software packages greatly reduced the time and complexity of machining many of the components for the engineered prototype.

Task 4: Machining and Finishing of Engineered Prototype Parts: The engineered prototype parts were machined and finished using CNC (computer numerical control) equipment.

Task 5: Engineered Prototype Tool Assembly: Eight engineered prototypes were assembled and functionality tests were completed. Subsequent laboratory and field tests were performed to verify the viability of the engineered prototype squeeze-off tool design.

Task 6: Laboratory Testing of Engineered Prototype Tool: Laboratory tests were performed on 4 and 6-inch squeezed polyethylene (PE) pipe sections. These samples were obtained from pipe squeezed at Timberline Tool facilities and from pipe squeezed during field tests.

Task 7: Field Testing: Field tests were performed to determine the functionality of the engineered prototypes under a broad range of field conditions.

Task 8: Safety and Integrity Testing of PE Pipe: Accelerated age testing on squeezed PE pipe samples was performed to assess the long-term safety and structural integrity of pipe samples squeezed with the engineered prototype.

Task 9: Technical Assessment of the Engineered Prototype Tool: The entire project team assessed the technical merits of the engineered prototype in preparation for certification and commercialization of the final product.

Task 10: Reporting: All reports were submitted to DOE as required. Close communications with DOE representatives was maintained during the course of the project.

Task 11: Commercialization Plan: A commercialization plan was developed for the new squeeze tool for 4 and 6-inch pipe. The plan included manufacturing facilities and equipment, marketing and sales strategies, and financial requirements.

Detailed Task Descriptions

Task 1 – Polyethylene Materials & Compression Testing and Analysis:

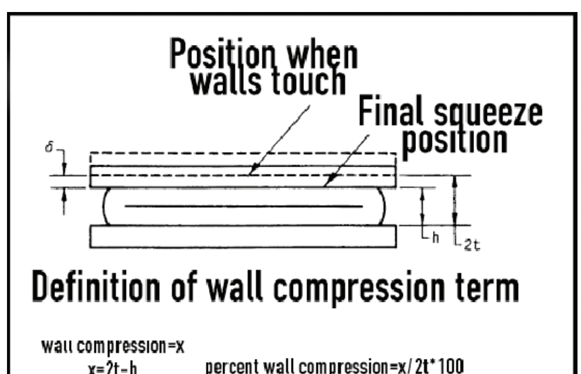


Figure 4: Pipe wall compression formula

The work done by Battelle Laboratories for the Gas Research Institute and reported in the GRI topical report, GRI 94/0205, indicated that squeeze-off tool jaw face profiles have a significant impact on the force needed and the amount of pipe wall compression needed to effectively seal-off the gas flow. The report clearly showed that values of wall compression ranging from 10 percent to 30 percent may be necessary when using different jaw profiles and different pipe diameters. Percentage of compression is calculated by formulas in Figure 4. The study also showed that for circular jaw profiles the required wall compression for sealing decreases with an increase in squeeze bar diameter. It further stated that contouring the squeeze-bar might be desirable to achieve a more uniformly distributed wall compression.

Because the exact wall compression is variable for stopping flow – closure forces depend upon the squeeze-bar shape – experimental investigation was conducted to provide both a suitable squeeze-bar profile and to accurately determine the forces required for the squeeze-off tool. Experiments focused on squeeze-bar face profiles, wall percent compression at seal, and the applied force to create a seal. This work was carried out on medium density (MDPE) polyethylene pipe with diameters of four inches and six inches.

Using the Baldwin Compression Test Machine, jaw profiles were tested on pipe that was pressurized at two levels, 60 psig and 100 psig. One jaw profile that was tested had a flat center with rounded edges because sealing with flatter squeeze-bar shapes reduces the amount of wall compression needed to seal the pipe. Compression force was monitored during squeeze-off and maximum values recorded for wall compression values of 5%, 10%, 15%, 20%, and 25%. To ensure experimental reliability tests were performed on two different pipe diameters, (4" and 6") and two different wall thickness values (SDR 11.5 and SDR 13.5). During wall compression, material relaxation effects become evident. This experiment was performed to measure this rate and the possible influence material relaxation would have on achieving an effective squeeze off with the different jaw profiles.

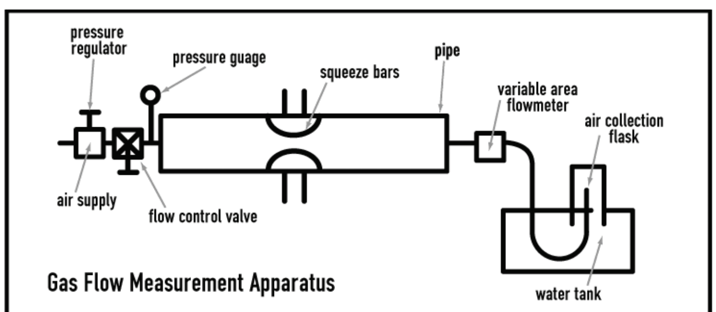


Figure 5: Diagram of direct reading variable flow meter

Jaw face profiles were machined to enable their installation in the Baldwin Test machine. The pipe samples, approximately four feet in length, were installed between the compression jaws. A direct reading variable flow meter was used to monitor and control the flow rate through the squeezed pipe. Once the flow meter indicated that significant sealing had occurred, the airflow through the squeeze-off point was determined by using the gas flow measurement apparatus proposed in ASTM F1563, which is a timed volume collection device (Figure 5).

During collapse of the pipe wall, the force and displacement of the wall was collected by an Agilent 34970A Data Acquisition/Switch unit interfaced with a 900.Mhz PC and data was downloaded to an Excel spreadsheet for processing and presentation. The Baldwin Test machine was equipped with 0 to 10 volt analog outputs. The load cell had 0 to 200,000.lb range with less than 1% FS error and the stroke had 0 to 12 inch range with 0.002-inch accuracy. The compression jaw movement rate was infinitely adjustable from 0 to 4 inches per minute maximum closure rate.

Prior to the start of each pipe sample test the actual wall thickness of the pipe was determined with calipers and compression proceeded until the distance between the jaw faces reached a minimum value that is 75% of twice the original wall thickness. This was the maximum extent of wall compression (i.e. 25% wall compression). Jaw separation distance was also separately monitored using a dial indicator mounted on the side of the jaw. This provided resolution of wall separation to 0.001 inch.

Once the walls touched, the compression force needed to achieve five distinct wall compression values ranging from 5% to 25% was recorded along with the corresponding squeeze-off leakage airflow rate. Since pipe material relaxation effects cause the initial applied force to fall off with time, the leakage flow rates were not recorded until this effect had stabilized. The final force value and the time required were also recorded.

Because the exact wall compression to seal PE pipe is variable, closure forces and compression are dependent on the squeeze-bar shape, the PE material to be compressed, and the temperature of the PE material. Tests were carried out on 4 and 6 inch diameter medium density PE pipe (MDPE) at 32°F (0°C), 73°F (23°C) and 110°F (43°C) to determine these factors.

The engineered prototype jaw profiles were tested on pipe that was pressurized at 85 psig. Compression force was monitored during squeeze-off and maximum values recorded for wall compression values of 5%, 10%, 15%, 20%, and 25%. The pipe compression values corresponding to incipient flow squeeze-off were established. Tests were performed on MDPE pipe of two different pipe diameters (4 and 6-inch), and two different wall thickness values (SDR 11.5 and SDR 13.5). Prior to the start of each pipe sample test, the actual wall thickness of the pipe was measured using calipers.

Three test replications were performed on each of the following combinations: Pipe diameter, wall thickness, pipe material, and percentage of compression; 5%, 10%, 15%, 20%, and 25%. All tests were performed in general accordance with ASTM F1562, including Appendix XI, and ASTM

F1734. Scanning Electron Microscopy (SEM) was used to inspect one each of the three specimens tested for squeeze-off functionality at 180-degrees from the area of highest induced strain. The inspection identified and documented any changes in the surface of the PE material due to the squeezing operation, specifically inspecting for micro-cracks, stress whitening, and other possible changes. This study focused on the characteristics of medium and high density polyethylene pipe, the forces necessary for compression, and the pipe area squeezed off to determine whether compression caused any long-term affects to the polyethylene.

Task 2 – Design of Engineered Prototype Squeeze-off Tool:

The initial conceptual designs (Figure 6) for the squeeze-off tool were based upon the Gas Research Institute report, “Guidelines and Technical Reference on Gas Flow Shut-Off in Polyethylene Pipes Using Squeeze Tools” which states that, “As squeeze-bar size increases, the flow shuts off at a smaller value of wall compression.” The design builds on the guideline that a lesser amount of wall compression is needed to achieve flow stoppage when using wide clamping jaws rather than narrow jaws.

