EVALUATION OF POLYAMIDE 12 (PA12) FOR HIGH PRESSURE GAS DISTRIBUTION APPLICATIONS

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EXECUTIVE SUMMARY

Since their introduction during the 1960's, the use of PE plastic piping materials has grown at an exponential rate. Their benefits have been clearly established: coupled with its relative ease of use, plastic piping materials eliminate the need for costly long-term corrosion control measures and the associated monitoring costs.

The design and construction of plastic piping systems are governed by Title 49, Part 192 of the Code of Federal Regulations, which establish the minimum requirements for the safe use of plastic piping systems. In particular, sections 192.121 and 192.123 prescribe procedures for determining the design pressure of thermoplastic pipe and its design limitations. Section 192.121, Design of Plastic Pipes, defines the formula used for computing the design pressure. Section 192.123, Design Limitations of Plastic Pipe, limits the maximum pressure of plastic pipe to 125 psig – per latest rule change announced June 2004. While the increase in the maximum design pressure limitations represents some level of improvement, conventional grades of polyethylene (PE) materials still cannot operate as significantly higher pressures without adversely compromising flow capacity – the corresponding wall thickness increases significantly. As a result, there exists a desire on the part of utilities to leverage the benefits of thermoplastic piping materials and extend the range of operating pressures and use of larger diameter piping systems which does not sacrifice flow capacity.

One promising family of thermoplastic materials is the Polyamide materials. Since 2004, with the support of Operations Technology Development (OTD) group and respective PA12 resin suppliers (Degussa, UBE, and EMS), the Gas Technology Institute (GTI) has been engaged in a comprehensive program to validate the feasibility for the use of Polyamide 12 (PA12) in high pressure gas distribution applications through comprehensive laboratory testing and field experiments. Specifically, the program was aimed at developing the required short term mechanical property data per applicable ASTM and industry standards and specifications, characterizing the long term performance considerations, evaluating various construction, maintenance, and operating practices, and obtaining valuable in-service performance related experience.

Based on the cumulative results of the overall program, the PA12 material from Degussa and UBE appears to be a technically feasible candidate material for high pressure gas distribution applications. In particular, the test data demonstrates that their respective PA12 material conforms to all relevant requirements contained within ASTM D2513 and its respective annexes specific to polyamide. Moreover, the results of long term sustained pressure testing at elevated temperatures demonstrate that these respective PA12 materials exhibit very high slow crack growth resistance characteristics. Specifically, the results demonstrate that these respective PA12 materials perform very well under the combined influence of internal pressure and other secondary stresses including surface scratches, rock impingement, earth loadings, and bending strain. Evaluation of construction, maintenance, and operating considerations demonstrates that conventional practices already in use for PE materials can be readily transferred to PA12 piping systems. In the context of this program, it has been shown that there are no deleterious

effects of squeeze-off with respect to long term performance considerations. In addition, qualified PA12 joining procedures have been developed consistent with the both industry and code requirements. Finally, the results of several installations under actual conditions validate the use of PA12 piping systems at operating pressures up to 250 psig.

This report presents a comprehensive summary of each of the technical aspects of the program: technical data for short term and long term performance characteristics, development and evaluation of O&M practices, and results of field evaluations. The cumulative results demonstrate that the PA12 materials from the various resin suppliers appear to be a very promising candidate material for high pressure gas distribution applications.

It is important to emphasize that only an abbreviated summary of the technical discussions are presented here. Detailed discussions with respect to the testing protocols and results are contained within a separate report entitled *"Technical Reference on the Physical, Mechanical, and Chemical Properties of Polyamide 12 (PA12) for High Pressure Gas Distribution Applications"* issued to OTD and the respective PA12 resin suppliers during December 2005.

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OTD -	**Operations Technology Development**
AGA –	**American Gas Association**
PPI -	**Plastics Pipe Institute**
GTI /GRI -	**Gas Technology Institute/ Gas Research Institute**
DOT -	**Department of Transportation**
PHMSA -	**Pipeline Hazardous Materials Safety Administration**
ASTM -	**American Society of Testing and Materials**
ISO -	**International Standards Organization**
CFR -	**Code of Federal Regulations**
MAOP -	**Maximum Allowable Operating Pressure**
SDR -	**Standard Dimension Ratio (OD/wall thickness)**
ID -	**Inside Diameter**
OD -	**Outside Diameter**
SCG -	**Slow Crack Growth**
RCP -	**Rapid Crack Propagation**
LTHS -	**Long Term Hydrostatic Strength**
HDB -	**Hydrostatic Design Basis**
HDS -	**Hydrostatic Design Stress**
LCL -	**Lower Confidence Limit**
MDPE -	**Medium Density Polyethylene (PE2708)**
HDPE -	**High Density Polyethylene (PE4710)**
PA11 -	**Polyamide 11**
PA12 -	**Polyamide 12**

Section 1
Introduction and Background

Prior to detailed discussions about the overall program, it is important to present a high level overview with respect to the chemical make up of Polyamide 12, its potential use, and the technical approach that was utilized throughout the program.

1.1 What is Polyamide 12 and History of Use?

Polyamide 12 is a thermoplastic belonging to the general class of polymers called polyamides. Polyamides are characterized by methylene groups of various lengths joined by amide linkages. Polyamides are named by the number of carbon atoms in the monomer unit. The general formula for polyamides like Polyamide 12 is:

$$[HN(CH_2)_{11}CO]_n$$

The properties of PA12 are significantly affected by the presence of amide groups in the polymer backbone which gives then their unique property profile. The amide group is characterized by the following formula:

$$—(NHCO)—$$

The frequency of occurrence of the amide groups (amide density) differentiate between specific polyamides.

Due to the presence of the amide group and amide density, polyamides exhibit varying degrees of polarity. As a consequence, polyamides exhibit interchain and intrachain hydrogen bonding. The presence of hydrogen bonds contributes to the overall strength, flexibility and toughness of polyamides. Additionally, the presence of polar sites within the polyamide molecule also affects the moisture absorption characteristics.

The development of Polyamide 12 was started in the 1960's. The first commercial production of Polyamide 12 began in the 1970's at what is now Degussa in Marl, Germany. At the present there are four commercial suppliers of Polyamide 12 worldwide:

- Degussa AG – Marl, Germany
- UBE Industries, Ltd. – Tokyo, Japan
- EMS-Grivory – Domat, Switzerland
- Arkema – Paris, France

In the late 1970's, The Australia Gas Light Company (AGL) identified a need to rehabilitate corroded cast iron service lines in New South Wales, Australia. At the time, polyamide 11 (PA11) was identified as a candidate material for this application due to a combination of high strength, excellent toughness and resistance to chemical degradation. It was found that the use of polyamide 11 allowed AGL to conveniently line the corroded cast iron pipe with a thin walled PA11 pipe without compromising the operating conditions of the system. A development program was initiated by AGL to develop a Polyamide 11 system suitable for rehabilitation.

During the early 1980's, a project was initiated to rehabilitate cast iron mains in Sydney with a Polyamide 11 solvent bonded system operating at low pressures. Concurrently, a program was initiated to introduce polyamide systems, up to pipe sizes of 110 mm, for new and replacement gas distribution systems operating at pressures up to 30 psig (210 kPa). As a result of the success of Polyamide 11 systems in the 1980's' a project was initiated to rehabilitate the entire low pressure cast iron pipe system in Sydney in 1988. The new polyamide system was designed to operate at 30 psig (210 kPa) with a future supply capacity of three times the existing load.

In the mid-1980s, AGL identified polyamide 12 as an alternative to polyamide 11 due to economic benefits and flexibility of supply.

In 1987, the Australian standards AS 2943, *"Plastics Pipes and Fittings for Gas Reticulation – Polyamide Compounds for Manufacture"* and AS 2944 , *"Plastics Pipes and Fittings for Gas Reticulation – Polyamide, Part 1 –Pipes, Part 2 –Fittings"* were developed. The standards outline the requirements for polyamide materials and pipe and fittings produced from polyamide materials operating at pressures up to 58 psig (400 kPa).

In the 1990's, polyamide distribution systems operating up to 58 psi (400 kPa) were installed in Poland and Chile.

In 1995, an evaluation was completed on a Polyamide 12 grade from UBE Industries, Ltd. The evaluation demonstrated that UBE PA12 was in compliance with the relevant Australian standards and was suited for the intended applications at lower costs.

Since 1991, the total consumption of polyamides for gas reticulation has been approximately 120 Mt/year. Approximately 50% of the total volume of pipe installed is Polyamide 12 . Most typically, 32 mm SDR 25 Polyamide 12 pipe is installed. Based on an annual volume of approximately 60 Mt/year, this translates to annual installed lengths of approximately 500 km/yr (approximately 300 miles/year).

Installation of polyamide pipe for gas distribution continues at AGL today. At present, approximately 80% of the distribution mains currently in service operate with a polyamide pipe installed by insertion.

Through extensive research performed at Agility Management Pty. Ltd. (Technical and Development Section) in Australia and through approximately 10 years of positive field service performance, Polyamide 12 has proven to be a viable candidate material for gas distribution systems.

