COMPREHENSIVE TESTING TO VALIDATE THE IN-SERVICE PERFORMANCE AND AGEING CHARACTERISTICS OF POLYAMIDE 12 (PA 12) PIPING SYSTEMS FOR HIGH PRESSURE GAS DISTRIBUTION APPLICATIONS

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BACKGROUND

The use of plastic piping systems for gas distribution applications is governed by Title 49 CFR Part 192 which prescribes a series of minimum requirements to ensure safe long term performance. Through reference, CFR Part 192 Appendix B incorporates the requirements contained in ASTM D25 13 with respect to both the short term and long term performance considerations.

Since 2004, the Polyamide 12 (PA 12) suppliers (Evonik-Degussa and UBE Industries), have been engaged in a comprehensive program to perform the necessary testing in order to validate the safe long term performance of Polyamide 12 (PA 12) piping systems for high pressure application.

In addition to the guidance within 49 CFR Part 192 requirements, sound engineering practices and previous experiences were employed to develop an effective hybrid approach consisting of laboratory evaluations and field demonstrations to validate the performance characteristics of the PA 12 piping systems. The results of comprehensive testing to characterize the mechanical, chemical, and physical properties of the PA 12 material amply demonstrate that the PA 12 material conforms to all relevant requirements contained within ASTM D 2513. As a result, the ASTM Committee F17 on Plastic Piping Systems approved the inclusion of PA 12 within Annex A5 of ASTM D2513.

While the results of laboratory testing are necessary and help to characterize the material specifications, an important technical consideration for any material relates to its in-service performance for the intended application. That is, while the material specifications help to ensure that a product has good overall stability with respect to short term and long term properties, the real issue is how well it performs under actual field conditions, and if there are any special construction and maintenance requirements which need to be established for the PA12 piping system.

Subsequently, the PA 12 suppliers supported a comprehensive hybrid approach to better understand the actual in-service performance of PA 12 piping systems operating at higher pressures. A series of laboratory tests were performed with actual pipe specimens subjected to a combined stress states resulting from both the internal pressure and effects of add-on stresses including rock impingement, excessive bending strain, and earthloading. In addition and more importantly, a series of field trials were performed to corroborate actual in-service performance under various types of add-on stress states with the data developed as part of the laboratory testing. Following the successful trial installations, additional comprehensive testing was performed on actual PA12 pipe specimens removed from service to evaluate any potential impact to the mechanical properties resulting from the various in-service conditions. The remaining sections of this summary report outline the results of the testing and evaluation.

EVALUATION OF IN-SERVICE STRESS STATES ON PA12 PIPING SYSTEMS

An important consideration in the overall acceptance of any new thermoplastic piping system relates to its performance under exposure to various types of in-service conditions for the intended application.

Over 40 years of safe operating experience with the use of plastic piping materials has demonstrated that the long term performance is not dependent solely on the plastic piping materials ability to withstand failures due to internal pressure. A complete analysis and evaluation of the stresses arising from various conditions must be taken into account and evaluated. Therefore, in any effort to effectively validate the performance of plastic piping systems, it is imperative to characterize the materials ability to mitigate localized stress intensifications resulting from various types of secondary effects which can potentially lead to failures in the “brittle” manner due to slow crack growth (SCG) mechanism.

While there are several industry accepted tests which help to characterize a materials resistance to the SCG mechanism, e.g. PENT test or three-point bend sector test, these tests are merely useful relative indices and do not correlate with actual field performance considerations with respect to piping system considerations.

In general, a typical gas distribution piping system can be potentially subjected to various types of additional stresses (add-on stresses or secondary stresses) which act in combination with the effects of internal pressure. Subsequently, additional battery of laboratory tests was performed to evaluate the effects of add-on stresses on the PA12 piping systems including:

- Effects of surface scratches
- Effects of rock impingement
- Effects of excessive bending strain
- Effects of earthloading (compressive stresses on the pipe)

The results of the testing are summarized in Table 1 below and were consistent with expectations – the PA12 piping system can safely operate at the increased stress levels.

Secondary Stress	Test Criterion	Results
Surface Scratches and Notches	*Varying notch depths = 20%, 30%, 50%* Test Pressure = 290 psig Test Temperature = 80C	Test time > 1000 hours with No Failures at 20% scratch depth
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 1: Summary of test conditions to simulate effects of secondary stresses

EVALUATION OF FIELD PREFORMANCE CONSIDERATIONS

In addition to the aforementioned laboratory testing, a series of actual simulated field trials were performed in various parts of the United States to validate the safe operations of the PA12 piping systems at the increased stress levels taking into account the combined effects of internal pressures and various add-on stresses. A summary of the various field trials is presented in Table 2 below and detailed discussions for each of the trials (1-4) can be found in Final Report issued by the Operations Technology Development, NFP. A summary report for the recently completed installations at the City of Mesa, WE Energies, and DTE (Michcon) is being finalized and will be submitted separately.