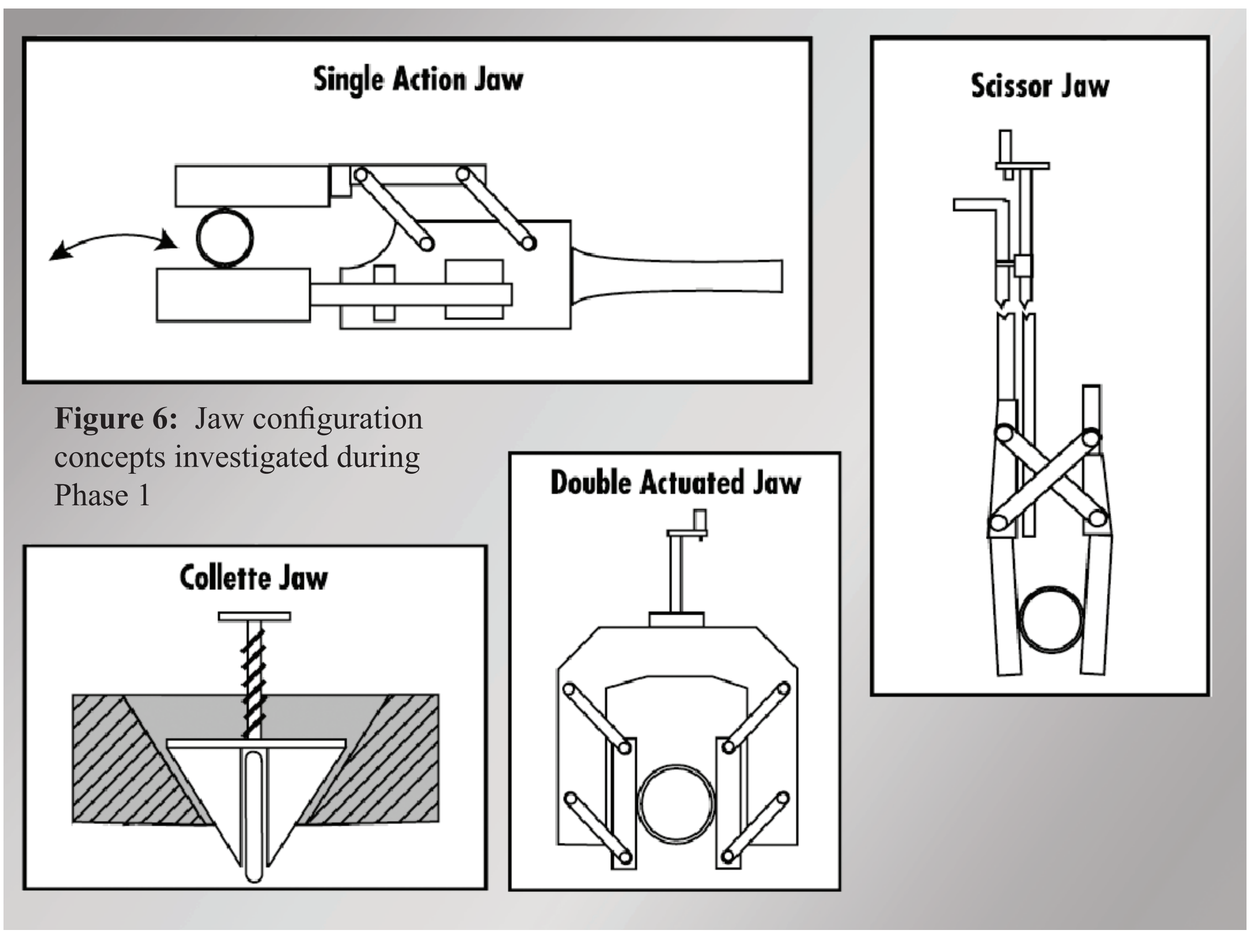


Figure 6: Jaw configuration concepts investigated during Phase 1

Several design concepts for the tool were investigated during Phase 1 and involved four different jaw configurations shown in Figure 6. These concepts were evaluated for desired jaw motion, relative size, and overall complexity. All of the design alternatives produced the parallel clamping motion and the rotating jaw system. The double-actuated design was chosen because of the minimal use of sliding interfaces and the simplicity of the clamping mechanism. A test tool was constructed during Phase 1 according to the design criteria (1 - 11) detailed below. Design modifications were identified during Phase 1 and these were implemented in Phase 2 according to the design criteria (12 - 15) listed below:

1. Aluminum construction for lightweight and non sparking tool
2. Compact, portable, easy to use.
3. Operate in keyhole and confined space
4. Effective for use on 4 and 6-inch diameter PE pipe for all wall thicknesses/SDR.
5. Provide enough force to effectively stop pressurized natural gas flow.
6. Protect against over-squeezing to prevent pipe damage
7. Operate from ground level without requiring under-the-pipe excavation.
8. Operate either hydraulically or manually.
9. Provide a built-in safety feature so the tool cannot be inadvertently released during operation.
10. Locking method to prevent unauthorized release of the tool from the pipe.
11. Accommodate off-axis alignment when squeezing pipe.
12. Optimize the system operation
13. Evaluate alternative manufacturing materials
14. Investigate casting-in-place reinforcement
15. Investigate use of pre-stressed components in critical areas

Design parameters for the engineered prototype tools included jaw displacements that provide 15% PE pipe compression, a jaw radius of 4 inches, and jaw force capability of 30,000 pounds. The concepts were analyzed using the software package ANSYS 5.4 for finite element analysis (FEA) to optimize the configuration of the squeeze-off tool structural elements. This ensured that the models efficiently provided the clamping forces necessary to squeeze off 4 and 6-inch polyethylene (PE) pipe. Solid Works™ computer modeling software was used to ensure that the proposed squeeze-off tool would function effectively either manually or hydraulically. Computer modeling was also used to determine the size of each component of the tool to ensure safe operation. Detailed engineering drawings of all tool components, assembly drawings, and a detailed parts list of the prototype squeeze-off tool were completed.

Task 3 – Design and Engineer Prototype Parts:

The mechanical engineering team recommended machining the engineered prototype parts from 7075-T6 aluminum instead of casting the parts from A356-T6 alloy. This change in material was recommended to minimize the possibility of the tool yielding when squeezing-off large diameter 6-inch pipe. The tool was subsequently modeled in CAD (computer-aided design) and simulated in CAM (computer aided machining) software (Figure 7).

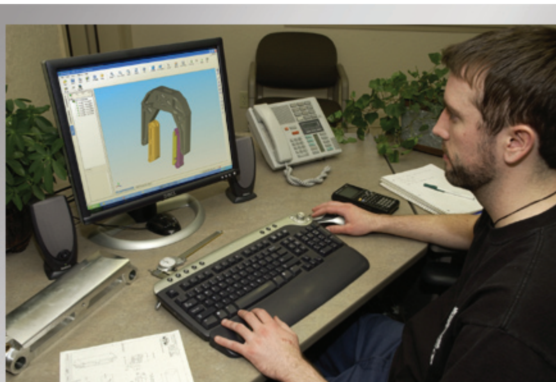


Figure 7: Design and engineering of yoke assembly using CAD & CAM software

Task 4 – Machine and Finish Engineered Prototype Parts:

The engineered prototype parts were manufactured and finished using CNC (computer numerically controlled) machining (Figure 8).

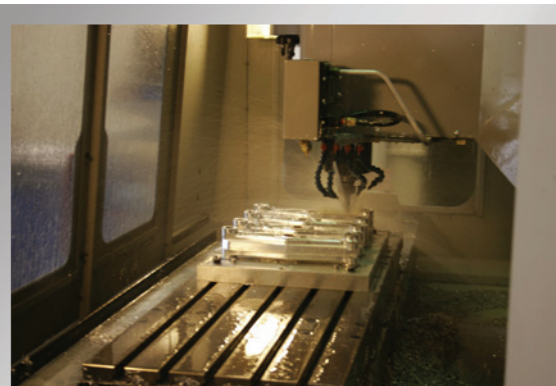


Figure 8: CNC machining of fixed jaw posts

Task 5 – Engineered Prototype Tool Assembly:

The CNC machined components were assembled and functionality tests were performed on the engineered prototypes prior to laboratory and field-testing evaluations. To ensure maximum performance of the engineered prototype, these squeeze-off functionality tests were performed on 4 and 6-inch pipe pressurized to 95 psi. During these initial tests, the engineered prototype was monitored for deflection, gap between the jaws on full squeeze, and the efficiency of the squeeze to determine if complete squeeze-off was achieved.

Task 6 – Laboratory Testing of Engineered Prototype:

This task evaluated the functionality of the engineered prototype to successfully stop pressurized flow (air) through 4 and 6-inch PE pipe. The testing equipment included various hydrostatic and hydrodynamic pressure sources, fixturing and shielding, and controlled temperature water baths. All test equipment such as pressure gauges and transducers, thermocouples, and linear dimensioning equipment, was calibrated in accordance with ISO 17025 (and also 9001 and 9002), and was NIST traceable.

The most critical question was to determine if the engineered prototype was able to effectively stop the flow of natural gas. In order to provide validation regarding the functionality of the engineered prototype, three test replications at 95 psi (pounds per square inch) were performed under each of the following combination of conditions resulting in a "full matrix" requiring 72 squeeze-off tests:

1. Pipe Diameters: 4 and 6-inch diameter PE pipe

2. Wall Thickness: SDR 11.5 and 13.5

3. Pipe Material: Medium density (MDPE) and high density (HDPE)

4. Squeeze-off Device Stops**:** In order to evaluate the effectiveness of the engineered prototype to squeeze off the gas flow, three different wall compression points were evaluated.Specific gap settings were selected at the time of testing based on the forces generated by the prototype and included at least three of the following points for wall compression: 5%, 10%, 15%, 20%, 25%, or 30%.

Testing was performed in accordance with ASTM F1563, including Appendix XI of this method, and ASTM F1734. Oregon State University performed ASTM testing on two of the engineered prototypes. These tests included pipe dimensioning, leak measurements, and operation at varying process parameters, material response, and environmental effects.

The wall thickness of the pipe was measured to determine the point of maximum wall thickness. The pipe was then squeezed off by the engineered prototype 180 degrees from the point of maximum wall thickness. This formed the "squeeze ears" at the thickest part of the pipe and, when measured, provided an indicator of the maximum squeeze per setting. Four and six inch pipe diameters were measured (SDR 11.5 and 13.5). Two types of polyethylene pipe were tested: medium density (MDPE) and high density (HDPE) at 32°F (0°C), 73°F (23°C), and 110°F (43°C).

These tests were performed at wall compressions of 5%, 10%, 20%, and 30%. At each of these settings, a leak pressure test was performed on a sample of pipe capped at both ends and then outfitted with a hose that pressurized the pipe. Once outfitted and compressed, the pipe was squeezed off by the engineered prototype. The cap not attached to the compressor used a flow meter to record the cubic centimeters per minute that escaped the tube. This accurate measurement was then recorded. All of these tests provided verification regarding the viability of the engineered prototype.