1.2 Polyamide 12 High Pressure Gas Distribution Applications

Recent demographic changes and rapid urbanization have presented significant challenges for gas utility companies to safely and effectively satisfy the Nations' ever growing energy needs. As a result, there is a tremendous desire on the part of gas utility companies to operate their gas distribution infrastructure to its maximum capabilities. This has been underscored by recent initiatives to increase the pressure limitations for plastic piping system up to 125 psig, as limited by its hydrostatic design basis and geometric characteristics. Moreover, the industry has been actively working to increase the design factor which is used in the formula for determining the design pressure. These initiatives notwithstanding, conventional grades of polyethylene piping will not be able to operate over a range of desired pressures and flow capacity considerations.

In general, Polyamide 12 (PA12) offers significant potential given its inherent mechanical, physical, and long term performance characteristics. Based on empirical test data for its long term hydrostatic strength, PA12 has an established hydrostatic design basis (HDB) rating of 3150 psi. Using this particular HDB rating for an SDR 11 pipe size with either a 0.32 or 0.40 design factor, the following maximum design pressure can be potentially realized:

DF = 0.32	DF = 0.40
$p = \frac{2S}{SDR-1} x0.32$	$p = \frac{2S}{SDR-1} x0.40$
$p = \frac{2(3150)}{11-1} x.32$	$p = \frac{2(3150)}{11-1} x.40$
$p = \frac{6300}{10} x.32$	$p = \frac{6300}{10} x.40$
$p = 200\, psig$	$p = 250\, psig$

(1)

Where:

P = design pressure, psig
S = long term hydrostatic strength as represented by the HDB rating, psi
SDR = standard dimension ratio (OD/t)

From Eqn (1), it is shown that an SDR11 PA12 piping system can potentially operate at pressures up to 250 psig on the basis of their inherent long term hydrostatic strength characteristics and the use of a 0.40 design factor. For additional capacity, gas utility companies can also choose to utilize an SDR13.5 (thinner wall for added capacity) piping system which can operate at 200 psig with a 0.40 design factor. Either scenario will permit gas utility companies to utilize PA12 piping systems as an effective alternative to steel piping systems.

1.3 Technical Approach

Title 49, Part 192 of the Code of Federal Regulations governs the minimum requirements for the safe use of plastic piping systems. While all of the respective sections are important, Part 192, through reference, requires that all thermoplastic piping materials suitable for use in gas distribution applications must conform to the requirements contained within ASTM D2513-98[1] specification entitled *"Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings"* [1]. Within the main body of the ASTM D2513, there are several requirements that are applicable to all thermoplastic materials. Additional requirements are also contained within Annexes specific to each respective thermoplastic material, e.g. PE materials are in Annex A1, PA11 and PA12 materials are in Annex A5, etc. Finally, additional guidance for the introduction and use of new thermoplastic materials is also provided in a non-mandatory Appendix within ASTM D2513. These guidelines include the following:

- Conformity to ASTM D2513 requirements and establishing a ASTM product specification
- Establishing the materials' long term hydrostatic strength through comprehensive long term sustained pressure testing at elevated temperatures per ASTM D2837 requirements and PPI TR-3 policies and procedures used to establish the hydrostatic design basis (HDB) rating
- Demonstrating at least 3-years of service-related experience to demonstrate that a particular material can safely be used for underground gas pressure piping without significant changes to its long term performance characteristics

In the context of this program, a comprehensive approach was utilized to address each of these key considerations. Specifically, the objective was to develop the necessary technical data to validate the feasibility for the use of PA12 piping systems at higher pressures consistent with the requirements and recommendations contained within ASTM D2513. Technical discussions with respect to the comprehensive testing which addresses each of these key considerations are presented in the respective sections to follow.

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[1] Per the rule change issued during May 2004, and effective July 2004, the previous specified ASTM D2513-96a has been changed to ASTM D2513-98

Section 2
Characterization of Performance Requirements

In order to demonstrate conformity to ASTM D2513-98 requirements and its applicable Annexes/Appendices, GTI performed comprehensive testing and evaluation of the PA12 pipe materials supplied by the each of the three respective PA12 resin suppliers including UBE (Japan), Degussa (Germany) and EMS (Switzerland). Arkema (France), the fourth supplier of PA12 did not participate in the program.

It is important to reiterate that only an abbreviated summary of the technical discussions are presented here. Detailed discussions with respect to the testing protocols and results are contained within a separate report entitled *"Technical Reference on the Physical, Mechanical, and Chemical Properties of Polyamide 12 (PA12) for High Pressure Gas Distribution Applications"* issued to OTD and the respective PA12 resin suppliers during December 2005.

2.1 Material Performance Characteristics

Per ASTM D2513, there are several test requirements to characterize the mechanical, physical, and chemical characteristics of a given thermoplastic material. These tests include:

- Minimum hydrostatic quick burst strength (ASTM D1598)
- Tensile strength determinations (ASTM D638 and ASTM D2290)
- Flexural Modulus (ASTM D790)
- Chemical resistance testing (ASTM D543)
- Melt point and Oxidation induction times (ASTM 3418)

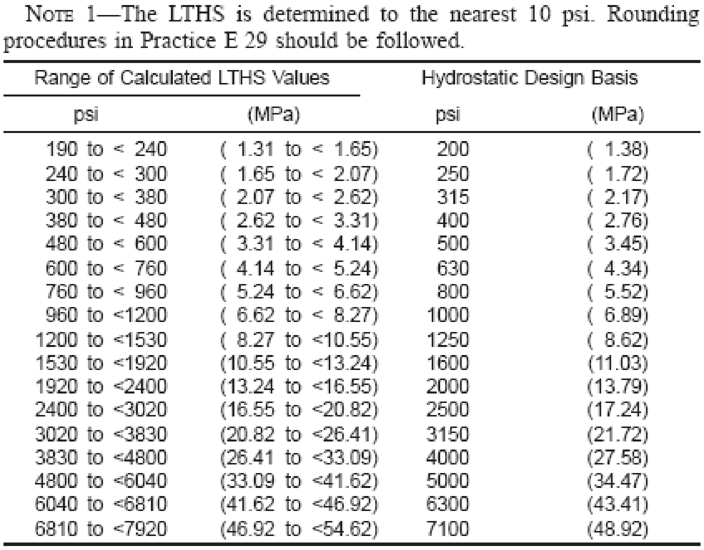
The cumulative results of the various short term testing used to characterize the mechanical, chemical, and physical properties indicates that the PA12 materials from each of the three PA12 resin suppliers conforms to the requirements of the main body of ASTM D2513 and its respective Annexes. Specifically, the respective PA12 materials from each of the three resin suppliers' either meets and/or exceed the requirements and compares well with the established PA11 requirements contained within Annex A5. On the basis of this and other test data provided in the following sections of this report, the PA12 material from UBE was successfully integrated within ASTM D2513 (2006 version).

2.2 Determination of Long Term Hydrostatic Strength (HDB Rating)

In addition to determining the mechanical, chemical, and physical properties of the PA12 material, additional comprehensive tests were performed to establish the long term hydrostatic strength, as represented by the materials' hydrostatic design basis (HDB) rating, pursuant to the requirements contained with ASTM D2513.

It is important to note that this particular activity was not a part of the OTD program and was carried out by each of the respective PA12 resin suppliers independently. The data and information has been provided to OTD within the context of the co-funding arrangements established at the onset of the program. It is important to emphasize that the HDB rating is a necessary prerequisite for any new thermoplastic material in order for it to be used for gas distribution applications. The HDB rating is the long term strength rating that is substituted within the design formula used to calculate the design pressure.

For a given thermoplastic material, the long term hydrostatic strength (LTHS) is determined on the basis of comprehensive tests as outlined per ASTM D2837 requirements and PPI TR-3 policies and procedures. The LTHS is determined by subjecting several pipe specimens to long term sustained pressure testing at elevated temperatures over a 10,000 hour test time. The resulting data (stress-rupture) are analyzed by linear regression analysis to yield a best-fit log-stress versus log time-to-fail straight-line equation. On the basis of this equation, the material's mean strength at the 100,000 hour intercept (LTHS) is calculated. The resultant LTHS is correlated to an appropriate Hydrostatic Design Basis (HDB) category, as shown in Figure 1 below from ASTM D2837.



NOTE 1—The LTHS is determined to the nearest 10 psi. Rounding procedures in Practice E 29 should be followed.