The cumulative results of the various installations amply validate the ability the field performance of the PA12 piping systems. Specifically, the results show:

- PA12 piping systems can be safely installed and operated at higher operating pressures up to 250 psig using various pipe sizes ranging from 2-inch through 6-inch IPS
- Conventional construction and maintenance practices specific to PE piping systems are readily transferrable to PA12 piping systems
- An array of procedures (butt heat fusion and electrofusion) and appurtenances (transition fittings, mechanical fittings, etc) were successfully utilized

Location	Key Criterion	Description	Status and Comments
February 2005 – Chicago, IL (GTI) Pressure = 250psig	Indigenous Backfill	2-inch SDR11 Sections of squeezed pipe and heat fusion joints 2-inch transition fittings installed.	• No leaks • Sections removed at 30 months for ageing studies • Planned removal after 36 months of exposure
October 2006 - Chicago, IL (GTI) Pressure = 250psig	Rocky Soil (80/20 mix of rocks and clay soil which is compacted over the pipe)	6-inch SDR11 Sections contain electrofusion couplings and heat fusion joints 6-inch transition fittings installed	• No leaks • Sections scheduled for removal following 24 months of ageing
October 2006 - Chicago, IL (GTI) Pressure = 250psig	Flowable Fill (highly compressive strength backfill)	6-inch SDR11 Sections contain electrofusion couplings and heat fusion joints 6-inch transition fittings installed	• No leaks • Sections scheduled for removal following 24 months of ageing
October 2006 – Buffalo, NY (National Fuel) Pressure = 250psig	Bending Strain (90 times pipe OD at joint and 20 times pipe OD on straight pipe)	6-inch SDR11 Sections contain electrofusion couplings and heat fusion joints 6-inch transition fittings installed 6-inch mechanical saddle installed and tapped at 250 psig.	• No leaks • Sections removed at 14 months for ageing studies • Planned removal after 36 months of exposure
March 2008 – Phoenix, AZ (City of Mesa) Pressure = 160 psig (pressure based on HDB rating at 140F)	Static and dynamic and vehicular loading	4-inch SDR11 Sections connected using electrofusion couplings 4-inch transition fittings and mechanical saddles installed	• No leaks • Sections to be removed at 12 months and 24 months
April 2008 – Wisconsin (WE Energies) Pressure = 250 psig	Cold climate	4-inch SDR11 Sections connected using electrofusion couplings and butt fusion 4-inch transition fittings and mechanical saddles installed	• No leaks • Sections to be removed at 12 months and 24 months
May 2008 – Detroit, MI (DTE, MichCon) Pressure = 330 psig	Cold climate and high pressure limit	4-inch SDR11 Sections connected using electrofusion couplings and butt fusion 4-inch transition fittings and mechanical saddles installed	• No leaks • Sections to be removed at 12 months and 24 months

Table 2: Summary of the field demonstrations simulating increased stress levels

AGEING CHARACTERISTICS OF THE PA12 PIPING SYSTEMS

Based on the preceding discussions, the cumulative results of the laboratory testing and simulated field trials amply demonstrate the ability of the PA12 piping systems to operate at the intended higher operating pressures under the combined influence of internal pressures and various types of secondary in-service stress states. However, an additional key piece of information was to quantify the ageing characteristics of the PA12 piping system as a function of various geographic and climatic conditions. Consequently, samples have been removed from the initial GTI trial performed during February 2006 and the National Fuel trial and subjected to a comprehensive battery of tests to investigate potential impact to the mechanical and physical properties of the PA12 pipe material.

The results of the ageing testing were consistent with expectations. There was no evidence of premature oxidative degradation, and the cumulative data amply demonstrates that the overall stability of the respective PA12 resin suppliers product is technically sound with respect to the mechanical and physical properties. The results of the testing are summarized in Appendix A and B for both Evonik-Degussa and UBE Industries PA12 pipe material, respectively.

SUMMARY AND CONCLUSIONS

Since 2004, both Evonik-Degussa and UBE have been engaged in a comprehensive program to perform the necessary testing in order to validate the safe long term performance of PA 12 piping systems for high pressure application.

Based on the comprehensive results of the testing to characterize the mechanical, chemical, and physical properties of the PA 12 piping material by both suppliers, the PA 12 material has been successfully incorporated into ASTM D2513 in Annex A5 during 2006.

While the results of laboratory testing are necessary and help to characterize the material specifications, an important technical consideration for any material relates to its in-service performance for the intended application. That is, while the material specifications help to ensure that a product has good overall stability with respect to short term and long term properties, the real issue is how well it perform under actual field conditions and if there are any special construction and maintenance requirements which need to be established.