In addition to the laboratory testing at Oregon State University, laboratory tests were also performed by five of the field-testing partners at their company facilities. These tests included accelerated age testing on squeezed-off pipe samples to assess the long-term safety and structural integrity of the pipe. The squeezed pipe samples were obtained from functionality tests. The safety and integrity sustained pressure testing was conducted in accordance with *ASTM D2513, Standard Specification for Thermal Gas Pressure Pipe, Tubing, and Fittings*. The companies that performed preliminary laboratory tests prepared sections of either MDPE or HDPE pipe at their facilities and squeezed them off according to the following testing procedure.

Test One – The engineered prototype was installed on a section of MDPE or HDPE pipe. This pipe was not pressurized and was used as a control test sample. The section of pipe was squeezed-off to pipe manufacturers' specifications.

Test Two – The engineered prototype was installed on a section of MDPE or HDPE pipe that was pressurized to 60 PSI and held for 24 hours. The section of pipe was squeezed off to pipe manufactures' specifications.

Test Three – The engineered prototype was installed on a section of pipe and checked for over-squeeze at pressures of .25 PSI, 1 PSI, 5 PSI, 10 PSI, 20 PSI, 40 PSI, 60 PSI, and 90 PSI.

Test Four – Test 3 was repeated three times.

Task 7 – Field Testing:

Engineered prototype tools were constructed for field-testing and delivered to seven participating natural gas companies. The tests varied with each natural gas company depending on their individual operating procedures. Five of the companies performed preliminary laboratory tests on sections of either MDPE or HDPE pipe prior to field evaluations. Two companies released the tool to their

field crews immediately for controlled field evaluations.
All participating natural gas companies evaluated the engineered prototype in conventional as well as keyhole access operations. The field tests consisted of a minimum of two MDPE or HDPE squeeze-offs on actual job sites or demonstrations at gas company facilities.

Field evaluations conducted by the natural gas companies provided feedback concerning the functionality of the engineered prototype. All companies were asked to respond to the following questions.

1. How did the engineered prototype perform in the field?

2. Was the engineered prototype comparable to existing tools currently in use?

3. Was the engineered prototype preferred over existing tools?

4. Did you experience any issues with the engineered prototype?

5. Provide comments or observations about the engineered prototype, positive or negative?

Task 8 – Safety and Integrity Testing of PE Pipe:

This task was performed primarily at Oregon State University (OSU) in Corvallis, Oregon. The pipe samples used in these tests were obtained from sections of pipe that were squeezed at Timberline Tool facilities, Oregon State University, and field samples obtained from natural gas company partners. The specimens were tested for possible long-term degradation of the pipe due to squeeze-off. These tests used visual inspection of the squeeze area followed by a sustained pressure test as described in ASTM Specification D2513. One pipe sample from each replication of the squeeze-off functionality testing, perfomred in Task 6, was inspected at the 180-degree area of highest induced strain (the area of the squeeze ear). This was done to inspect and identify any changes in the surface of the PE material due to the squeezing operation. The surface was then inspected for micro-cracks. Per ASTM specifications, the inspection viewed the squeezed-off section of pipe under ten-power magnification to identify any stress whitening and other possible changes. The long-term safety and structural integrity of the squeezed PE pipe samples were tested utilizing thermal cycling of pressurized pipe sections between -25°C and +80°C, and pressure cycling of pipe at constant temperatures of 23°C.

Task 9 – Technical Assessment of Engineered Prototype Tool: The entire project team continually reviewed and assessed the design and performance of the engineered prototype to identify design modifications prior to production of the squeeze-off tool.

Task 10 – Reporting: Close liaison with DOE representatives was maintained during the course of this project. Semi annual and final reports documenting work performed and results achieved were delivered.

Task 11 – Preparation for Commercialization: A business plan was developed through the DOE Commercialization Assistance Program. This plan detailed personnel requirements and financial requirements necessary to attain the commercialization goal.

RESULTS AND DISCUSSION

Summary of Results

Task 1. Polyethylene Materials & Compression Testing & Analysis:

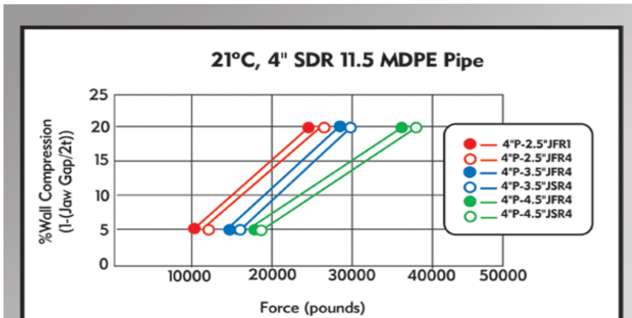


Figure 9: Force necessary to attain target wall compression on 4" MDPE pipe with different jaw radii

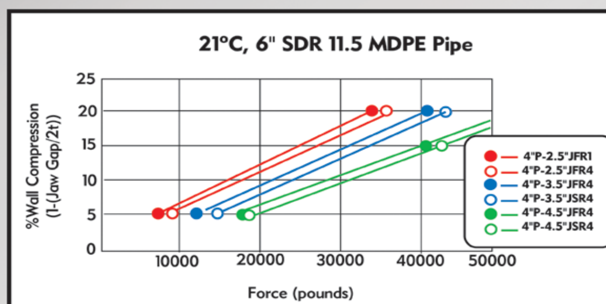


Figure 10: Force necessary to attain target wall compression on 6" MDPE pipe with different jaw radii

The forces required to achieve a range of pipe compressions (5% - 20%) for three different squeeze-off tool jaw radii (2.5, 3.5, 4.5 inches) were determined. Each test point was repeated three times. The variance in data was very low for the three runs at each test point. Data is shown for 4 and 6 inch pipe experiments (Figures 9 & 10). Zero jaw displacement corresponds to the squeeze-off tool jaws just touching the pipe walls but with no deformation of the pipe. As shown, as displacement increases, an increasing force is exerted on the pipe causing deformation. When the pipe walls come into contact, the force required for further displacement (and pipe compression) increases rapidly. Lower compression to achieve squeeze-off is desirable because it decreases the chance of the pipe wall being damaged during the squeeze-off process. However, the force required to achieve the desired compression increases as the squeeze bar jaw radius increases. This increases the structural requirements for the squeeze-off tool. Therefore, the optimal squeeze-off design condition must trade off these two design drivers: lower PE pipe compression vs. lower force requirements for the squeeze-off tool jaws.

Task 2. Design of Engineered Prototype Squeeze-off Tool

The test tool developed during Phase 1 did not provide a desirable seal on 6-inch diameter SDR 11.5 PE pipe and some of the components of the test tool showed signs of coming close to yielding or failure. Further research focused on testing the physical limits of the tool.

In order to achieve a complete squeeze-off on 6-inch MDPE and HDPE pipe, it was necessary to increase the strength of the tool developed during Phase 1 of this project. Most of the components of the Phase 1 test tool were manually machined from 6061-T6 aluminum. To increase the strength of the prototype tool, the design team chose 7075-T6 aluminum with a yield strength about 80% greater than 6061-T6 (ASM Metals Handbook Desk Edition, pg 464). This change in material increased the strength of the tool and allowed the tool to successfully squeeze off 6-inch MDPE and HDPE pipe.

As observed from tests to yield the Phase 1 test tool, all of the major components showed signs of major deflection. Components such as the yoke, links, jaws and even the pins showed potential for improvement through design changes. In order to further increase the strength of the tool, all major components were designed and manufactured using 7075-T6 aluminum. This eliminated any possibility to cast the parts for the tool since aluminum casting alloys are not readily available with strength equal to 7075-T6, a wrought material (hot worked). In designing the new components for the engineered prototype, each component was designed to utilize more material in high stress areas to decrease deflection without adding much weight to the tool. Based on the results of tests performed, the feedback from field testing and review of material strength characteristics of the Phase 1 test tool, it was agreed that the following design modifications be incorporated in construction of the engineered prototype.

Yoke

- Four holes were enlarged to accommodate larger (3/4"dia) pins
- Taper was removed from cavity for acme thread
- Ribs were added to outside of legs
- Compound taper angles for cast design were removed to facilitate 100% machining. Replaced with 2-step machining and 15° angle.
- Web thickness was increased around inside of yoke to increase stiffness.
- Material was changed to 7075-T6 aluminum
- Part gained approximately 3 lbs.

Bushings for 3/4" pins

- Selected larger bronze bushings to handle bigger pins 3/4" Pins
- Diameter increased from 5/8" to ¾"
- Sized ring groove for ¾ shaft
- Material changed to 17-4 stainless steel
- Reduced endplay by placing ring grooves properly

Links

- Holes were enlarged to accommodate larger (3/4" pins)
- Thickness was increased from ½" to 5/8"
- Prior two items increased bearing area by 50%
- Material was changed to 7075-T6 aluminum
- Removed all tapers, and drafts to facilitate easier machining

Jaw Post, Pivot

- Increased hole size for larger pin and bushings
- Added material around larger holes
- Added two ribs for increased stiffness

Jaw Post, Rotating

- Increased hole size for larger pin and bushings
- Added material around larger holes
- Changed offset between link holes and rotate axis (.635 instead of .770)
- Added second hole for additional ball detent
- Moved ball detents out 1/8" radially for more control

Jaw, Rotating

- Change material to 7075-T6
- Jaw is thicker, 2.75 instead of 2.5, will stiffen against bending
- Jaw is wider, 2.75 instead of 2.5, will help splaying problem.
- Angled bevel machined on ends to allow rotation of larger jaw past links
- Less eccentric (.07 offset instead of .125, B-5)
- Larger screws clamping two halves together (5/16 instead of ¼)
- Drive-in steel threaded inserts to sandwich aluminum halves
- Centered screw hole for cable attachment
- Two pockets per side instead of three, for increased bending strength
- Added fillets at bottom of pockets for increased bending strength
- Straddled end bearings better with screws to minimize splaying of 2 halves at end of jaws. Moved screws 3/8 closer to ends.
- Moved ball detents out 1/8" radially for more control

1" Pivot Jaw Pin

- Added length and grooves for cable hook-up on ends
- Increase bronze bearing to 1" ID, 1.25 OD and 3/16" flange.