Range of Calculated LTHS Values		Hydrostatic Design Basis	
psi	(MPa)	psi	(MPa)
190 to < 240	(1.31 to < 1.65)	200	(1.38)
240 to < 300	(1.65 to < 2.07)	250	(1.72)
300 to < 380	(2.07 to < 2.62)	315	(2.17)
380 to < 480	(2.62 to < 3.31)	400	(2.76)
480 to < 600	(3.31 to < 4.14)	500	(3.45)
600 to < 760	(4.14 to < 5.24)	630	(4.34)
760 to < 960	(5.24 to < 6.62)	800	(5.52)
960 to <1200	(6.62 to < 8.27)	1000	(6.89)
1200 to <1530	(8.27 to <10.55)	1250	(8.62)
1530 to <1920	(10.55 to <13.24)	1600	(11.03)
1920 to <2400	(13.24 to <16.55)	2000	(13.79)
2400 to <3020	(16.55 to <20.82)	2500	(17.24)
3020 to <3830	(20.82 to <26.41)	3150	(21.72)
3830 to <4800	(26.41 to <33.09)	4000	(27.58)
4800 to <6040	(33.09 to <41.62)	5000	(34.47)
6040 to <6810	(41.62 to <46.92)	6300	(43.41)
6810 to <7920	(46.92 to <54.62)	7100	(48.92)

Figure 1: Hydrostatic Design Basis Categories as a function of LTHS

Using the aforementioned approach, as of preparation of this report, both the UBE and Degussa PA12 materials have an established HDB rating. The UBE material has undergone the complete 10,000 hours of required testing and has already received a *standard* listing of 3150 psi at 73F and 2500 psi at 140F within PPI TR-4/2006 listings. The Degussa PA12 material has completed nearly 8,000 hours of the required 10,000 hours of testing. It also has received an *experimental grade* listing (E-2) of 3150 psi at 73F and 2500 psi at 140F within PPI TR-4 listing. As of preparing this report, EMS has not provided any information with respect to their status of testing and/or the results.

2.3 Characterization of Slow Crack Growth Resistance

Over 40 years of field experience using polyethylene materials has demonstrated that the primary mode of in-service failures are due to the slow crack growth (SCG) failure mechanism.

Because plastics are very complex combinations of elastic and fluid like elements and they exhibit properties shared between those of a crystalline metal and a viscous fluid - viscoelastic behavior. As a result, when a plastic is subjected to a suddenly applied load that is then held constant, it deforms immediately to a strain predicted by the stress-strain modulus. It then continues to deform at a slower rate for an indefinite period. If the stress is large enough, then the rupture of the specimen will eventually occur. This particular time dependent viscous flow component of deformation is known as creep, and the failure that terminates it is known as creep rupture.

As the stress levels decrease, the time to failure increases and material deformation becomes smaller. At very long times to failure, deformation is usually less than 5% for most thermoplastics. The fracture is then a result of crack initiation and slow crack growth (SCG). A large body of previous GTI sponsored research and empirical observations in the field indicates that this type of “brittle” failure, not the excessive deformation, is the ultimate limit of the long-term performance of plastic pipe in service. Failures in the ductile mode also may potentially occur, but only in operating conditions where the pressure in service is accidentally increased.

Therefore, in order to ensure that only those materials exhibiting excellent SCG characteristics are utilized for gas distribution applications, ASTM D2513 prescribes several tests including validating the long term hydrostatic strength over a 50-year theoretical design life, PENT test, etc.

In the context of this particular program, several tests were performed consistent with the ASTM D2513 requirements. A brief summary of the results includes:

- Because there are no validation protocols specific to polyamide materials within ASTM D2513, the project team employed the same theoretical considerations that were used for PE materials. The primary assumption within ASTM D2513 is that materials which are used for gas distribution applications must demonstrate ductile performance over their intended design life – 50 years. Subsequently, ASTM D2513 requires additional long term sustained pressure testing at elevated temperature using specified test conditions for test time, temperature, and pressures. As a result, six specimens from both UBE and Degussa were subjected to comprehensive long term sustained pressure testing at 290 psig and 80C. The threshold test time was determined to be 1000 hours. It is important to note the significant degree of conservatism inherent within this approach – the test conditions are greater than the calculated values using the bidirectional shift functions, and are consistent with proposed International Standards Organization (ISO) requirements for PA materials. The results of the testing demonstrated that there were *no failures* from either the Degussa or UBE pipe specimens at test times greater than 1500 hours.

- In addition to LTHS validation testing, comprehensive PENT tests were performed on injection molded plaques. The PENT test is useful relative index for a particular materials' resistance to the SCG failure mechanism. For all of the PA12 test specimens from both the Degussa and UBE pipe, there were *no failures* at times greater than 1000 hours at a test stress of 2.4mPa and 80C.

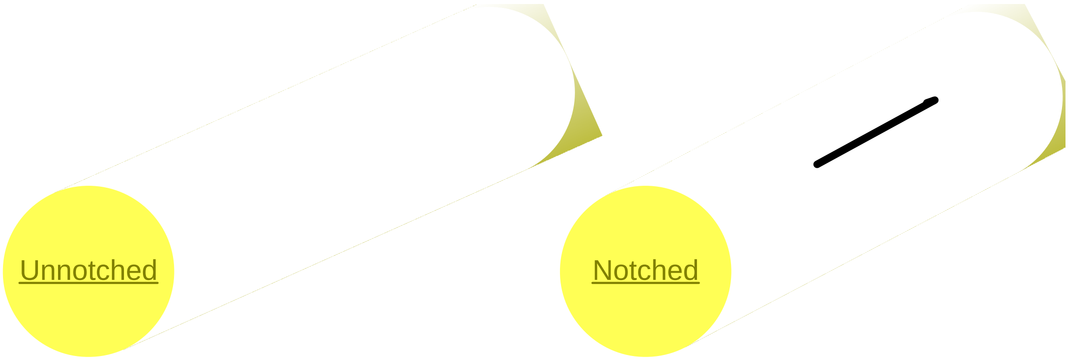
While the results of the aforementioned testing effectively addressed the SCG performance requirements contained within ASTM D2513, the ISO specification for thermoplastic piping materials contains additional test requirements to characterize the influence of surface scratches on the outside diameter of the pipe - the notched pipe test (ISO 13479).

The notched pipe test is somewhat analogous to the validation testing required under ASTM 2837 whereby actual pipe specimens are subjected to long term sustained pressure testing at elevated temperatures. However, the ISO 13479 notched pipe test provides for intentionally introducing a controlled notch (20% of the wall thickness) along the axial direction of the pipe specimens located 90° apart circumferentially. The notched pipe specimens are then subjected to constant internal pressure based on the respective material and the time to failure is recorded. It is important to note that this is a very aggressive test in that the actual stress at the remaining ligament is extremely high. Because ISO 13479 only prescribes test conditions for PE materials, a slightly modified approach was used to establish the appropriate test conditions. It was reasoned that while gas utility companies employ effective construction practices to minimize the potential for installation induced scratches, they invariably do occur. However, once installed, the pristine pipe and the pipe with the scratches both operate at the same pressures. Therefore, the project team agreed to use the same test pressure which was used to validate the long term hydrostatic strength – 290 psig. Six (6) specimens from each of the three suppliers PA12 pipe were subjected to notched pipe testing per ISO 13479. As expected, the results of the notched pipe test for each of the three suppliers' PA12 product were positive. There were no failures for any pipe specimens with a 20% notch depth at test pressures of 290 psig at 80C at test times greater than 2000 hours.

While these respective tests provided excellent insight into the SCG performance characteristics of PA12 materials, additional tests were requested by UBE to further characterize the influence of varying degree of notch depths. As a result, GTI performed comprehensive long term sustained pressure tests using notch depths of 30% and 50% of the wall thickness and a test pressure of 290 psig at 80C. In order to illustrate the extreme degree of conservatism inherent within this approach, Table 1 and Figure 2 presents the comparative illustration of the actual applied hoop stress at the location of the each respective notch depths based on the test conditions. From Figure 2, it is important to note that, at 50% notch depth, the corresponding test stress is approximately 2 times greater than the stress used to validate the HDB rating.

Conditions	Test Conditions	Time to Failure (hrs)
Condition 1 (UBE PA12)	Test Pressure: 290 psig (20 bars) **Notch Depth: 30%** **Stress at remaining ligament: 2132psi** Test Temperature: 80°C 50-year substantiation time: 877 hours	> **2000** hours with no failures
Condition 2 (UBE PA12)	Test Pressure: 290 psig (20 bars) **Notch Depth: 50%** **Stress at remaining ligament: 3043 psi** Test Temperature: 80°C 50-year substantiation time: 877 hours	> **500** hours with no failures of 3/6 specimens

Table 1: Notch pipe testing of UBE PA12 pipe specimens with at 30% and 50% notch depth



Temp = 80°C
Internal Test Pressure = 290 psig
Test Stress = 1450 psi
Time to Failure = 877 hours

Note: Time is for 50 yrs
Substantiation

Temp = 80°C
Internal Test Pressure = 290 psig
Test Stress (100% wall) = 1450 psi
Time to Failure = 165 hours

Note: Current Time Requirements
Per ISO 13479

Temp = 80°C
Internal Test Pressure = 290 psig
Test Stress (70% wall) = **2132 psi**
Time to Failure = 877 hours

Temp = 80°C
Internal Test Pressure = 290 psig
Test Stress (50% wall) = **3043 psi**
Time to Failure = 877 hours

Figure 2: Comparison of notch pipe test criterion with 30% and 50% notch depths

Cumulatively, the results of comprehensive tests to characterize the SCG characteristics for PA12 materials were extremely positive.