As a result, a comprehensive series of tests under both laboratory conditions and actual in-service conditions were performed to evaluate the effects of various types of secondary stress states and in-service conditions. The results of the testing were consistent with expectations. Specifically,

- The results demonstrated that the PA12 piping systems (pipe, fittings, and appurtenances) can safely operate at pressures up to 250 psig (SDR 11 pipe sizes and use of a 0.40 design factor) in conjunction with various types of secondary stresses acting on the pipe.

- The use of existing construction and maintenance practices specific to PE piping systems can be readily used with PA 12 piping systems. Results of the testing demonstrated that strong PA 12 joints can be made using the qualified PA 12 joining procedures; the results confirmed the ability that the use of "squeeze-off" does not adversely impact the long term performance of the pipe; the results conformed the safe use and operations of other types of appurtenances installed on the piping systems including transition fittings, mechanical fittings, and electrofusion fittings.
- There were no adverse reactions to the PA 12 piping systems as a result of exposure to various types of in-service stresses acting on the piping system or environmental considerations such as premature oxidative degradation after nearly three years of exposure to in-service conditions

Appendix A

EVALUATION OF THE AGEING CHARACTERISTICS OF THE VESTAMID LX9030 PA 12 PIPE MATERIAL

The cumulative results of these respective installations amply demonstrate the effectiveness of using PA12 piping systems over a range of sizes (2-inch through 6-inch) and increased operating pressures (250 psig). 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.

While the ability to safely install and operate the PA 12 piping systems is critical, an equally important consideration is to ensure that there are no deleterious effects to the PA12 pipe material over the intended design life as a result of exposure to various types of in-service conditions or environmental factors once installed.

HEAT AGEING CHARACTERISTICS

Laboratory Simulations – Evonik-Degussa VESTAMID LX9030

During January 2006, Arkema issued a technical report which outlined unexpected degradation of its Polyamide 11 (PA 11) natural gas piping material. The report indicated that after being installed for slightly over two years, the PA 11 pipes which were installed at several locations throughout the United States were strongly discolored and revealed brittle fracture in burst pressure tests.

A detailed investigation by Arkema demonstrated that the pipes experienced oxidative degradation which started at the outside of the pipe and moved over time into direction of the inner side. The results of the testing performed by Arkema clearly identified that this phenomenon was a direct result of the high contents of phosphoric acid in the PA 11 base material which together with the yellow bismuth vanadate pigment and air-born oxygen led to a heavy catalytical decomposition of the polymer.

This rapid decomposition of the PA 11 resin was simulated in the laboratory by simple heat aging tests on the material at 110°C using tensile test bars as specimen. The data showed that there was a dramatic loss of elongation at break values within just 8 days. In order to resolve this issue, Arkema subsequently reformulated its PA 11 resin by replacing the bismuth vanadate pigment with a yellow Cd-pigment[1].

In order to demonstrate that this particular issue is specific to PA 11 and not Polyamides in general, Evonik Degussa performed comprehensive testing of its Polyamide 12 (PA 12) piping to verify that there are no adverse degradation issues with its PA 12 resin formulation..

Comprehensive heat ageing tests in air of its VESTAMID LX9030 yellow material in accordance with accepted methodology for performing ageing exposure experiments. Several injection moulded tensile specimens of VESTAMID LX9030 yellow were subjected to heat ageing at 90, 100 and 110 °C under air, exactly as done for the critical PA 11 formulation . Specimens were removed after 2, 21, 42, 105 and 208 days, respectively, and tensile tests performed. The results of the testing are summarized in Figure 1 below.

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[1] In conformity with international environmental protection legislation, Evonik Degussa does not use pigments containing heavy metals like lead or cadmium compounds)