Pivoting Jaw

- Removed 2 tapped holes for shoulder bolts (cable mounting)
- Removed draft from inside
- Eliminated taper angle in throat

Acme Thread

- Changed to ¾-8 from ¾-6 to lessen effort in closing tool

Task 3 & 4. Design, Engineer, Machine & Finish Prototype Parts

A manual mill and lathe were used to construct the test tool developed in Phase 1. To decrease the time of production, the engineered prototype was machined entirely using CNC (computer numerical control) equipment. The tool was completely designed with 3D solid CAD (computer aided drafting) software and CAM (computer aided machining) software for virtual representation and machining of the components to produce a program (Figure 11). This utilization of engineering software packages greatly reduced the time and complexity to machine many of the components for the engineered

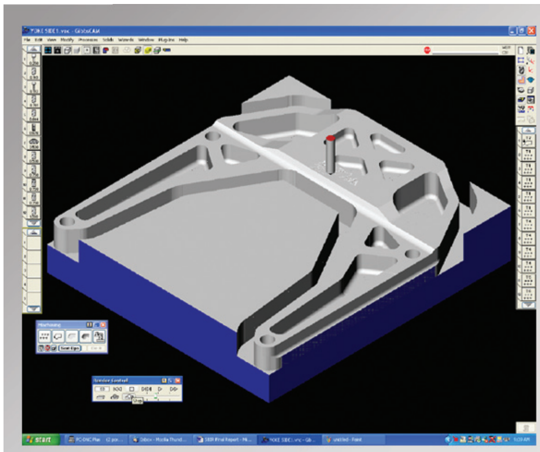


Figure 11: Computer Aided Machining (CAM) of yoke

Figure 12: Catastrophic Failure of C937 bronze follower nut

prototype. Once all the components were machined to tight tolerances, the assembly of the tool was straightforward.

Upon completion of the first engineered prototype, initial tests were performed on 4 and 6-inch SDR 13.5 HDPE pipe. During the initial testing, a problem was encountered when the ACME nut catastrophically failed (Figure 12). This follower nut was made from a C937 bronze (SAE 660 bronze). This failure occurred during the redesign process due to a larger load being placed on the ACME follower nut when other components of the tool were strengthened. The follower nut was re-machined from C954 Aluminum Bronze, which has a yield point approximately twice that of the previous bronze. Although the material yield strength was almost double, the second round of testing on 13.5 SDR 4 and 6 inch MDPE pipe still caused the follower nut to yield. The follower nut was then re-machined from a heat treated C954 Al-bronze which has a yield strength 50% greater than the untreated Al-Bronze. A third round of testing was performed on 13.5 SDR 6 inch MDPE pipe, and again, the follower nut yielded. To avoid redesigning the part and other components, a stronger bearing material suitable for the follower nut was investigated. Research revealed that a C17200 heat treated Beryllium-Copper alloy would provide yield strength more than twice that of the heat-treated Al-Bronze. This was the material chosen for the nut and resolved the issues concerning nut yielding or fatiguing.

During manufacture of the engineered prototype, one field-testing partner requested a rotating jaw for 13.5 SDR 4 and 6-inch pipe instead of the 11 and 11.5 SDR that the tool was designed for. This brought about some dramatic dimensioning changes to both the rotating jaw and the rotating jaw post (Figure 13) and required changing some machining fixtures and CNC programs. It was apparent that jaw posts and rotating jaws would need to be designed and manufactured specific to

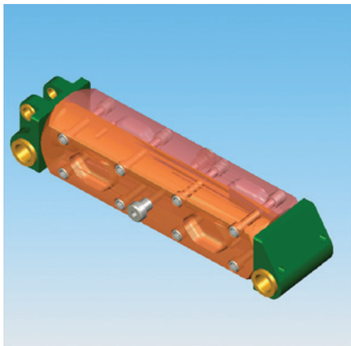


Figure 13: Rotating Jaw & Post of test tool developed in Phase 1

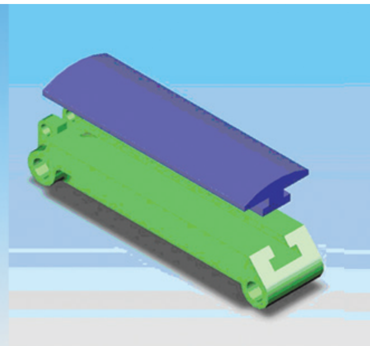


Figure 14: Slide-on Jaw Concept

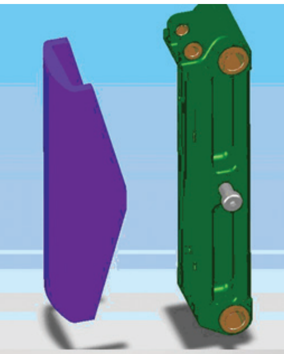


Figure 15: Pin-on Jaw Concept

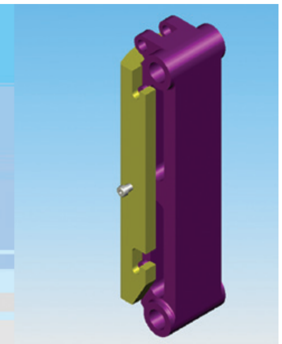


Figure 16: Interchangeable Jaw Concept

each customer's needs. This created a very complicated and expensive process to manufacture a tool to accommodate multiple pipe diameters and wall thicknesses.

To solve this problem, a standard jaw post was designed with an interchangeable jaw instead of the rotating jaw. With the new design, each jaw would be manufactured for a specific pipe size and SDR. Several design concepts incorporating an interchangeable jaw and a standard post were considered (Figures 14, 15, & 16). After several design iterations, a final design for the interchangeable jaw and post was selected (Figure 16). This design proved to be simpler and more economical to manufacture than the rotating jaw and post. It offered greater flexibility and strengthened the tool. This design change allowed one tool to squeeze-off all 3 to 6-inch PE pipe regardless of the wall thickness. This resulted in a very versatile and cost-effective tool.

The new interchangeable jaw and post were incorporated into the design of the engineered prototype and tested for complete seal on 4 and 6-inch pipe SDR 11.5. Results of testing on the 4-inch pipe sizes produced consistently good seals while tests on the 6-inch pipe sizes did not. To obtain consistently reliable seals on 6-inch pipe, extensive testing was performed.

During testing, it was observed that some of the inconsistencies were the result of the pivot jaw and pivot jaw post. The original intention of the pivot jaw and pivot jaw post was to equalize and balance the distribution of force on the squeezed pipe. When the two components were analyzed using FEA (finite element analysis) software, it was revealed that both components were prone to large distortions, without approaching the yield point of the material (Figures 17 & 18). Although the two parts were strong enough, the deflections of the parts interfered with each other during squeeze-off operations. This limited the motion of the pivot jaw and caused inconsistent distribution of force onto the pipe. This also explained why some of the changes in the interchangeable jaw profile did not have the desired effect.

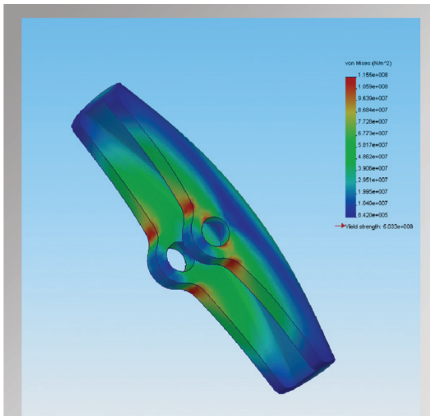


Figure 17: Finite Element Analysis of Pivot Jaw

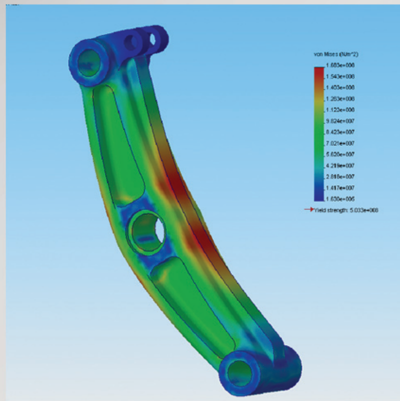


Figure 18: Finite Element Analysis of Pivot Jaw Post

Additional testing was done with the pivot jaw fixed in place. Both ends of the pivot jaw had set screws so that the angle of the jaw could be adjusted with each test. The testing revealed that if the pivot jaw was set to approximately the same angle of deflection observed in the arms of the yoke, the seal on 6-inch pipe improved and was more consistent.

Using the data from this testing a one-piece fixed jaw post was designed to replace the pivot jaw and pivot jaw post (Figures 19 & 20). This design change, like the interchangeable jaw change, proved to be simpler and more cost effective to manufacture, while providing the benefits of more consistent squeeze-off. Once the new fixed jaw post was complete, more testing was done to verify the effectiveness on the tool.

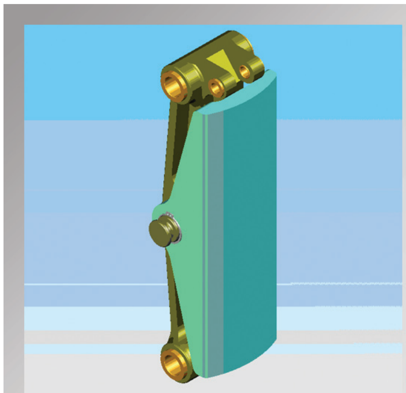


Figure 19: Initial Design of Pivot Jaw & Jaw Post

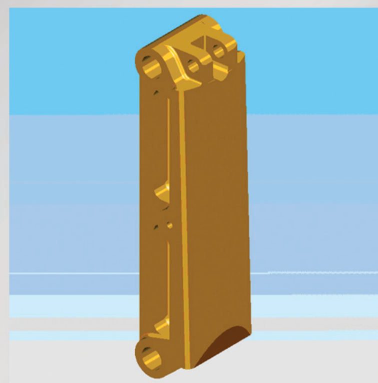


Figure 20: Redesign of Pivot Jaw & Jaw Post to a Single Fixed Jaw & Post

Modification of the tool from the pivot jaw to the fixed jaw decreased the distance between the jaws making it harder for the tool to slide over the 6-inch pipe. The problem was solved by shaving the top ends of the jaw posts that are exposed to the yoke (Figures 21 & 22) thereby allowing the tool to open wider. Removal of this material did not affect the integrity of the tool because the portions that were removed were under little stress when squeezing pipe.