2.4 Effects of Secondary Stresses

In addition to characterizing the SCG performance characteristics and influence of surface scratches, additional tests were performed to characterize the influence of secondary stresses. The motivating factors for performing these tests were two-fold. First, as previously discussed, ASTM D2513 suggests (non-mandatory requirement) that new thermoplastic materials must demonstrate at least 3-years of in-service experience through either field demonstrations and/or suitable tests which simulate the effects of in-service conditions. Second, more importantly, all of the previous tests discussed thus far only take into account the stress contribution due to internal pressure. However, under actual field conditions, the piping systems are subjected to the combined effects of both internal pressure and other secondary stresses including rock impingement, earth loading, and bending. Often, these secondary stresses, not internal pressure, are the root cause of many in-service field failures.

Therefore, comprehensive long term sustained pressure tests were performed at elevated temperatures to characterize the effects of various types of secondary stresses. It is important to note that these tests are not a part of either the ASTM or ISO standard. The test methodology is an extension of previous research performed by Dr. Charles Bargraw – DuPont and further refined by Dr. Michael Mamoun – Gas Technology Institute to study the performance characteristics of older generation PE materials. For the case of the rock impingement, the intent is to evaluate the performance of pipe materials subjected to indentations by a ½” rock. For the case of the earth loading, the typical safe deflection limit that is specified is 5%. For the case of the bending strain, the typical bend radius limits for a pipe specimen without any joints or appurtenances is 20 times the outside diameter.

Six (6) 2-inch SDR11 PA12 pipe specimens from Degussa and UBE were placed in appropriate test rigs to simulate the effects of rock impingement, earth loading, and bending strain. The entire test assembly was placed under long term sustained pressure testing at 290 psig at 80C. Again, note the significant degree of conservatism – the 290 psig test pressure is the same pressure used to validate the LTHS values. Like the case of the notched pipe test, Like the case of the notched pipe test, the applied secondary stresses in combination to the circumferential stresses resulting from the internal pressure significantly increases the overall applied stress beyond the stress value used to validate the HDB raring. The results of the testing demonstrated that there were <u>no failures after 1000 hours of testing</u>, as presented in Table 2 below.

Secondary Stress	**Test Criterion**	**Results**
Rock Impingement	*½" Indentation* Test Pressure = 290 psig Test Temperature = 80C	Test Time > 1000 hour with No failures
Earth Loading	*5% Deflection of Outside Diameter* Test Pressure = 290 psig Test Temperature = 80C	Test Time > 1000 hour with No failures
Bending Strain	*20 times OD* Test Pressure = 290 psig Test Temperature = 80C	Test Time > 1000 hour with No failures

Table 2: Summary of test conditions to simulate effects of secondary stresses

2.5 Rapid Crack Propagation Characteristics

In general, RCP considerations become more critical with increasing pressures, increasing diameters, increasing wall thickness, and decreasing temperatures. In order to effectively characterize the RCP resistance of plastic piping materials, promising test methodologies have been developed including the small-scale steady-state (S4 test) and full scale RCP test (FST). Given the cost effective nature of the S4 test as compared to the FST, it is the preferred test method.

The S4 test is performed in accordance to ISO 13477 guidelines *"Thermoplastic pipes for conveyance of fluids – Determination of rapid crack propagation (RCP) – Small-scale Steady-state (S4 Test).* Per the test requirements, a specified length of the plastic piping material is pressurized and maintained at a specified test temperature of 32°F in a test rig. The specimen is then impacted to initiate a fast growing longitudinal crack along the pipe length.

In order to establish the appropriate test conditions, a series of initiation tests are performed with un-pressurized pipe specimens at 32°F. Using a blade speed of 15m/s ± 5m/s, the pipe specimen is impacted and the crack growth is measured. For a given set of temperature and blade speed conditions, if the crack growth is greater than one (1) pipe diameter, the initiation conditions are considered to be satisfied and the same conditions are then used to determine the S4 critical pressure values.

Following the initiation testing, a series of iterative tests are performed using the initiation blade speed and constant temperature conditions (32F) at varying internal pressures. Crack propagation is then defined at pressure values where the measured crack exceeds 4.7 times the pipe diameter. The transition pressure from crack arrest to crack propagation then determines the S4 critical pressure value. It is important to note, the temperature is the most critical parameter. If the temperature of the pipe specimen is not closely monitored, then the S4 values obtained through this test can be overstated.

A series of S4 tests were performed using 6-inch SDR 11 pipe specimens supplied from both Degussa and EMS at varying internal pressures and 32°F until the S4 critical pressure values were obtained. Additional S4 tests were performed on 4-inch SDR 11 pipe supplied from UBE. The results of the testing are presented in Table 3 below.

PA12 Supplier	S4 Critical Pressure at 32°F
Degussa (6-inch SDR11)	55 psig
EMS (6-inch SDR 11)	40 psig
UBE (4-inch SDR 11)	40 psig

Table 3: Summary of the S4 critical pressure for the various PA12 suppliers

At present, no definitive statements can be made with respect to the significance of this particular test and its correlations to service performance. There is tremendous degree of uncertainty associated with the test procedure and the formulas used to correlate the S4 test results with the full-scale critical pressure values and maximum allowable operating pressure.

Additional work has been on-going at the ISO level to perform full scale RCP testing of the PA12 materials by the various PA12 suppliers, which again is outside the scope of this project. Based on information provided by the various PA12 suppliers and as of preparing this report, there are no definitive conclusions derived from the test data. Additional meetings at the ISO have been scheduled for March 2007 to investigate the matter further.

Section 3
Characterization of Critical Operating Considerations

Based on the preceding discussions, the results of comprehensive laboratory testing effectively demonstrated that the respective PA12 materials from both Degussa and UBE conforms to relevant ASTM standards and specifications with respect to performance considerations, both through short term and long term tests. However, additional tests were also performed to evaluate the impact of critical operating practices including impact of squeeze-off and joining characteristics / procedures for PA12 piping. Other than information related to the 6-inch butt heat fusion joining, the following sections contain only an abbreviated discussion with respect to each point – detailed discussions can be found in the Technical Reference Report.

3.1 Effects of Squeeze-off

A commonly used practice to safely and effectively shutoff the flow of gas is squeeze-off. The practice involves placing the piping materials between two plates and compressing the pipe until the internal pipe walls meet (“squeezed” together). In previous GRI sponsored research, it has been amply demonstrated that improper squeeze techniques can potentially adversely impact the long term performance of the piping material.

In order to ensure that long term performance of the pipe is not compromised following the use of the squeeze-off technique, ASTM D2513 Annex A1 specifies that the pipe subjected to squeeze-off shall exhibit no leakage or visual evidence of splitting, cracking, breaking, or reduction in 1000-hour sustained pressure tests at elevated temperatures values.

In order to test the effect of squeeze-off on the PA12 materials, six specimens from each of the pipe producers were squeezed (un-pressurized) and then subjected to long term sustained pressure testing. Because the primary motivation was to ascertain information with respect to the long term performance after squeeze-off, the time, temperature, and stress condition were the same as the conditions utilized to validate the HDB ratings discussed in Section 2.3 above. Specifically, long term sustained pressure testing was performed at 80°C with an internal test pressure of 290 psig (20 bars) for a period of 1000 hours. The results were consistent with expectations. There were no failures in any of the PA12 test specimens from each of the three PA12 resin suppliers pipe at times greater than 1000 hours.

3.2 Polyamide 12 Joining Procedures

A critical construction and maintenance concern involves the safety and integrity of various types of joints on plastic piping systems. To promote the safe joining of plastic piping materials, Title 49CFR 192.283 and 192.285 prescribes certain guidelines for developing and qualifying approved joining procedures that must be in place at each utility for their thermoplastic piping materials. Specifically, per Part 192 requirements, joining procedures are qualified when heat fusion joints are made in accordance to those procedures and are then subjected to a combination of tensile strength tests and either the quick burst or long term sustained pressure tests.

There are several factors that govern the integrity of the joint including pipe preparation, heater (iron) temperature, applied force, and cooling times. In order to develop suitable ranges for these parameters, GTI performed comprehensive parametric testing using the UBE and Degussa PA12 material for 2-inch pipe sizes. On the basis of the test result, “qualified” PA12 joining procedures were developed. For the PA12 materials, the joining parameters were determined to be:

- Butt Fusion Interface Pressure Rang: 60 - 90 psi
- Heater Surface Temperature Range: 495 – 505°F
- Time of contact with Heater Face: 60 – 75 sec
- Melt Bead: 1/16” – 1/8”

It is important to note, like PE butt heat fusion, the PA12 butt heat fusion process is also a visual process. The specified times are an estimate and ambient temperature conditions must be taken into account.

Given that the primary intended application for PA12 piping system is for higher pressures and larger diameters, additional tests were performed to qualify these procedures for 6-inch IPS pipe specimens – the following discussion contains new information not found in the Technical Reference Report. Comprehensive tests were performed on parametrically controlled fusion joints made in accordance to the previously developed PA12 joining procedures with exception of varying the interfacial pressures and heater iron temperatures. Moreover, the compatibility of cross-fusions between each of the PA12 resin suppliers’ product was also investigated.