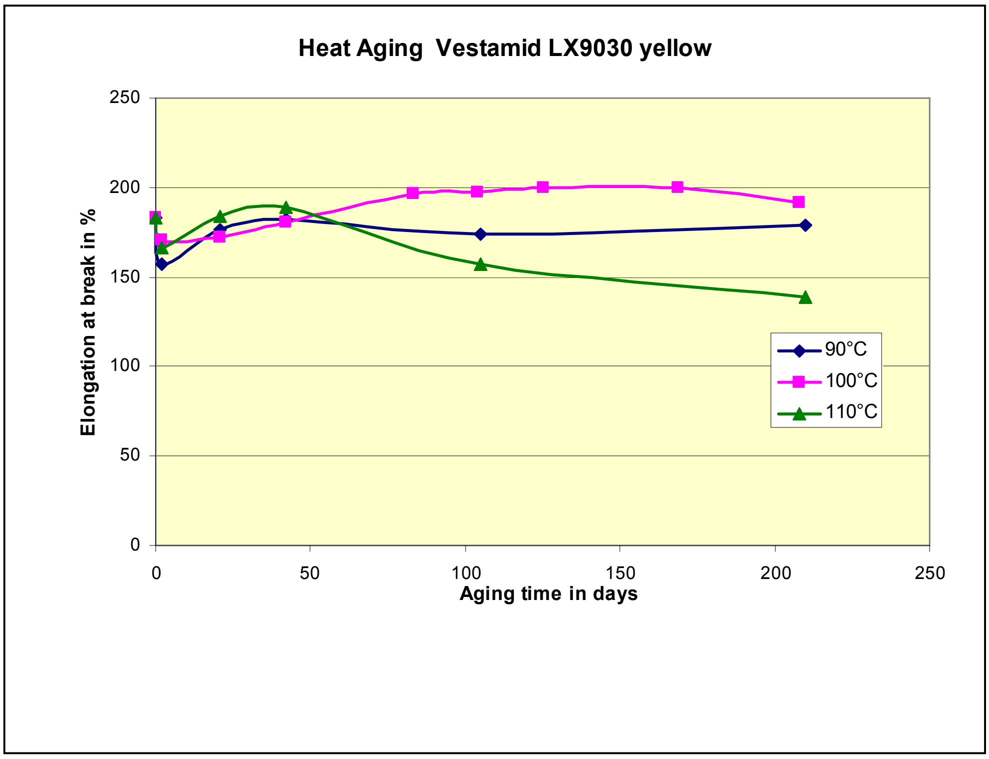

Figure 1: Heat ageing of VESTAMID LX9030 yellow

Figure 1 presents the mean value of the elongation at break as a function of the ageing time. The results confirm the excellent resistance of the VESTAMID LX9030 yellow material. Specifically, the data demonstrates that the LX9030 yellow material does not experience a significant loss in the elongation at break property following exposure to a temperature of 110 °C after 208 days.

2” SDR-11 pipes from field installation on GTI pipe farm

While the preceding discussions clearly demonstrates the outstanding heat ageing resistance of the VESTAMID LX9030 yellow resins, additional tests were performed using actual pipe specimens from the first GTI installation which was installed during 2005 (see previous section) and specimens were recovered following 30 months of exposure to buried underground conditions.

After approximately 30 months of exposure to in-service conditions (two complete seasonal cycles), several sections of the VESTAMID PA 12 pipe were removed during August 2007. In order to characterize the impact of the in-service condition on various types of construction practices, additional specimens were removed which included butt heat fusion joints and sections which were intentionally “squeezed”. A new pipe section was spliced in and the entire test section was re-pressurized back to 250 psig.

The removed pipe sections were visually inspected for any evidence of premature ageing or oxidative degradation. No visual change of the color was observed as compared to an uninstalled pipe section which was stored indoors. Following the visual inspection, comprehensive mechanical and ageing tests were performed as outlined in the sections to follow.

Mechanical test – 2” SDR-11 pipes from GTI pipe farm

Tensile testing was performed on Type I specimens in accordance to ASTM D638. The results of the testing were compared to tensile testing results presented in the original GTI test report (control specimens). In addition to the tensile testing, additional testing was performed to characterize the moisture content. This is an important consideration in being able to interpret the mechanical test results because moisture has a plasticizing effect on Polyamides; however, this is entirely reversible. For the various test specimens, the water content measured by Karl Fischer Method was 0.8%, which corresponds to the equilibrium for PA 12 at 73 °F (23 °C).

The results of the tensile testing were consistent with expectations. There was a small-scale reduction in the tensile strength at yield. This is a direct consequence of the hygroscopic nature of Polyamides. The tensile test results demonstrated that the stress at yield was equal to 4630 psi (34 MPa) with an elongation at break of greater than 200%. This corresponds to a reduction of the stress at yield by 8% compared to the value reported in the GTI report on non-aged specimens. Again, it can be reasonably inferred that this is a direct consequence of the plasticizing effect due to the influence of moisture over two complete seasonal cycles.

Based on the measured moisture content values of 0. 8% corresponding closely to the equilibrium point, it can be reasonably inferred that the reduction in the mechanical strength has reached an asymptotic limit. This inference can be validated based on data developed on pipe specimens from subsequent planned removals.

In addition to testing pipe specimens, additional test specimens were prepared from the butt fusion joint and tested in accordance to ASTM D638 requirements. The results were again consistent with expectations. The stress at yield was 5003 psi (34.5 MPa) and clearly demonstrates that there is no significant difference in the mechanical strength of the PA12 butt heat fusion joint as compared with data from pipe samples. All of the specimens failed in a ductile manner outside the welding area.

Ageing Characterization

2” SDR-11 pipes from GTI pipe farm

To determine the potential for polymer degradation of the VESTAMID PA 12 pipe material removed from in-service caused by oxidation or other impacts, the viscosity number (VN) was measured along various points in the pipe wall in accordance to ISO 308. The VN correlates with the molecular weight of Polyamide 12 and is an established procedure in the industry. Samples were prepared from the outer and inner surface and from the center of the pipe wall to investigate any surface effects. The measured VN shows little to no change in comparison to the control samples (Fig. 2). Also, there was no discernable difference in the VN along the various points in the pipe wall.