Figure 21: Beveled Top of Fixed Jaw Post to increase the opening for 6" pipe

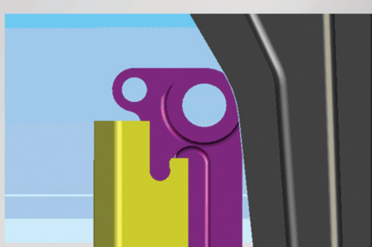


Figure 22: Beveled top of Interchangeable Jaw Post to increase opening for 6" pipe

Another design change was also made at this time. The original process of milling out the cavity of the yoke was very costly and the possibility of cutting the 6-inch thick cavity utilizing a CNC water jet machine was researched. However, water jet cutting tends to flare in corners and radiuses, which creates stress concentrations in the yoke. To solve the problem, the cavity was redesigned in an octagonal shape, leaving more material in the corners to cater to water jet cutting (Figure 23). This design and manufacturing change made the tool simpler to manufacture thereby reducing the cost of production.

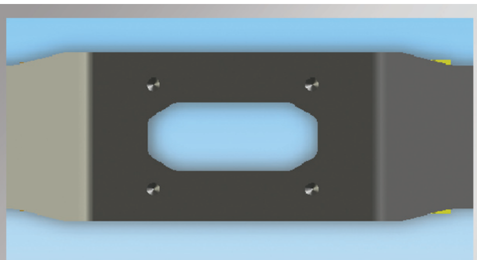


Figure 23: Design change of yoke cavity to facilitate water jet cutting

The tool was rigorously tested and results revealed that there were still issues concerning consistent sealing on thicker walled SDR 11.5 6-inch pipe sizes. To resolve this problem many different interchangeable jaw profiles were designed and tested. After each test, the data collected was analyzed and discussed to determine the next test profile. Testing was done to determine whether temperature, rate of squeeze, or varying amounts of compression of the pipe were factors in obtaining a complete seal. Minor changes were made to the interchangeable jaw profile to improve the quality and consistency of the squeeze-off based on results of these tests.

Task 5. Engineered Prototype Tool Assembly

Eight engineered prototype tools were assembled following completion of the machined component parts. An instruction manual was completed to aid in the assembly process and to guarantee correct usage of the tool (Figure 24).

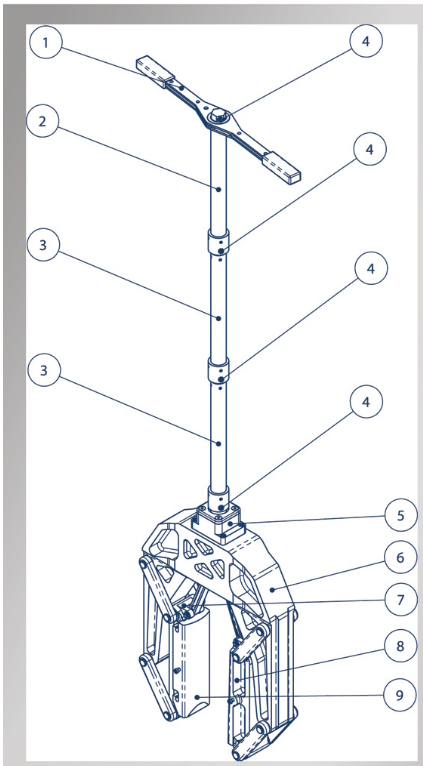


Figure 24: Schematic of components for engineered prototype tool assembly

Task 6. Laboratory Testing of Engineered Prototype Tool

Two engineered prototypes were tested at Oregon State University, Serial Numbers EP01 (Figure 25) and EP02, for compliance with ASTM specifications F 1563, F 1734 and D 2513. The first tool remained at Oregon State University for functionality testing, and the second (EP02) was sent to Northwest Natural Gas (NWNG) for field-testing. The new engineered prototype design utilizes an interchangeable jaw for four pipe sizes – 4” SDR 11.5, 4” SDR 13.5, 6” SDR 11.5, and 6”SDR 13.5 (with the possibility to include other sizes in the future). The interchangeable jaws are easily exchanged by sliding them off the interchangeable jaw post. The interchangeable jaw was designed, through extensive testing at Oregon State University and Timberline Tool, to give a balance between minimizing pipe wall compression and giving repeatable flow squeeze-off results. The applicable pipe size and wall thickness (SDR) information is permanently engraved into both sides of the interchangeable jaw for easy identification (Figure 26). Tool centering and alignment is achieved by two cable assemblies that support the tool on the pipe to be squeezed-off and center the pipe in the vertical middle of the jaws (Figure 27).

Figure 25: Engineered Prototype EP01 delivered to OSU for testing

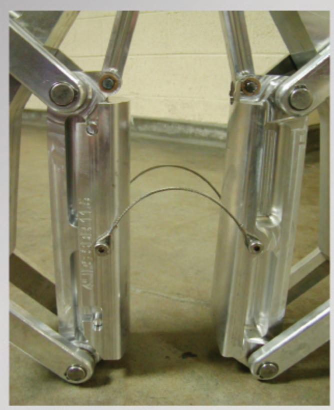


Figure 26: Identification of pipe size and SDR etched on the interchangeable jaw

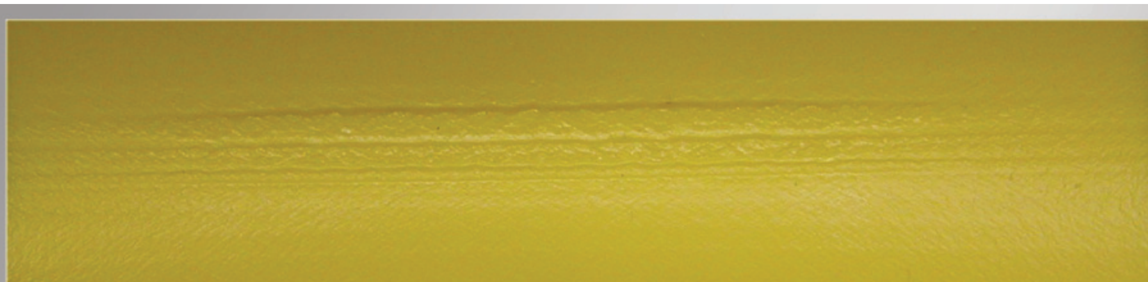
Figure 27: Alignment and support are achieved with two cable assemblies.

Both of the engineered prototypes tested were able to squeeze-off the heavier walled (SDR 11.5) medium density polyethylene (MDPE) pipe sections without difficulty, even when the pipe and tool were cooled to 5ºC. The engineered prototype successfully squeezed off the pipe samples and the tool was not damaged. The engineered prototype utilized a ratcheting T-handle, lead screw, and linkage design to limit the squeeze rate and provide a positive maximum squeeze-off linkage stop to ensure against over squeezing the pipe. The engineered prototype was applied to the pipe and squeezed until the jaw posts contacted the tool body.

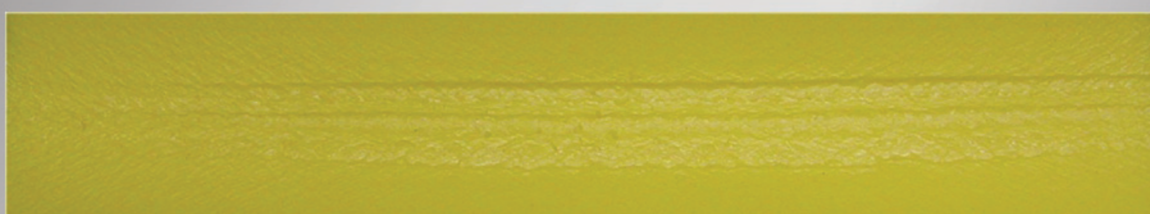
The squeeze-jaws were firmly held in all positions by the lead screw and linkage design. This mechanical design made it impossible for an accidental release during any part of the squeezing process. The rotation of the lead screw was reversed to open the jaw assemble. This provided a natural limiting agent for excessive release rates.

A grounding cable and spike were provided with the tool to allow for positive grounding any electrostatic discharges to/from the tool during pipe squeezing activities. There are no electrically isolated areas on the tool as it is fabricated with all electrically conductive materials (mostly aluminum).