With the assistance of McElroy Manufacturing, several 6-inch PA12 butt heat fusion joints were prepared using the specific PA12 joining procedures. Specifically,

- 36 fusion joints were made from each resin supplier (UBE, Degussa, and EMS)
- 3 base materials – pipe only for use as control specimens
- 3 cross fusions – different materials

Four (4) coupons were machined from each fusion joint and subjected to McSnapper™ testing, as shown in Figures 3. The McSnapper™ is a high speed tensile-with-impact testing machine which combines the Tensile Impact Test ASTM D1822 and High Speed Tensile Test ASTM D2289. The McSnapper™ unit uses a hydraulic cylinder to provide the necessary force and velocity and uses a piezoelectric load cell to measure resistance forces on the samples. The unit then measures or calculates and records the force, energy, velocity, and position of the data for the respective test specimen. Figure 4 illustrates the progression of the McSnapper™ testing apparatus.

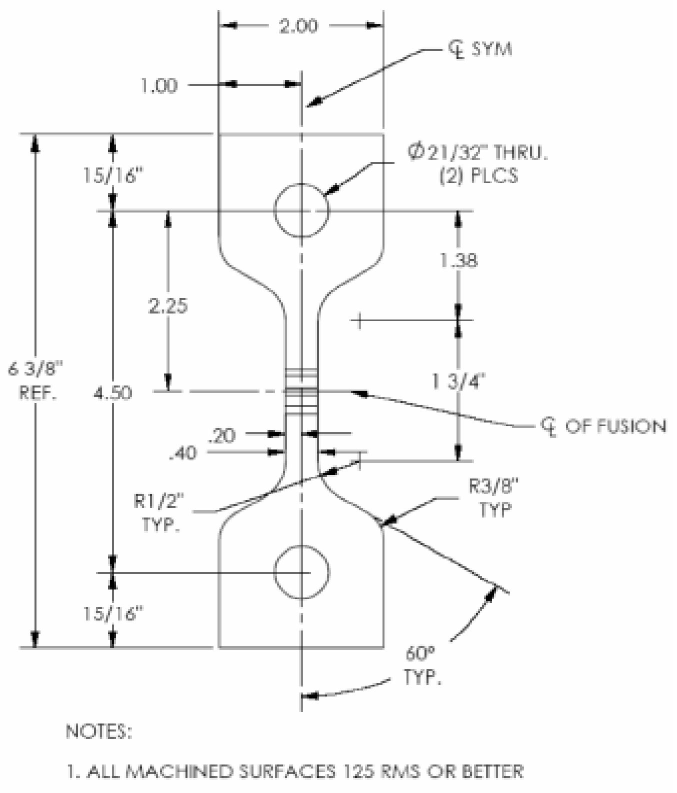


Figure 3: Schematic Illustration of test specimen used for McSnapper™ Testing

Figure 4: Typical McSnapper™ test set-up and testing progression of a typical PA12 test specimens at an average speed of 6 in/s.

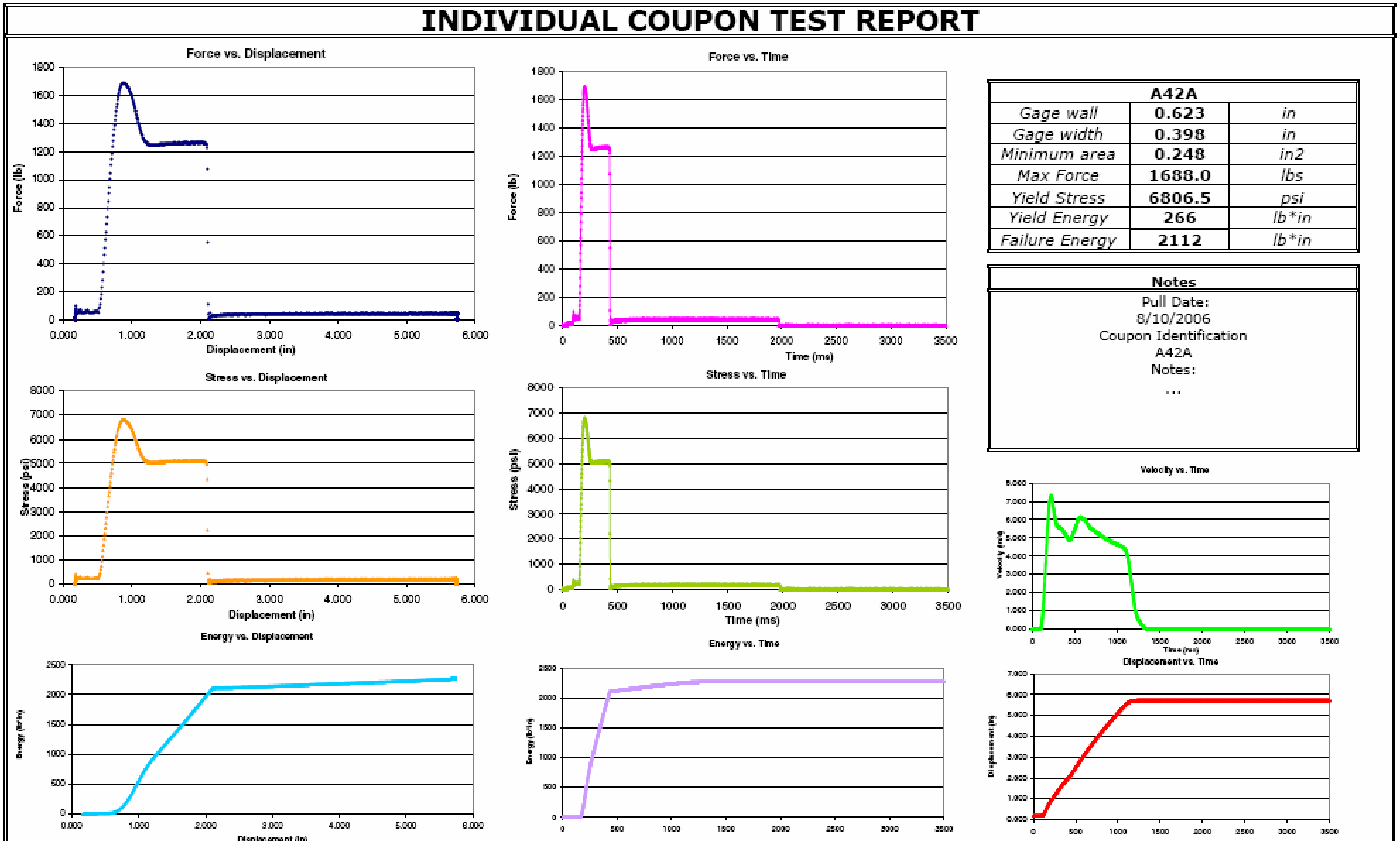
The results of the McSnapper™ testing on the 6-inch PA12 fusion joints from the various resin suppliers were consistent with expectations. There was an excellent degree of corroboration between the tensile strength values of the PA12 joints as compared to PA12 pipe specimens. Figures 6-7 presents a summary of the test data for various joints and control specimens – this is for illustrative purposes only as there were over 216 data points in total.

In addition to validating the performance of PA12 joints from each of the respective PA12 resin suppliers using their materials, various cross fusions were made using PA12 pipes from different suppliers – unlike pipe. The test results confirmed the ability to make strong and effective cross-fusion joints, i.e. joints made using PA12 pipes from different suppliers such as Degussa pipe to UBE pipe. It was reported that in all of the test specimens, with the exception of one coupon, all of the failures originated outside the fusion interface, as shown in Figure 5 below. The exact cause for this particular failure is unknown. Regardless, the overall results demonstrated that strong effective 6-inch PA12 joints can be made using the qualified PA12 joining procedures.

Figure 5: Illustration of the fracture surface of a PA12 joint which did not satisfy the visual criteria for an acceptable joint

In addition to the McSnapper™ testing, additional long term sustained pressure testing at elevated temperatures were performed on 6-inch PA12 pipe specimens using 290 psig at 80C. As expected, the results of the testing were consistent with expectations. There were no failures in any of the test specimens from each of the three PA12 resin suppliers' products at times greater than 1000 hours.

Cumulatively, the results of the testing amply demonstrated the ability to make strong joints using the qualified PA12 joining procedures consistent with CFR Part 192 requirements.