6-inch SDR11 pipes from National Fuel – Buffalo, NY

As previously discussed, the premature oxidative degradation experienced by the PA11 resin was not isolated to a particular geographic territory, rather, the PA11 pipes from each of the respective installations throughout the United States were removed due to the premature oxidative degradation.

To ensure that the VESTAMID LX9030 pipe material maintained excellent overall stability regardless of the installation setting, additional tests were performed on PA 12 pipe specimens recovered from the Nataional Fuel installation in Buffalo, NY following 14 months of in-service experience. Like the pipe specimens from the GTI installation, the viscosity number (VN) was measured at three points along a cross section of the pipe. The results were consistent with expectations. There was no significant change in the VN along the pipe wall from the samples recovered from National Fuel: VN is 98% of the reference data as shown in Table 2 below.

Cumulatively, this data along with the mechanical testing clearly demonstrates that there is no adverse effect of the VESTAMID LX9030 yellow formulation and its ability to safely perform under various types of in-service conditions and in various geographic areas.

UV - Weathering under real conditions

Additionally, UV - Weathering tests are also concurrently ongoing at Atlas Weathering in Phoenix, AZ which represent worst-case conditions. The first set of pipe samples have been tested after real-time exposure of 6 and 12 month. There was no visual evidence of any deleterious effects after real time ageing, i. e. no change in color was observed.

Mechanical testing - U.V. Weathering and Real Conditions

Like the previous discussions, tensile tests were also performed. The water content of the pipe sample was also measured. The tensile test shows a stress at yield of 39 MPa and an elongation at break of >200 % (Fig. 3). This again is consistent with expectations. As previously discussed, the absorption of moisture by Polyamide materials tends to have a plasticizing effect which is reversible. The higher strength of the samples compared to the GTI samples may be a direct results of the “drying” of the specimens under intense UV exposure leading to a reduced moisture content value.

Ageing – U.V. Weathering under Real Conditions

The ageing of the pipe sample was also tested by determining the VN as described in 3.1.2. The measured VN shows little to no change in comparison to the control sample (Fig. 2). Also, there were no differences in VN number values along the pipe wall.

				2” SDR-11 pipe	2” SDR-11 pipe 2,5 years	6” SDR-11 pipe 14 months
Properties	**Unit**	**Standard**	**Requirements**	**GTI report**	**Installation on GTI pipe farm**	**Installation at National Fuel**
Tensile Strength, 74 °F						
- Strength at yield	psi / MPa	ASTM D2513/ D638		5370 / 37	4931 / 34	-
- Elongation at yield	%			12	14	-
- Strength at break	psi / MPa			6457 / 44	5800 / 40	-
- Elongation at break	%		> 150	219	> 200	-
Water content	%				0,80	-
Relative Viscosity number (VN) along wall thickness						
outer surface	%	ISO 307			100	98
center	%			100*	100	98
inner surface	%				99	98

Fig. 2: Test results after installation at GTI and National Fuel VESTAMID LX9030 yellow

Properties	Unit	Specification	0,5 years at Atlas	1 year at Atlas
Tensile Strength, 74 °F		ASTM D2513 / D638		
- Strength at yield	psi / MPa		5656 / 39	5661 / 39
- Elongation at yield	%		13	13
- Strength at break	psi / MPa		6960 / 48	7628 / 52
- Elongation at break	%		> 200	> 200
Relative Viscosity number (VN) along wall thickness*		ISO 307		
outer surface	%		100	100
center	%		100	100
inner surface	%		100	100

* compared to result of the control sample

Fig. 3: Test results after UV weathering at Atlas in Phoenix VESTAMID LX9030 yellow

Appendix B

EVALUATION OF THE AGEING CHARACTERISTICS OF THE UBESTA 3035 PA 12 PIPE MATERIAL

EVALUATION OF AGEING CHARACTERISITICS – UBESTA 3035

Accelerated Weathering

In order to demonstrate that premature oxidative degradation due to the reaction of components of the formulation do not occur with UBESTA 3035, a series of accelerated weathering studies were performed. Both heat ageing and accelerated weathering testing were performed. The results indicate no premature oxidative degradation of UBESTA 3035. A description of the testing follows.

ASTM D638 tensile test specimens were exposed to hot air ageing at 130°C. After exposure the samples were characterized for tensile properties according to ASTM D638 and relative viscosity according to ASTM D789. Figures 1, 2 and 3 present the results.