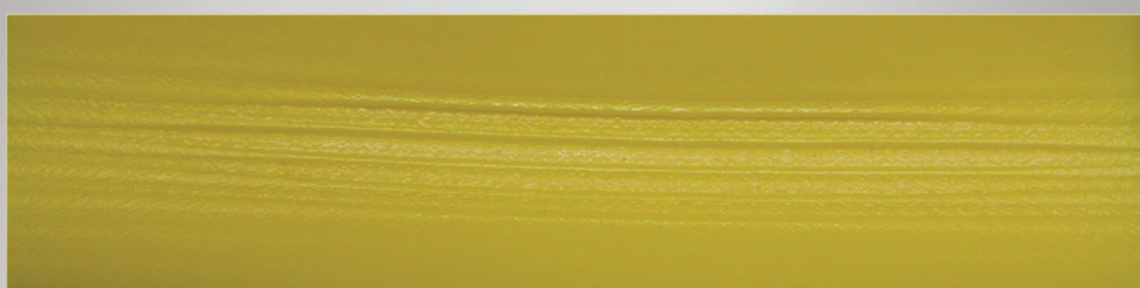
Chevron Phillips Chemical Company Driscoplex™ 6500 Gas Pipe PE 2406 (SDR 11.5) and Rinker Materials PolyPipe® 3810 Gas Pipe PE 2406 (SDR 13.5) were used for the squeeze-off



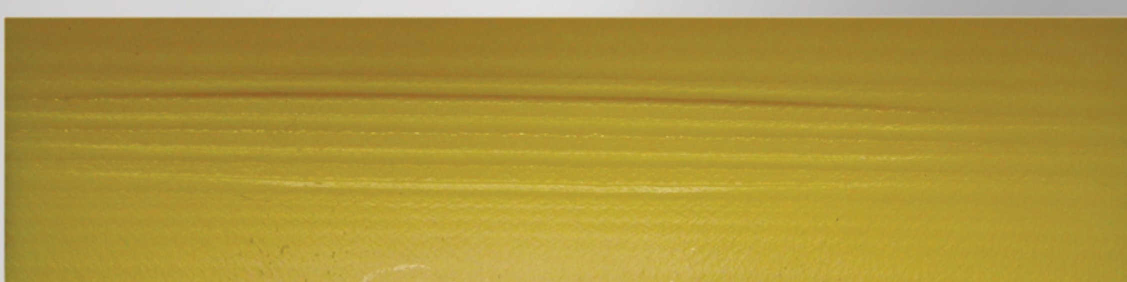
Typically wrinkling of 4” SDR11.5 Driscoplex™ 6500 Gas Pipe at 29-31°C



Typically wrinkling of 4” SDR11.5 Driscoplex™ 6500 Gas Pipe at 6-7°C



Typically wrinkling of 6” SDR11.5 Driscoplex™ 6500 Gas Pipe at 29-31°C

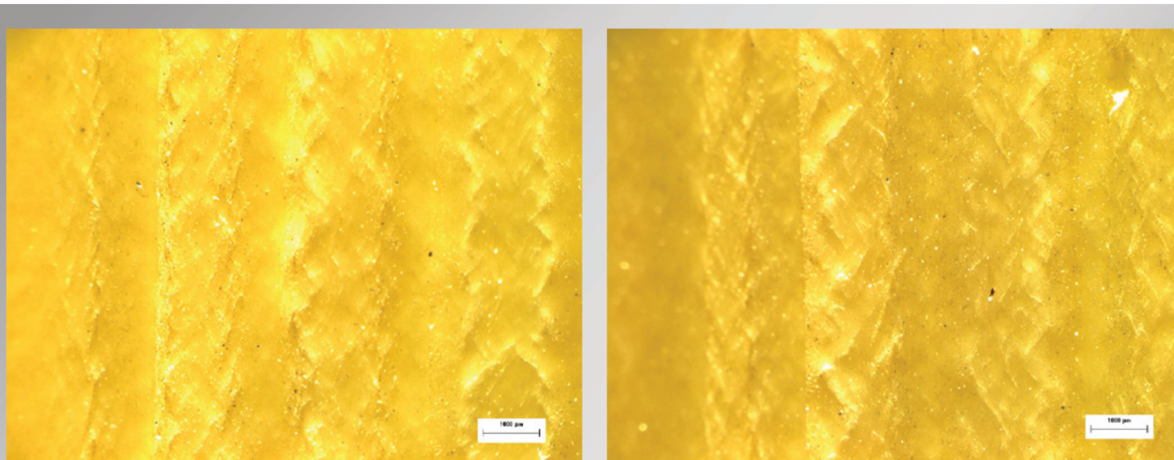


Typically wrinkling of 6” SDR11.5 Driscoplex™ 6500 Gas Pipe at 6-7°C

Figure 28: 10X digital images of interior squeeze ears

qualification tests. The 4” and 6” pipe was cut into 41” long sections and the tool was applied in the middle of the each section. A concerted effort is made to include the thickest section of the pipe wall one of the squeeze ears. Three temperatures were used in these tests: 6°C, 22°C, and 30°C (43°F, 72°F, and 86°F). The squeeze tool and all pipe samples were held at each testing temperature for a minimum of 24 hours to allow adequate time for the material to reach equilibrium. All squeeze-offs were based on an approximate 1 inch per minute squeeze rate. The samples were held in the full squeeze-off position for 30 minutes and then released at the same 1 inch per minute rate.

All squeezed-off pipe samples were held at their conditioned temperature for at least another 24 hours to allow the pipe time to relax – no pipe re-rounding was conducted. The relaxed sections were brought to room temperature where the ear sections were cut from the pipe and visually inspected for any cracking or white lining. Typical wrinkling or creasing was evident on all samples; however, no visual damage (cracking, voids, or dimpling) could be seen on any of the tested samples. Digital images where taken at >10X of the interior ear area (Figure 28); also, a series of samples were inspected and digitally photographed in an optical microscope at higher magnifications (Figure 29).



4” SDR11.5 squeeze ear wrinkle close-up 6” SDR11.5 squeeze ear wrinkle close-up

Figure 29: Optical microscopy of interior squeeze ear. Scale = 1000µ

ASTM F 1563: <u>Standard Specification to Squeeze-off Polyethylene Gas Pipe or Tubing</u>

5.1 Force Mechanism Results:

The force mechanism (mechanical, hydraulic or pneumatic) shall provide a force of at least 1.25 times the force required to squeeze-off the most rigid pipe size within the squeeze parameters recommended by the manufacturer of the tool. The most rigid pipe is a function of pipe diameter, wall thickness, pipe material and temperature. The tool manufacturer determines which pipe products his tool is suitable for. Power tools such as impact wrenches or pneumatic motored torque multipliers shall not be used.

The mechanical design of the engineered prototype was conducted at Timberline Tool. The tool was designed to withstand greater than 1.266 times the force required to squeeze-off 6" SDR11.5 MDPE pipe to the predetermined squeeze-off gap.

The yoke (Figure 30) is the heart of the engineered prototype and was designed to provide up to 30,000 lbs of crushing force to a 6" pipe without causing plastic deformation. The yoke was constructed entirely from a single piece of 7075-T6 aluminum machined from a four-inch thick plate.

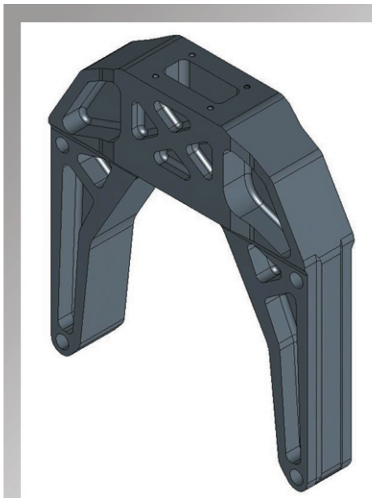


Figure 30: SolidWorks® Drawing of engineered prototype yoke

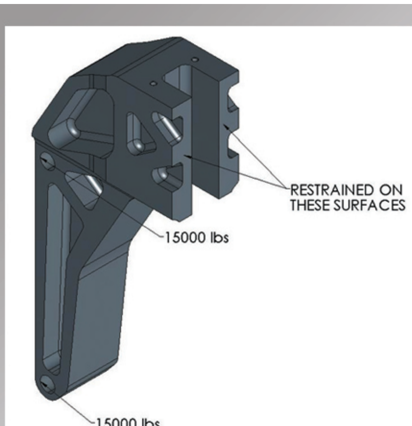


Figure 31: Cosmos Software depiction of symmetry of yoke

Cosmos software was used to perform the stress analysis on the yoke. Symmetry allowed one-half of the yoke to be modeled to simplify the numerical solution (Figure 31). A freebody diagram of the jaws in the closed clamp position revealed that 30,000 lb crush force will always divide equally between the top and bottom pins on the yoke. Thus, a 15,000 lb load was applied horizontally to each hole in the yoke. The two surfaces at the plane of symmetry were restrained by material on the other half of the yoke.

The high stress concentration areas in the yoke were predictably in the fillets on the inside of the yoke (Figure 32). Dividing the yield stress by the maximum stress in the part (73,000/ 57660) resulted in a 1.266 safety factor for the yoke when manufactured from 7075-T6 aluminum. The exaggerated shape of the yoke under load is shown in

Figure 33. Since only half the yoke was modeled, the actual measured deflection across the tips of the yoke would be 5.8mm shown or .460 inch. This prediction was correlated to actual measured deflections across the tips when squeeze-off was achieved on a 6-inch pipe. This deflection will be entirely in the elastic range and will return to zero when the clamping load is released. The data generated through the use of the Cosmos computer software qualifies that the yoke of the engineered prototype tool is capable of supplying 30,000 lbs of crushing force to a 6" pipe while maintaining a 1.266 safety factor if manufactured from a single billet of 7075-T6 aluminum in the configuration shown.

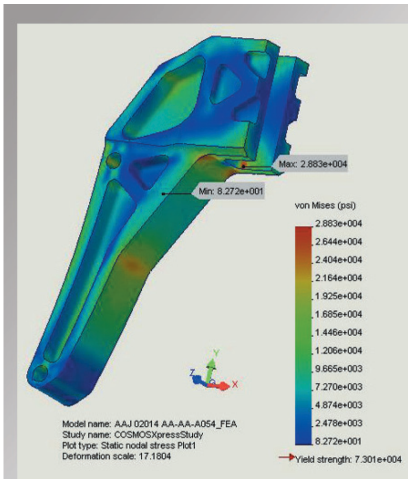


Figure 32: Areas of high stress concentrations of yoke under load using Cosmos Software

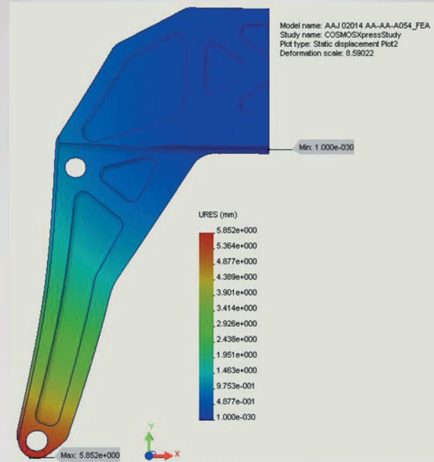


Figure 33: Exaggerated shape of yoke under load using Cosmos Software

5.2 Tool Strength Results:

A tool shall not be structurally damaged or functionally affected when tested as follows:

5.2.1 Measure the load (P) required to squeeze-off the most rigid pipe (largest size, thickest wall, highest density, lowest temperature) within the range of the tool.