INDIVIDUAL COUPON TEST REPORT

A42A		
Gage wall	0.623	*in*
Gage width	0.398	*in*
Minimum area	0.248	*in2*
Max Force	1688.0	*lbs*
Yield Stress	6806.5	*psi*
Yield Energy	266	*lb*in*
Failure Energy	2112	*lb*in*

Notes

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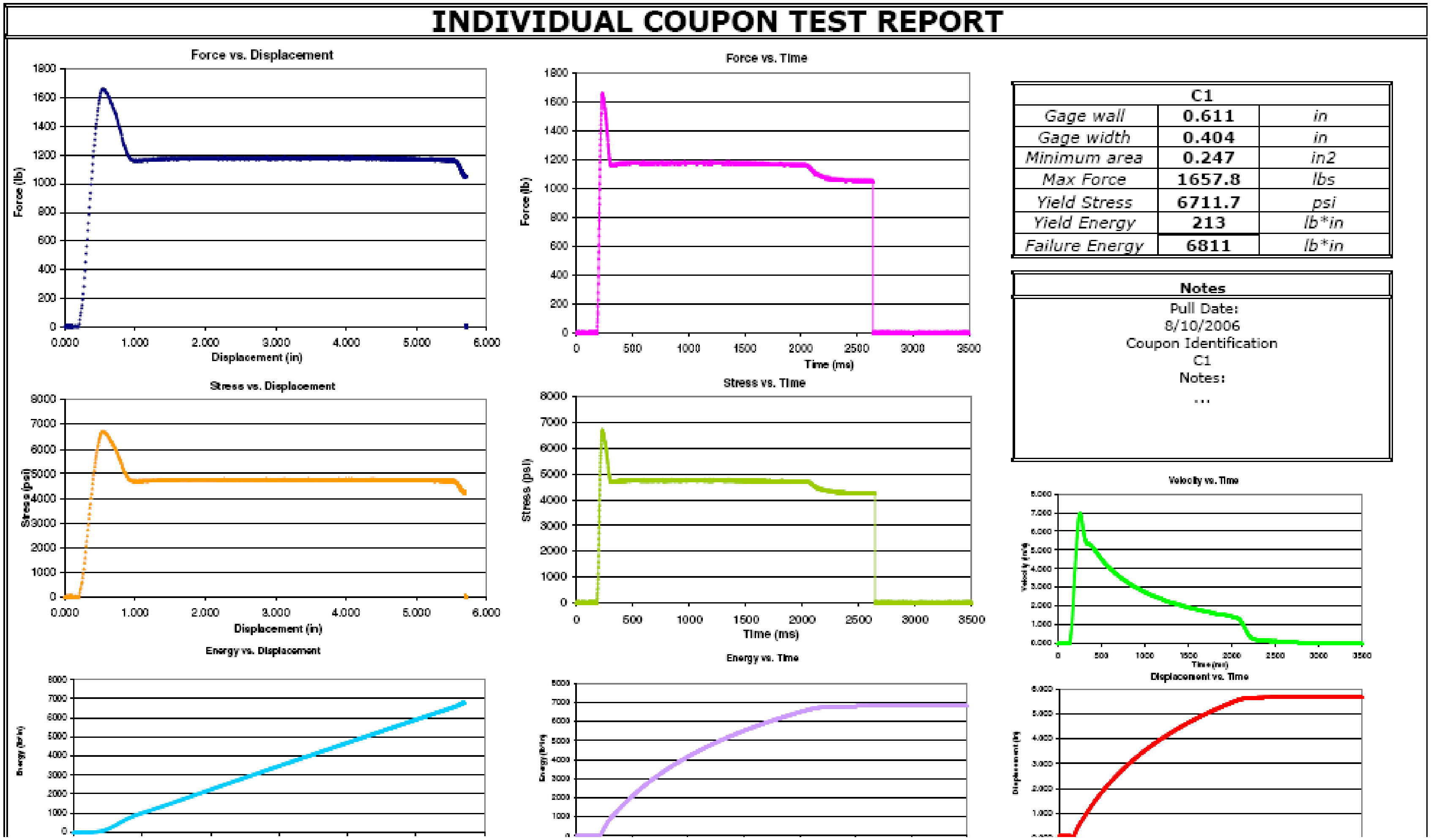
Figure 6: Illustration of test results from McSnapper testing for a typical PA12 heat fusion joint



INDIVIDUAL COUPON TEST REPORT

C1		
Gage wall	**0.611**	*in*
Gage width	**0.404**	*in*
Minimum area	**0.247**	*in2*
Max Force	**1657.8**	*lbs*
Yield Stress	**6711.7**	*psi*
Yield Energy	**213**	*lb*in*
Failure Energy	**6811**	*lb*in*

Notes

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C1
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Figure 7: Illustration of test results from McSnapper testing for a typical PA12 pipe specimen

Section 4
Evaluation of Appurtenances

Another critical element of this particular program was to evaluate various types of fittings and appurtenances. While there are numerous types of fittings that may be required to construct an overall PA12 piping system, the intent of this program was to test and evaluate transition fittings at a minimum. The following sections presents detailed discussions with respect to the evaluation of transition fittings, mechanical fittings, and electrofusion fittings. It is important to emphasize that the development and evaluation work specific to mechanical and electrofusion fittings was outside the OTD scope of work. Both the development efforts and the evaluations were performed independently by the PA12 resin suppliers and the information contained herein has been provided to OTD as past of the co-funding agreements.

4.1 Transition Fittings

In the context of this program, transition fittings are a critical element for the development of an overall PA12 piping system. Because the intended application for PA12 piping systems are at high pressures (150 – 250 psig), it is important to have a means to safely facilitate tie-in to steel piping systems.

The qualification and use of transition fittings for use in gas distribution applications is governed by ASTM F1973 entitled *“Standard Specification for Factory Assembled Anodeless Risers and Transition Fittings in Polyethylene (PE) Fuel Gas Distribution Systems”*. Although the requirements contained within this specification are specific to PE, this standard was used as guidance for the relevant testing of PA12 transition fittings.

Per ASTM F1973 requirements, there are several tests which are prescribed. The two most important tests include: temperature cycling and tensile testing. Given the limited quantities of transition fittings that were manufactured, the consensus decision of the project team was to evaluate the temperature cycling requirement which was believed to be the more critical between the two. The temperature cycling requirement states that the joint shall be leak-free after exposure to 10 temperature cycle tests ranging between 20F and 140F.

As a result, several 2-inch PA12 transition fittings were developed by Continental Industries using their existing PE designs and tooling. Six PA12 transition fittings from both Degussa and UBE were subjected to the range of test temperatures (20F to 140F). Three samples were then leak tested at 7 psig, and all of the specimens passed. The remaining three specimens were then tested at 1.5 times the MAOP (375 psig). For the PA12, the MAOP was chosen to equal to 250 psig assuming a HDB rating of 3150 psi and using a 0.40 design factor, see section 1.2. Under these conditions, there were no failures that were observed for the transition fittings made from the Degussa and UBE PA12 pipe.

4.2 Mechanical Fittings

The qualification and use of mechanical fittings for use in gas distribution applications is governed by ASTM F1924 and ASTM F2129 depending on the operating pressure and choice of material for the plastic mains. ASTM F1924 provides the qualification requirements for mechanical fittings to be installed on PE piping system, and ASTM F2129 provide qualification requirements for mechanical fittings to be installed on Polyamide (PA) mains. It is important to emphasize that the requirements for both of these standards is the same with the exception of minor changes to certain test conditions.

Like the case with the transition fittings, targeted tests were performed on 2-inch mechanical fittings made from injection molding trials at Continental Industries using the UBE and Degussa PA12 resin. Specifically, mechanical fittings installed on PA12 piping were subjected to long term sustained pressure tests at elevated temperatures and temperature cycling tests.

Six pipe/fitting assemblies were subjected to long term sustained pressure tests at 290 psig and 80C. The mechanical fittings were tapped prior to test to ensure that entire joint is under test. The results of the testing were consistent with expectations. There were no failures that were observed in any of the test specimens at test times greater than 1000 hours.

In addition to the long term sustained pressure tests, six specimens from each supplier was subjected to temperature cycling testing. Like the previous testing on the transition fittings, the temperature cycling tests for mechanical fittings require that the mechanical joint be leak tight following exposure to 10 alternating temperature cycles ranging in temperature from 20F to 140F at pressures of 7 psig to 1.5 times MAOP. Like the case with the transition fittings, the MAOP was assumed to be 250 psig based on the use of a 3150 psi HDB rating and a 0.40 design factor. Again, as expected, there were no failures observed with any of the mechanical fittings that were tested.

4.3 Electrofusion Fittings

In addition to transition fittings and mechanical fittings, another valuable component(s) that was also developed for PA12 piping systems are electrofusion fittings. It is important to emphasize that this particular activity was performed by Degussa independently and the information included herein is made in the context of the co-funding arrangement between Degussa and OTD.

The qualification for the use of electrofusion fittings is governed by ASTM F1055. Degussa, in conjunction with Friatech, developed the necessary electrofusion fittings made from PA12 resin for use on PA12 piping using the universal electrofusion box. It is important to note, the primary factor for performing this developmental activity is that given the inherent chemical make-up of PA12 materials, they will not bond with PE using heat. As a result, conventional PE electrofusion fittings will not work on PA12 piping systems. Moreover, the differences in the range of operating pressure also preclude the use of conventional PE electrofusion fittings.

Based on information provided by Degussa, the electrofusion fittings made at Friatech using the PA12 resin conforms to all relevant requirements contained within ASTM F1055 requirements.