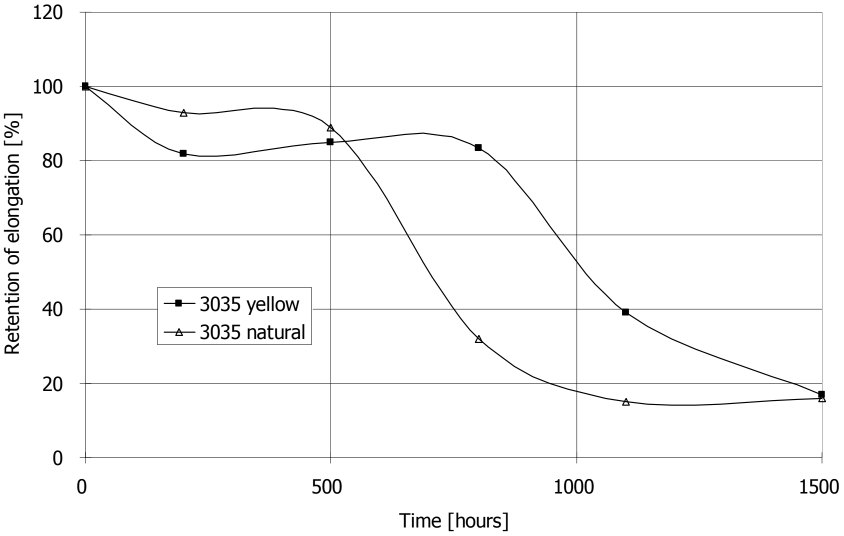

Figure 1. Heat Ageing @ 130°C – Retention of Elongation

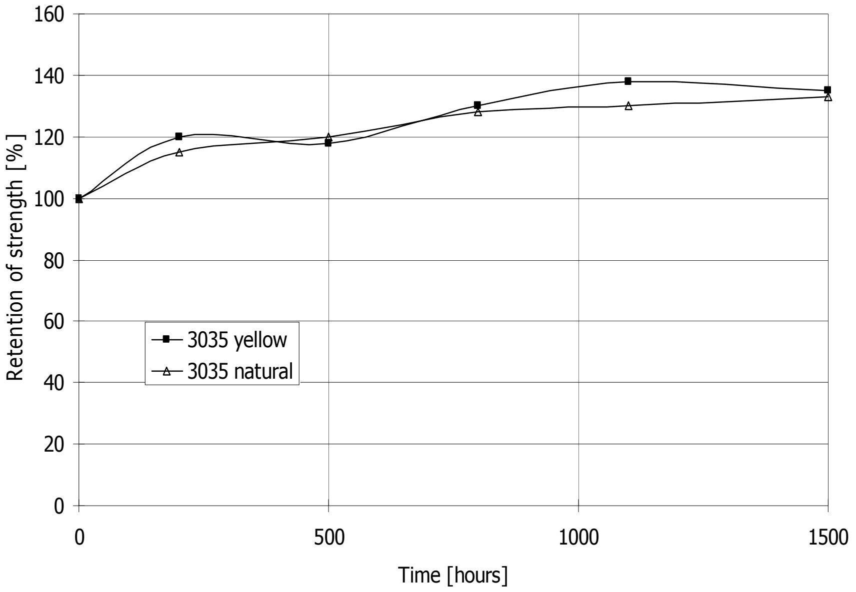

Figure 2. Heat Ageing @ 130°C-Retention of Tensile Strength

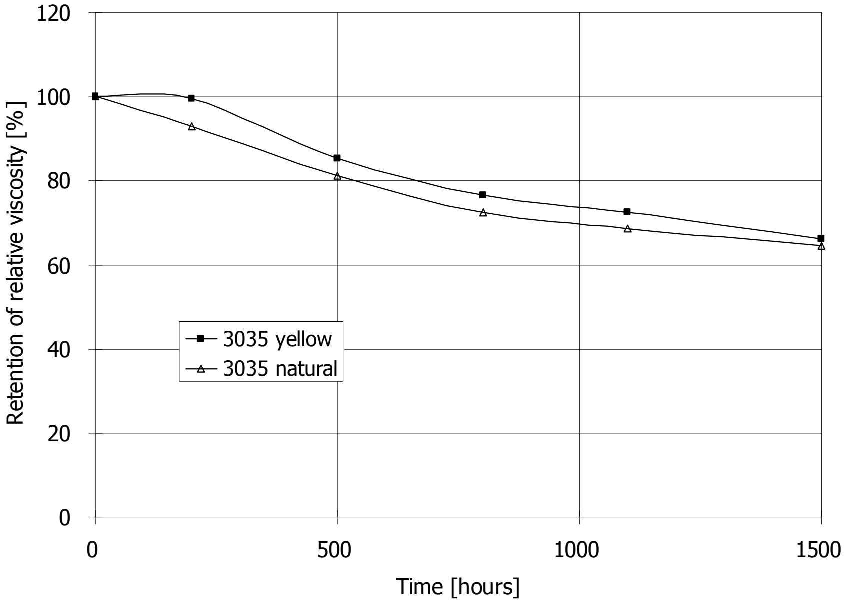

Figure 3. Heat Ageing @ 130°C – Retention of Relative Viscosity

Figures 1 and 2 indicate that there is no significant reduction in tensile properties due to the presence of the yellow pigment. Figure 3 indicates that there is no significant deterioration in molecular weight as compared to an unpigmented grade of UBESTA 3035. From the data, the conclusion can be drawn that there is no unexpected reduction in properties due to thermal oxidative degradation.