5.2.2 Prepare a pipe specimen from this pipe. The specimen length shall be no less than five times the nominal outside diameter of the pipe, but in no case less than 12 in. (305 mm).

5.2.3 Insert the pipe specimen into the tool. Center the specimen in the tool.

5.2.4 Apply the largest load attainable by the force mechanism (without additional mechanical advantage) onto the mechanical stops and then inspect. Any permanent damage or deformation to the mechanical or hydraulic components is cause for rejection of the tool.

5.2.5 Apply a load of 1.25 X P (see 5.2.1) on the pipe for twenty cycles. A cycle is: apply load, hold load for one minute, remove load. For each cycle, use a new un-squeezed area of pipe, at least three pipe diameters from a previous squeeze (Figure 34).

Once the engineered prototype was in the full squeeze-off position (linkages bottomed out) the T-handle would not advance any further under the normal forces exerted by the tool operator. The engineered prototype performed a series of squeeze-offs without any tool fatigue or failure.

5.3 Release Protection Results

Each tool shall be built to prevent unintentional release in the squeeze mode. A screw-feed mechanism used to apply force in some tools qualifies as premature release protection if the force can only be removed by unscrewing the mechanism at the 1.25 X P test load.

The T-handle and lead screw design of the engineered prototype acts as a natural limiting agent for excessive release rates.

Figure 34: ASTM F1563 testing at OSU

5.4 Release Rate

For pipe sizes greater than 1 in. (25 mm) IPS, it is recommended the tool design provide a release rate of 0.5 in/min (12.7 mm/min) or less, as suggested in Guide F 1041.

The engineered prototype release rate can be adjusted by the tool operator to align with the specific conditions and specifications of each pipe manufacturer and/or ASTM F1041.

5.5 Flow Control

Squeeze-off results in the reduction of gas flow and in some cases the complete stoppage of gas flow. This specification does not specify what degree of gas flow control is required for any set of squeeze-off conditions. Appendix X1 provides a procedure for evaluating flow control. Other procedures for flow control evaluation may also be used.

The final squeeze-off jaw gap for each pipe diameter and wall thickness has been determined through extensive testing. The engineered prototype typically seals off the gas flow either immediately or within about a minute.

5.6 Grounding Results

Squeezing and releasing the squeeze of plastic pipe containing flowing gas can increase the presence of static electricity on the pipe surfaces. The tool shall include a suitable electrical grounding feature or recommendations for controlling electrostatic discharges.

The engineered prototype is equipped with a T-bar grounding spike connected to a jacketed flexible grounding conductor, which is bolted to the aluminum yoke of the tool. There are no electrically isolated areas on the tool as it is fabricated with all electrically conductive materials (mostly aluminum).

ASTM F 1734 - Standard Practice for Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-Off Procedures to Avoid Long-Term Damage in Polyethylene (PE) Gas Pipe

10.1 Acquire randomly selected pipe samples at least five pipe diameters long but not less than one foot long.

10.2 Measure the wall thickness around the circumference at 15° increments, and identify the location of maximum wall thickness.

10.3 Condition the sample to the temperature of interest. Studies at very low temperatures or on thicker-walled pipe may require significant hold times to reach thermal equilibrium. Experience with smaller-diameter, lower SDR pipe (for example, 2 to 6-in. SDR 11 pipe) indicates that a minimum of 24 hr is required for the sample to reach equilibrium.

Results: Pipe samples were obtained using the method described in ASTM F1734 Section 10. Sections of pipe 41 inches long were used for both 4 and 6-inch pipe and the maximum wall thickness was identified using calipers to measure the wall thickness around the circumference at 15 degree increments. The sample was conditioned and held for 24 hours to reach equilibrium.

11.1 Place the sample in the squeeze tool so that the thickest portion of the pipe forms one of the squeeze-off ears, Locate the sample such that the midpoint of its length is between the squeeze-off bars- Also, center the sample squarely in the squeeze-off tool.

11.2 The squeeze bar shims or stops, or both, must be within 1% of the target level.

11.3 Operate the tool at the specified rate, closing the bars to the "stops:' and hold for 30 min. In order to induce damage beyond that observed in typical practice, add a shim to one of the squeeze bars or use a smaller stop.

11.4 Release the sample at the designated rate of release.

11.5 If re-rounding is included in the squeeze-off procedure being considered, re-round the sample as directed.

11.6 Allow the sample to sit without external force at the chosen temperature for 24 hr.

11.7 Cut a ring containing the squeeze location (the ears) from the sample at least 2 diameters long. Then, saw-cut this ring along its length at 90° to the squeeze-ears.

11.8 With the unaided eye, visually inspect the interior of each sample for stress whitening, crazing, or cracking. Likewise, inspect the exterior of the sample for evidence of a dimple centered in the ear.

11.9 Wrinkling of the interior of the squeeze-off ear are expected to occur. Some stress whitening along the ridges and in the valleys of wrinkles is also expected to occur. Stress whitening should be limited to these ridges and valleys in the region where wall thinning occurs in response to the squeeze process. The stress whitening should be diffuse in appearance rather than an intense white band.

11.10 Cracking or voids on the inside or a dimple on the outside disqualify the squeeze-off process.

11.11 A dimple on the outside of the pipe, or stress whitening strung out along a severe wrinkle on the inside of the pipe, at squeeze levels equal to or less than that needed for flow control, disqualify the process. Thus, if none of the features indicative of long-term damage are seen at squeeze levels adequate to control the flow, that combination of squeeze procedure, squeeze tool, and pipe is acceptable. If such features are seen at a squeeze level 5 % greater than that needed for flow control, modifications to the squeeze process (such as alternative bar designs) should be considered, because a 5 % squeeze range may not be an adequate margin in field practice.

11.12 For samples passing the unaided-eye evaluation, the inside should be inspected at 10X magnification. Cracking or voids disqualify that combination of pipe, tool, and procedure.

11.13 For inspections at 10X, stress whitening strung out along a wrinkle again is evidence of damage that can grow with time. Judgment, depending on the severity of the features, the service conditions, and the utility's service record for that pipe can disqualify the squeeze procedure if such features are found.

11.14 General widespread evidence of changes in color such as intense stress whitening or crazing, is evidence of damage and indicative of possible subsurface damage. Judgment based on experience related to the service record of the pipe involved should be considered in qualifying procedures that produce such features. Examination of cross sections prepared on a cut through the ear can be used to determine if subsurface damage has occurred in such cases. An indication of small voids in these sections is the basis to disqualify that squeeze-off process.

11.15 If the process is not disqualified by the foregoing examination, samples of squeezed pipe are subjected to a sustained pressure test as described in Specification D 2513.

Results: The pipe samples were squeezed off using the engineered prototype according to the procedure described in ASTM F1734 Section 11 above. The interior of each pipe sample was visually inspected for stress whitening, crazing, or cracking and none was observed. Likewise, the exterior of the pipe samples were inspected for evidence of a dimple centered in the ear and none was observed. No cracks or voids were seen in the pipe sections squeezed with the engineered prototype using 10X magnification. Occasionally diffuse stress whitening was seen along squeeze-off ridges; however, this stress whitening was of such a low level that no significant damage to the pipe wall occurred during squeeze-off. Intense stress whitening was not observed. Cross-sections of numerous ear sections were examined and no subsurface voids were found. Results of the above testing qualified the squeezed pipe samples for sustained pressure testing.

Task 7. Field Testing

During the development of this tool, seven natural gas companies expressed interest in evaluating and field-testing the tool. A field-testing plan for the engineered prototype was developed and field-testing of the engineered prototype under live gas line conditions conducted.

Company	Location
NW Natural	Portland, OR
Sempra Energy Utility	San Diego & Los Angeles , CA
Questar Gas Company	Salt Lake City, UT
Southwest Gas Corporation	Tempe, AZ & Las Vegas, NV
Nicor Gas	Naperville, FL
DTE Energy (MichCon)	Melvindale, MI
KeySpan Energy Delivery	Hicksville, NY
Oregon State University	Corvallis, OR

Figure 35: Laboratory and Field Testing Partners

Eight engineered prototypes were manufactured for initial field-testing at Timberline Tool facilities in Kalispell, MT. After initial ASTM (F1563 & F1734) laboratory testing, Timberline Tool supplied a squeeze-off tool and instructions for its use to seven natural gas companies and Oregon State University (Figure 35): Each tool was used according to procedures provided by Timberline to squeeze both 4 and 6-inch MDPE and HDPE gas pipes. Field trials were conducted to provide feedback on whether the tool met the required design criteria. Overall tests results were favorable as indicated by company responses to the following questions:

a. How does the engineered prototype perform in the field? (Comments)
b. Is the engineered prototype comparable to your existing tool? (Explain)
c. Would you use the engineered prototype before your current tool? (Explain)
d. Did you experience any issues with the engineered prototype? (Explain)
e. Any other comments or observations about the engineered prototype?

Summary of Participation

Company 1

Company 1 used the engineered prototype three times, all on 4-inch MDPE pipe. All the crews had positive comments on the performance and operation of the tool. They state that because the tool can drop directly over the pipe, it cuts down on the size of the excavation and in an emergency, this can be very important for control time. They would use this product before their current product even though the unit they currently have is also easy to operate. They did not experience any issues with the engineered prototype but feel the carrying box could be much smaller. They suggest cables be supplied with the pins that attach the handle parts together. The tool will be evaluated by at least four other districts for this Company.