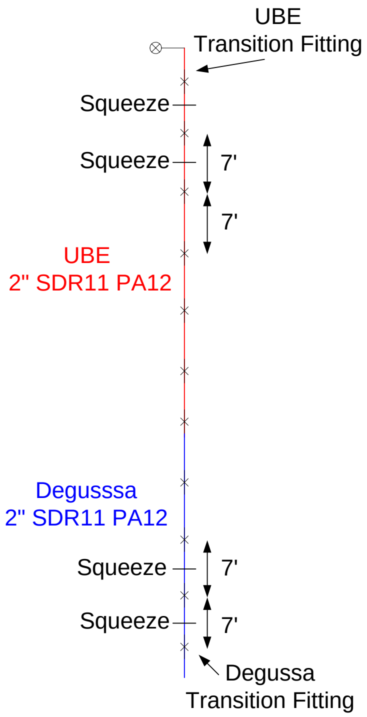
Section 5
Field Demonstration

In addition to comprehensive laboratory evaluations, another critical element of the overall program was to validate the technical feasibility for the use of PA12 piping systems and to ensure safe performance under field testing.

5.1 GTI Installation – 2-inch piping with surrounding soil

A small scale field installation was performed on GTI private property to gain better insight into the construction and maintenance of the PA12 piping systems and to characterize the effects of in-service conditions during February 2005. The primary objectives of this field demonstration were to evaluate the handling capabilities of PA12 pipe and the impact of squeeze-offs on PA12 piping material.

Two inch IPS SDR 11 PA12 pipes from UBE and Degussa were used for the installation. Approximately 70' of PA12 pipe was installed, of which 42' was UBE and 28' was Degussa. The schematic below is a layout of the PA12 piping material used for the field installation.



The PA12 pipes were supplied in 7 foot stick lengths, which were fused together using the qualified PA12 joining procedures as shown below.

- Butt Fusion Interface Pressure Range 60 - 90 psi
- Heater Surface Temperature Range 495 – 505°F
- Estimated Time of contact with Heater Face 60 – 75 sec
- Melt Bead 1/16" – 1/8"

All of the pipe ends were cleaned about 1-2” back with an alcohol wipe. The pipes were then clamped into a McElroy No. 14 Pitbull fusion machine. Alignment of the pipe ends were checked and adjusted as necessary. The pipe ends were faced to obtain clean, smooth mating surfaces. A heating tool was used to simultaneously heat both pipe ends. The temperature range of the heating tool was 495 – 505°F. The pipe ends were in contact with the heating tool for approximately 60 seconds until the desired melt pattern was observed (1/16 – 1/8” bead). Upon removing the heat source, the pipe ends were fused together using an applied torque of 10 ft-lb. This force was applied for approximately 45 seconds. The fused pipe ends remained in the machine for a period of 10 minutes to ensure the integrity of the joint, as shown in Figure 8. Two transition fittings, one of each of the respective suppliers, were also installed. The transition fittings were heat fused to the end pipe lengths from each of the respective suppliers.

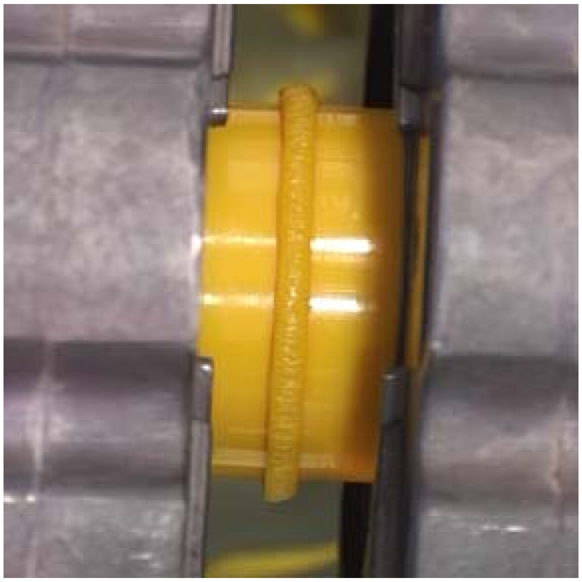


Figure 8: Typical PA12 butt fusion joint

Since a squeeze-off technique is commonly used to control the flow of gas in the natural gas industry, the effects of this technique needed to be evaluated. Therefore, the pipe specimens were squeezed at various intervals over the length of pipe to be installed. As seen in the above diagram, two squeezes were performed on pipe segments of each of the respective suppliers. Each squeeze was performed in the middle of a 7’ pipe stick length, so that it was not in close proximity to any fusion joints. The PA12 pipe was inserted into a squeeze tool and centered between the squeeze-off bars. The squeeze time for a 2” diameter pipe is approximately 4 minutes. The screw clamp was turned 360° every 15 seconds to compress the tubing. The squeeze was continued until the tubing was completely compressed. The squeeze was then held in the squeeze tool for 4 hours, as shown in Figure 9.

Figure 9: Application of squeeze-off procedure on PA12 pipe

After the 4 hours elapsed, the tool was released in the same manner as it was applied. The screw clamp was turned 360° every 15 seconds until the tubing was completely released, as shown in Figure 10.

Figure 10: Completed squeeze-off on PA12 pipe

After completing the fusions and squeeze-offs, a trench was excavated for the field installation. The trench was approximately 100’ in length, 1’ in width, and 3’ in depth. Once installed, the PA12 flow loop was pressure tested for one hour to observe any leaks. The entire line segment was then pressure tested at 1.5 x MAOP, or 375 psig. After the pressure testing, the pressure of the flow loop was decreased and installed operating at 250 psig, as shown in Figure 11.

Figure 11: Installation of 2” PA12 pipe at GTI test facilities

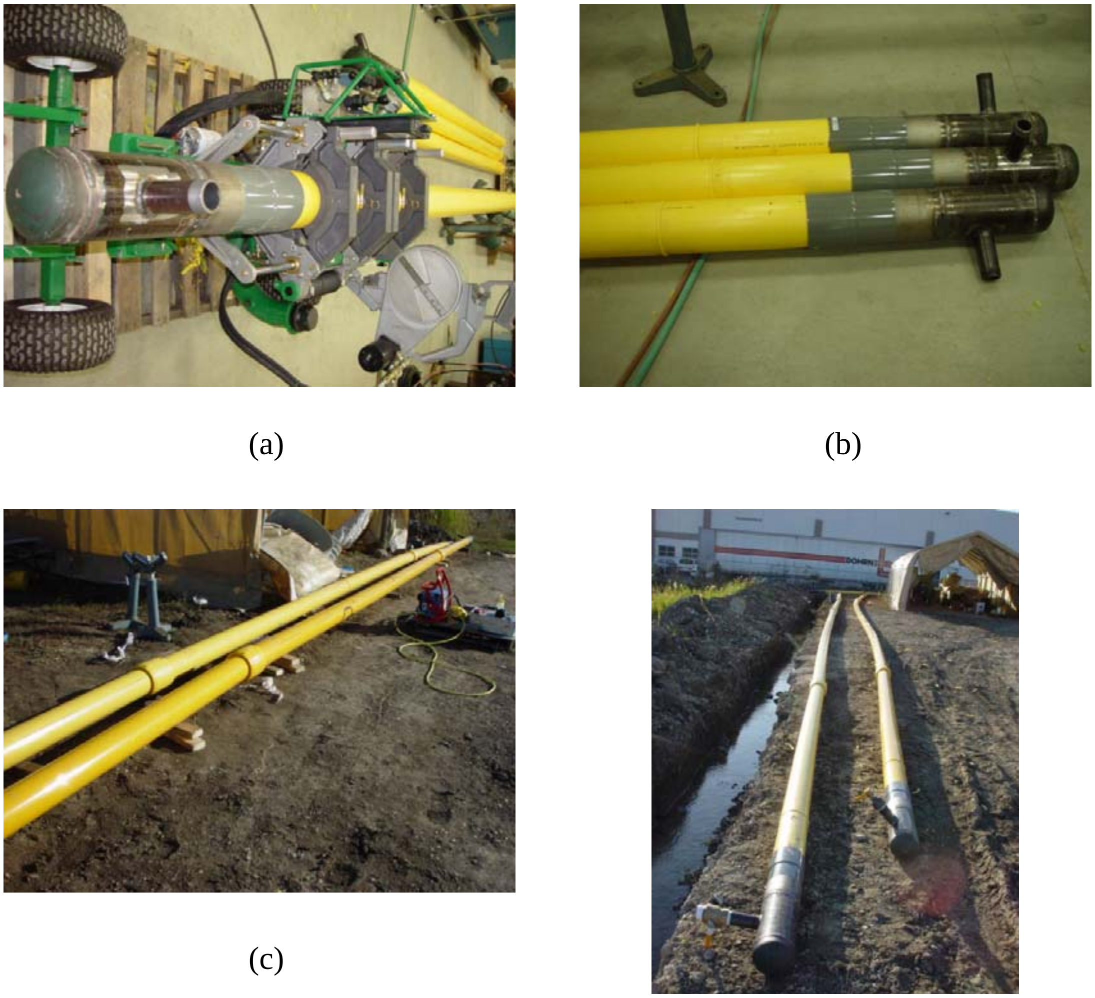
Following the installation, the trench was backfilled with indigenous soil. Approximately 6” of sand were placed above and below the pipe to mark the location of the flow loop for future excavations.