Additionally, Xenon Arc weathering according to ASTM D2565-99 was performed to assess the effect of exposure to UV irradiation. ASTM D638 Type 1 specimens were exposed for a total of 180 days. This corresponds to 645 MJ/m^2 total irradiation. Figures 4 and 5 present the results of testing on the exposed specimens.

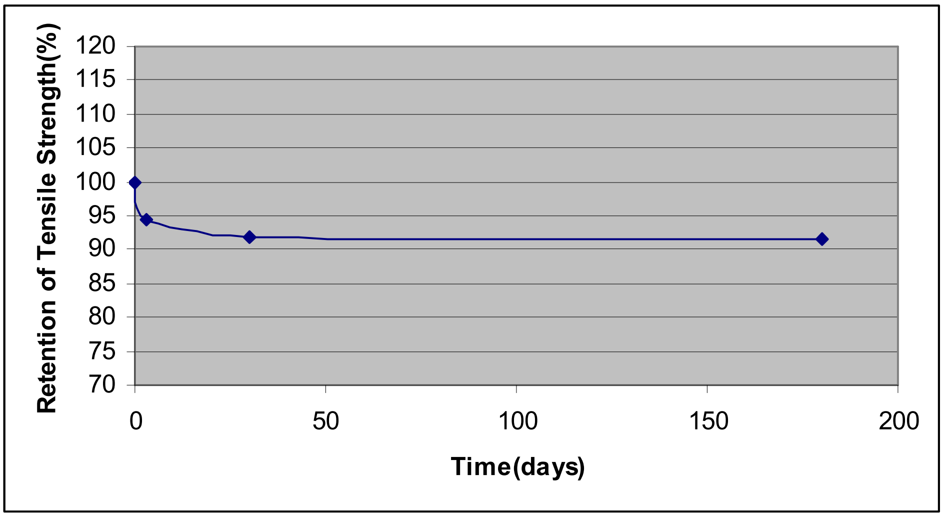

Figure 4. Xenon Arc Weatherometer Exposure – Retention of Tensile Strength

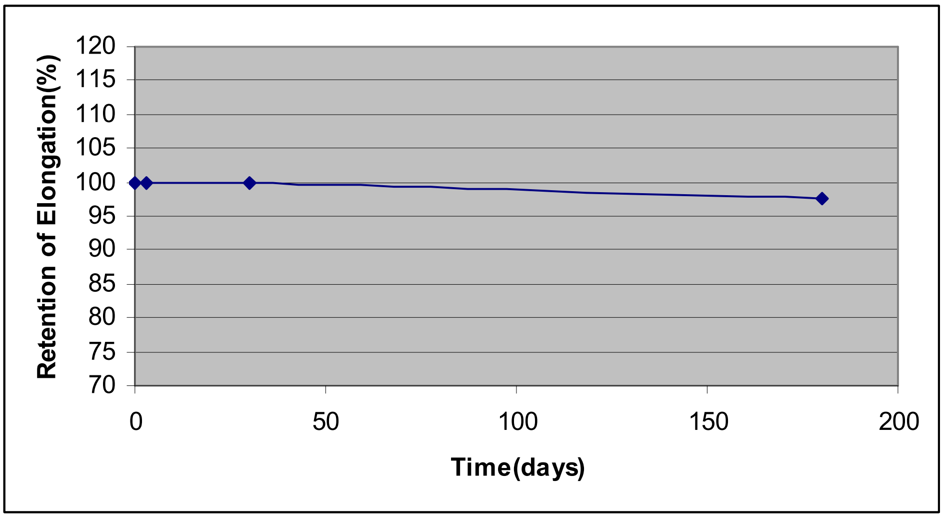

Figure 5. Xenon Arc Weatherometer Exposure – Retention of Elongation

The data indicates no significant degradation of tensile properties after accelerated UV exposure.

Overall, the results indicate that there is no degradation of properties of UBESTA 3035 after exposure to accelerated ageing conditions.

Characterization of Samples Removed from Field Installations

As described in a previous section of this document, a series of field installations have taken place as part of the Phase 1 GTI project. Subsequently, aged samples have been removed from two installations for evaluation. Two inch SDR 11 pipe samples of UBESTA 3035 were removed from the February 2005 installation at GTI's pipe farm in August 2007, 30 months after the original installation. In January 2008, 6" IPS SDR 11 pipe samples of UBESTA 3035 were removed from the National Fuel private property installation. These samples were removed 15 months after the original installation.