Company 2

Company 2 used the prototype routinely in field operations for eight months. Their field crews used the tool for routine maintenance and emergency situations on both 4 and 6-inch MDPE pipe. The tool was used in both "keyhole" and conventional excavations. They state that there is absolutely a strong need for this tool in the field and they are extremely positive when asked about the performance of the tool in the field. They report that it is superior to their existing product in that it is lightweight, mechanical, saves time for set up and does not require a large crew. It gives 100% squeeze-off, keeps operators out of the trench and works in a "keyhole". It is the best they have found of it's kind. The only issue they have is slowing the crew down during squeeze-off – when they squeezed off the pipe faster than the instructions for the tool, then they experienced problems with By-Pass.

Company 3

Company 3 used the prototype fourteen times in field operations after successful completion of laboratory tests. The tool was used for routine maintenance and emergency situations on both 4 and 6-inch PE pipe in conventional excavations. Field crews preferred the new Timberline squeeze tool over existing products because it was lighter, less cumbersome and easy to operate. They reported that the greatest benefit of the tool was the safety features it provides to keep operators out of the trench away from potential hazards. The only recommendation they had was to improve the pin system used to secure the handle extensions.

Company 4

Company 4 released the tool for use in field operations following extensive laboratory testing. Their field crews used the tool for routine maintenance and emergency situations on both 4-inch and 6-inch MDPE pipe. Their field crews were very positive concerning the use of the tool and it was preferred over existing squeeze-off tools currently being used. The greatest benefit was that they no longer needed to enter the trench to facilitate repair on the pipe. Another key benefit was that only one person was required to position and operate the tool.

Company 5

Company 5 performed laboratory tests on the tool and then released it for field operations for three months. Their field crews used the tool on 4-inch MDPE pipe for both routine maintenance and emergency situations. Their crews were extremely positive when asked about the performance of the tool in the field. They found the tool to be lightweight and easy to use, making it far superior to heavier squeeze-off tools they currently use. They listed the out-of-the-trench operation as the most important benefit of the tool.

Company 6

Company 6 tested the engineered prototype extensively in their laboratory prior to using the engineered prototype in routine field operations over an eight month period. Their field crews used the tool for routine maintenance and emergency situations on 4 and 6-inch HDPE pipe. The tool performed favorably in all field conditions that they encountered. They were particularly impressed with the performance of the tool when squeezing off high density PE pipe. They are not able to completely stop the flow of gas on large diameter pipe with their current squeeze tools. They reported that the safety features of the tool are the greatest benefit. In addition, they site another key benefit of the tool is the ability to access the pipe without the need for a backhoe.

Company 7

The tool was extensively tested in the laboratory prior to field evaluations. The field personnel reported the engineered prototype to be superior to their existing squeeze tools as a result of the safety and reliability benefits it provides. Another key benefit listed was only one operator was required to perform the task compared to the need for larger crews when using their existing tools. (Some operators turned in their existing squeeze tools thinking the prototype was already being stocked in their warehouse). Other comments were to strengthen the ratchet handle and mechanism, incorporate a gear reducer in the screw mechanism, adapt the mechanism for an air ratchet, adapt this design to other pipe diameters from 2 through 8-inch.

Task 8. Safety and Integrity Testing of PE Pipe

Safety and Integrity Testing: Accelerated age testing on squeezed PE pipe samples was performed to assess long-term safety and structural integrity of the squeezed PE pipe samples. Results showed no change to the structural integrity of the pipe at the area of squeeze-off. The safety and integrity sustained pressure testing was conducted in accordance with *ASTM D2513, Standard Specification for Thermal Gas Pressure Pipe, Tubing, and Fittings*.

Oregon State University in Corvallis, Oregon performed accelerated age testing with the engineered prototype supplied by Timberline Tool. Six (6) 4-inch MDPE, SDR 11.5 specimens and six (6) 6-inch MDPE, SDR 11.5 specimens were tested. The specimens were all three foot long squeezed pipe samples obtained from the engineered prototype functionality tests in Task 6. The squeezed pipe samples were pressure tested per ASTM F 1734-96 Section 11.15. Squeeze-off was performed on the center of the pipe section at room temperature and held for four hours. The samples were then capped with test heads and placed under a hoop stress of 575 psi (an internal pressure of 110 psig) in a heated water bath held at 90ºC. The pipes were held at that pressure and temperature for over 295 hours without any failures. This test substantiates the fifty-year intercept for the pipe material, indicating that the squeeze procedure and engineered prototype were within the requirements contained in ASTM D 2513 standards and specifications.

Figure 36: Timberline's State-of-the-art Top-down Technology to Squeeze off PE Pipe

Task 9. Technical Assessment of the Engineered Prototype Tool

Timberline's engineered prototype tool provides state-of-the-art technology to squeeze-off 4 and 6-inch polyethylene gas pipe (Figure 36). In order to achieve successful squeeze-off on all pipe sizes within the four through six inch range, it was necessary to modify the jaw configuration from a rotating jaw to an interchangeable jaw. The successful demonstrations of the engineered prototype at natural gas utility test sites, the enthusiastic response of utility representatives, and the supporting laboratory tests and analyses provided evidence for technical merit. Utility operators were consistently able to squeeze-off the pipe without inducing damage

(Figure 37). Operational procedures were developed to insure the safety of the operator when using the tool.

Task 10. Reporting

Timberline maintained close communication with the DOE Project Officer and submitted technical and financial reports as required in the contract for this project.

Task 11. Commercialization

Timberline developed a business plan through the DOE Commercialization Assistance Program and participated in their Opportunity Forum to network with potential investors in preparation for commercialization and product launch. **The new squeeze-off tool is commercially available as the Timberline TR650 Top-down Squeeze-off Tool for 3" to 6" PE Pipe.**

Figure 37: Engineered prototype consistently squeezed-off the flow of natural gas without damaging the pipe.

CONCLUSION

Timberline Tool, under the sponsorship of the DOE-SBIR Contract DE-FG02-03ER83858, successfully completed the development of an innovative squeeze-off tool to enable above-ground repair of large, 3 to 6-inch polyethylene gas pipe (Figure 38). Initially the tool was designed for 4 and 6-inch diameter pipe only, but the final design included an interchangeable jaw to accommodate all pipe sizes ranging from 3 to 6-inch diameter. This feature provides utility companies with a cost-effective, versatile tool to operate on multiple pipe sizes. The most important feature of the new tool is it's ability to keep operators out of the trench making it ideally suited for use in keyhole operations.

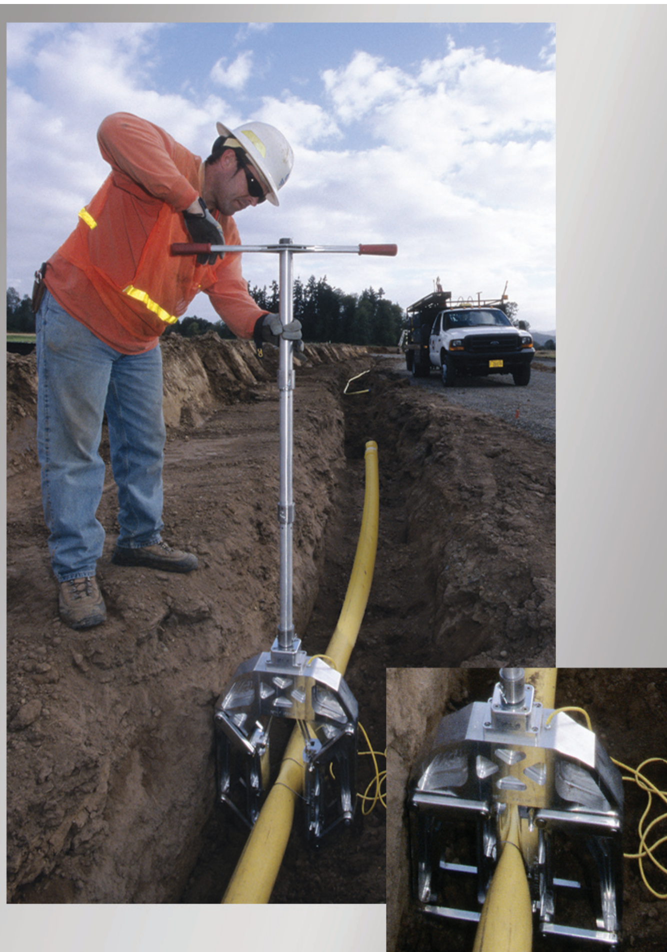


Figure 38: An operator releases the TR650 after successfully squeezing-off the flow of natural gas.

Timberline's new squeeze-off tool provides many advantages over existing large diameter squeeze-off tools. The tool is 17.75 inches wide with a lead screw that delivers up to 30,000 lbs. of controlled force. The unique vertical squeeze bar design allows for top-down application without under-the-pipe excavation giving operators access to the pipe in confined spaces or through a small "keyhole" excavation. The length of the handle is adjustable for adaptability to all field conditions. The self-locking mechanism prevents premature release and the interchangeable jaw enables one tool to be used on multiple pipe sizes. Most importantly, the single bar squeeze-off feature completes the flow stoppage of gas at 5% pipe wall compression which is below the ASTM standard of 30%. The tool is constructed of 7075-T6 aluminum for a total weight of 60 lbs., which is 66% lighter than steel double bar squeeze tools currently in use for the same size pipe.

The engineered prototype was validated in laboratory tests according to ASTM Standards F1563, F1734 and D2513. A field testing plan for the engineered prototype was developed and the engineered prototype was successfully tested in the field under live gas line conditions. Testing was conducted by seven gas pipeline companies and the tool was well received by all participants. All project activities were successfully completed.

Timberline's new state-of-the-art design is a real victory for the natural gas industry. It is lightweight, allows for operation by a single operator, and is easily transported to the job site. Excavations are kept to a minimum and workers are kept out of the trench. With the substantial advantages of Timberline's top-down squeeze-off technology, service companies who take advantage of this technology will see a reduction in operating costs and increased safety for their workers. This U. S. Department of Energy project has advanced commercialization of the first "keyhole" squeeze-off tool, Timberline's TR650, for large diameter gas pipe.

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