5.2 GTI Installation – 6-inch piping with different backfill materials

Having confirmed the ability to install and operate the PA12 piping systems at higher operating pressures using 2-inch piping, additional installations were performed on GTI private property to evaluate the use of larger diameter PA12 pipe sizes – 6-inch. Specifically, two separate installations were performed to evaluate the effects of various types of backfill including rocky soil and flowable fill during October, 2006.

This particular installation(s) was extremely challenging and difficult due to the adverse weather conditions. However, it was also an excellent test installation given that these conditions represented the worst case conditions that could be possible in many portions of the United States – cold, rain/snow, and windy conditions. As a result, the entire installation took several days longer than expected to complete.

Two separate PA12 lines (one from Degussa and one from UBE) were installed in a single joint trench which was 120’ long, 3’ deep, and 3’ wide. There were a total of two separate trenches running perpendicular to one another using two different backfill materials respectively – rocky soil and flowable fill. The 6-inch PA12 pipes were supplied in 40-foot straight lengths by both Degussa and UBE and were extruded overseas at DEKA Systems in Germany. The respective pipe segments were joined using both PA12 butt heat fusion procedures and Friatech electrofusion couplings made from the PA12 resin. Given the limited availability of additional fittings such as end caps and reducers, 6-inch PA12-steel transition fittings were installed on both ends of the line segments with the appropriate steel end connections (steel end caps) to facilitate pressurization. Figure 12 presents representative illustrations of the overall installation.



(a)

(b)

(c)

(d)

Figure 12: Representative illustrations of the 6” PA12 installation at GTI pipe farm during October 2006. (a): Illustration of the butt heat fusion using the McElroy 28 machine. (b): Illustration of end connections used to facilitate pressurization and tie-in. The end connections consist of a 6-inch PA12 transition fitting and schedule 40 steel fittings and end caps. (c): illustration of pipe connected using both PA12 electrofusion fittings and butt heat fusion joints. (d): Illustration of pipe to be installed using flowable fill as the backfill material.

The respective PA12 lines were installed in each of the respective trenches and subjected to a 48-hour leak test at 150 psig (Note, this extended test time was due to rain delays). Following the leak test, the lines were then pressure tested at 375 psig for a period of 24 hours, as shown in Figure 13 (again, the extended test time was due to rain). The pressure was then reduced for each line segment to 250 psig and installed at a 3’ feet burial depth. Each trench was then backfilled with the respective materials, and the test installation was completed on 10/11/2006.

(a) (b)

Figure 13: Representative illustrations of installed PA12 pipe segments using both (a)flowable fill and (b)rock soil mixture

While the overall installation was successful, there were some minor issues that were observed. Specifically, there were minor difficulties installing the 6-inch electrofusion couplings on the UBE pipe outdoors. Following the completion of the heating and cooling cycles, significant amount of the melt extruded outside the ends of the couplings, as shown in Figure 14. This was inconsistent with previous experience. All of the fusions which were performed indoors under controlled laboratory conditions did not exhibit this kind of behavior. It is believed that the most likely cause of these particular failures were as a result of operator error given the adverse weather conditions and lack of proper tooling.

(a) (b)

Figure 14: Representative illustrations of the inside and outside surfaces of the failed electrofusion couplings using on the UBE PA12 pipe

5.3 National Fuel Installation – 6” piping with surrounding soil

Besides the installations at GTI, an additional test installation was performed by National Fuel on its private property located at their Mineral Springs facility. Like the GTI installation, this particular installation was also impacted due to adverse weather conditions. During the week prior to the installation, record snowfalls (20 inches) fell on the Buffalo, NY area. Regardless, the installation took place as planned.

The primary objective(s) of this particular installation was to evaluate the impact of bending strain on the in-service performance characteristics of the PA12 piping system and gain critical feedback from an operator’s perspective. Approximately 500 feet of 6-inch straight length PA12 pipes supplied in 40-foot sections from Degussa and UBE were installed under the influence of two different bend radius. For the UBE pipe with no joints or appurtenances, the bend radius for the test installation was 20 times the OD. For the Degussa pipe, the test bend radius was 90 times the OD at the location of the heat fusion joint. This is significantly more conservative than the specifications prescribed for PE piping. Figure 15 presents an illustration of the overall test installation site.

Figure 15: illustration of National Fuel installation with varying bend radii

Like the installations at GTI, the PA12 pipe segments were joined using both heat fusion and electrofusion couplings, as shown in Figure 16. Given the previous experience with the electrofusion coupling and the UBE pipe, there was addition scrutiny during the installation of these respective pipe/coupling joints. There were no failures that were observed. This underscores the possibility that the electrofusion fitting failures that were observed during the GTI installations were a result of operator error and/or improper tooling.

Figure 16: Representative illustrations of the National Fuel installation at its Mineral Spring facilities.

After overcoming some minor installation issues not related to the PA12 piping systems (poor welds on the steel end connections), the lines were installed and were pressure tested using compressed natural gas at a test pressure of 375 psig for approximately 4 hours. Following its completion, the line pressure was reduced to 250 psig. Additional 6x2” mechanical fittings from Continental Industries were installed using their recommended installation procedures. The fittings were tapped against line pressure and leak tested, as shown in Figures 17. The installation was completed on 10/25/06.

Figure 17: Illustration of the installation and leak testing of a 6x2" Continental Industries mechanical fitting. The mechanical fittings were installed at 250 psig and tapped with no observed issues.

5.4 Additional High Pressure Installations – Europe

In addition to this particular program, additional installations have been performed in a parallel effort that this on-going in Europe with similar objectives and technical approach as the OTD program.

In order to demonstrate safe operations at high pressures, Degussa has worked with Germany's largest utility company, E. ON Ruhrgas to install a 60m line of 4-inch SDR11 pipe from coiled pipe using both the electrofusion and butt heat fusion process. The line was installed by E. ON Rhurgas operators using their company's approved installation and operating practices. Since November 2005, the line has been pressurized to 345 psig (24 bar) and has not experienced any failures. In parallel, a 3m test line has also been pressurized at 515 psig (36 bar). Both installations have performed well without any reported failures to date. Figure 18 are some illustrations of the 345 psig installation. Figure 18 presents a few illustrations from the E.ON Rhurgas installations, as shown below.

Figure 18: illustrations of Ruhrgas installation operating at 345 psig

The cumulative results of these respective installation alongside the installations as part of the OTD program amply demonstrate the effectiveness of using PA12 piping systems over a range of sizes (2-inch through 6-inch) and increased operating pressures. Moreover, the installation in Europe also demonstrated the applicability of using coiled pipe which provides additional installation cost savings due to the reduction in the number of joints that are required over the length of the installation.

Section 6
Summary and Conclusions

Since 2004, through the support of Operations Technology Development (OTD) group and PA12 resin suppliers, a comprehensive program has been established to perform testing and evaluation of Polyamide 12 (PA12) material. Specifically, to validate the technical feasibility for the use of Polyamide 12 (PA12) pipe at higher operating pressures and larger diameters through a series of laboratory and field experiments focused on the development of comprehensive physical properties and critical construction, maintenance, and operating considerations data.

Based on the cumulative results of the comprehensive testing, several conclusions can be made:

- The results of the comprehensive testing with respect to the physical, mechanical, and chemical properties demonstrate the PA12 material conforms to all of the requirements contained with ASTM D2513 and its respective Annexes.
- The results of each of the SCG tests demonstrate that the PA12 piping material has excellent resistance to the SCG mechanism. This is substantiated by the lack of failures in all of the testing including: HDB validation, notched pipe testing (20%, 30%, and 50%), and PENT testing using very aggressive test conditions. Over 40 years of field experience has demonstrated that the primary mode of in-service field failures is as a result of the SCG mechanism. Given the positive results of testing, it is reasonable to infer that the PA12 piping systems will be able to sufficiently withstand the combined effects of both internal pressure and the influences of secondary stresses resulting from outside surface scratches, rock impingement, earth loadings, and bending strain.
- Critical construction and maintenance procedures can be readily applied to the PA12 piping material without the need for additional equipment and or major modifications to existing procedures used for PE piping systems. Specifically, the test data demonstrates that strong and effective joints can be made using PA12 joining procedures. Moreover, electrofusion joints also can produce strong and effective joints.
- The results of the RCP testing were slightly inconsistent with expectations. The calculated maximum operating pressure based on the S4 test data is lower than the target range of 200 psi; however, the meaningfulness of the test procedure, the efficacy of the correlation functions, and the implicit safety factor are at best questionable at this time. These doubts do not apply exclusively to the PA12 piping material but also to PE materials. As a result, at present, there are no requirements in place for either the PE materials and/or the Polyamide 11 and 12.
- The results of various field installations and feedback from operators has been positive. The feedback indicates that the operators did not realize any difficulties with the use of the PA12 materials as compared to PE piping systems.

Based on the cumulative results of the testing, it can be reasonably inferred that the PA12 material is a suitable candidate material for high pressure gas distribution piping applications.