Both 30 month aged samples from the GTI pipe farm and 15 month aged samples from the National Fuel installation were forwarded to UBE Industries, Ltd. laboratories in Japan. Samples were characterized for relative viscosity to determine if any deterioration in molecular weight had occurred since the original installation. Additionally, samples were characterized for tensile properties according to ASTM D638. The results were compared to test results from uninstalled reference pipe produced from the same lot of base material from the same extrusion run. The test results are presented below.

Samples were characterized for relative viscosity according to the Japanese standard JIS K6920. A modification to the normal procedure was employed. Rather than determine the relative viscosity of the bulk sample, 5 samples were microtoned through the wall of the sample and the relative viscosity of each respective layer determined. The intent was to determine if any degradation gradient was present through the pipe wall due to environmental exposure. Figure 6 illustrates the sample preparation scheme. Table 1 and 2 presents the relative viscosity measurements for reference pipe and samples from the GTI installation and National Fuel installation respectively.

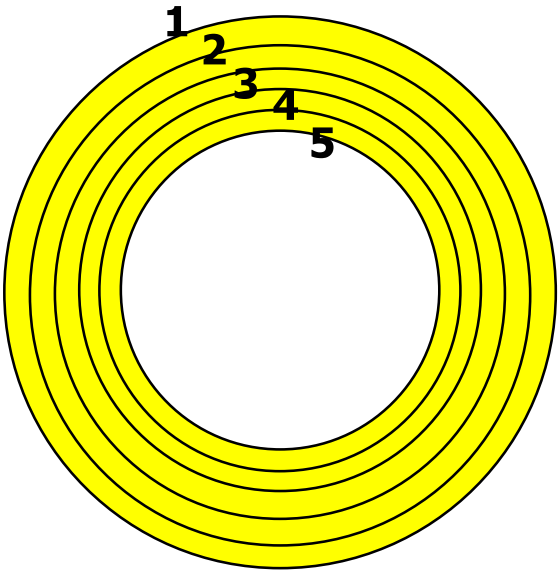

Figure 6. Layers of Pipe Sample for Relative Viscosity Measurement – Layer Thickness = 1.2mm

Zone	Description	Relative Viscosity, Uninstalled Reference Pipe	Relative Viscosity, 30 Months In-Service
1	0-1.2mm from outside wall	2.44	2.34
2	1.2 – 2.4 mm from outside wall	2.47	2.39
3	Center 5.4 mm	2.42	2.46
4	1.2-2.4 mm from inside wall	2.43	2.43
5	0-1.2 mm from inside wall	2.41	2.44
Cross Section	Entire wall thickness	2.43	2.41

Table 1. Relative Viscosity – 30 Month GTI Samples; 2" IPS SDR1 1Pipe

Zone	Description	Relative Viscosity, Uninstalled Reference Pipe	Relative Viscosity, 15 Month In-Service Pipe
1	0-3.1mm from outside wall	2.45	2.45
2	3.1-6.2mm from outside wall	2.46	2.45
3	Center 153mm	2.44	2.44
4	3.1-6.2mm from inside wall	2.45	2.47
5	0-3.1mm from inside wall	2.47	2.49
Cross Section	Entire wall thickness	2.45	2.46

Table 2. Relative Viscosity – 15 Month National Fuel Samples; 6" IPS SDR11 Pipe

The data would indicate no significant degradation of the molecular weight of either samples removed from the GTI installation after 30 months or the National fuel samples removed after 15 months.

The moisture content of the 2" IPS SDR 11 pipe removed from the installation was measured and determined to be 1.03%. The slight differences in the relative viscosity of the outer two layers of the removed pipe as compared to the reference pipe is due to the effect of absorbed moisture on the sample. This is consistent with expectations and does not indicate any significant degradation of the material nor deterioration in performance. The effect of moisture in the solid state on Polyamide 12 is completely reversible.

Additionally, tensile testing according to ASTM D638 was performed on the 30 month GTI samples. The results are presented in Table 3. Testing on the 15 month National Fuel samples is ongoing.

	Control	**Reference**	**Pipe removed after 30 months**
Tensile stress @ yield	6612 psi	5684 psi	5235 psi
Elongation @ yield	10.0%	9.7%	10.5%
Tensile strength @ break	7772 psi	7410 psi	6656 psi
Elongation @ break	254%	272%	227%
Relative Viscosity	2.42	2.43	2.41
Moisture content	-	0.78%	1.03%

Table 3. Physical Property Profile

The control data is taken from 2: SDR 11 samples submitted to GTI in April 2004 at the onset of the initial evaluation. The reference pipe data was generated on uninstalled pipe samples from the same lot of base material and the same extrusion run as the installed samples. The slight difference in tensile properties between the control, reference and removed samples can be attributed to the difference in moisture content between the three samples. Once more, this change in tensile properties does not indicate a permanent reduction in physical properties. The effect of moisture is completely reversible. The consistency of the relative viscosity values for the three samples supports the contention that no permanent degradation has taken place.