Correlating Aldyl "A" and Century PE Pipe Rate Process Method Projections with Actual Field Performance

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Abstract

The recent Department of Transportation Advisory Bulletin, "Notification of the Susceptibility to Premature Brittle-Like Cracking of Older Plastic Pipe" cited lower ductile inner wall Aldyl "A" and Century polyethylene (PE) pipe as two materials that were known to be susceptible to brittle-like cracking or slit failures. Many miles of these materials are still in service in the United States. The key question is – what is the projected life of these PE pipes still in the ground? The Rate Process Method (RPM) is used to project performance (lifetime) of PE materials at their in-ground temperatures and pressures based on both internal pressure as the primary load and secondary loads such as rock impingement and squeeze-off.

This paper will provide a discussion on the Rate Process Method. RPM involves exhuming samples of pipe from service and subjecting them to laboratory elevated temperature sustained pressure testing that results in slit failures. These slit or SCG (slow crack growth) failures are the long-term failure mode for PE materials. A three-coefficient equation is then used to project performance at actual service temperatures and pressures. RPM testing is conducted not only with pressure as the primary load, but is also used to investigate secondary loads such as rock impingement, deflection, bending and squeeze-off.

RPM testing was conducted on exhumed Aldyl "A" PE pipe. The RPM projected performance is correlated with actual field experience from two gas utilities for control pipe (primary load only), indented pipe (to simulate rock impingement) and squeezed pipe. This paper also correlates control, indented and squeezed RPM projections for exhumed Century PE pipe with its corresponding field experience from another gas utility.

Introduction

Dr. Chester Bragaw originally described the concept and mathematical basis for using the Rate Process Method for polyethylene (PE) pipe and fitting service projections (1) (2). The Plastics Pipe Institute (PPI) Hydrostatic Stress Board (HSB) conducted an extensive evaluation of this and other methods for forecasting the effective long-term performance of PE thermoplastic piping materials. Basically, all these methods require elevated temperature sustained pressure testing of pipe where the type of failure is of the slit or brittle-like mode. Dr. Gene Palermo and Ivan DeBlieu reviewed details of these evaluations and conclusions in their paper "Rate Process Concepts Applied to Hydrostatically Rating Polyethylene" (3).

As a result of these studies, HSB determined that the three-coefficient Rate Process Method (RPM) equation provided the best correlation between calculated long-term performance projections and known field performance of several PE piping materials. It also had the best probability for extrapolation of data based on the statistical "lack of fit" test. Dr. Gene Palermo provided further validation of the Rate Process Method by comparing RPM projections for PE pipe and fittings obtained at elevated temperatures with actual room temperature laboratory failures for the same pipe and fittings (4).

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Many resin and pipe producers, as well as users, are using RPM to one degree or another to make relative judgments on specific materials and/or piping products. One example described in this paper has been using RPM to determine projected life of PE pipe exhumed from buried service. The gas engineer may use this projection to determine how much estimated life the PE pipe has, and whether he should leave pipe in the ground or dig it up. These projections are based on the primary load (which is the internal pressure) and service temperature. RPM can also be used to determine the effects of secondary loads such as indentation (rock impingement), squeeze-off, bending or deflection.

Another use of the Rate Process Method is projected performance of polyethylene fittings as discussed in "Prediction of Service Life of Polyethylene Gas Piping Systems" by Dr. Bragaw (5) and "Designing PE Piping Systems: Old Questions and New Answers" by Dean Hale (6). When testing and evaluating fittings it is very important that all the failure modes be the same. Because fittings have different geometries, different failure modes may be observed at different test conditions. When applying the RPM calculation, all failure modes must be the same. The three RPM coefficients from each fitting will be different; again, this is due to their different geometries. The referenced paper by Dr. Bragaw shows different Arrhenius plot slopes (log t vs. 1/T) for the different fittings tested, indicating different coefficients due to the different activation energies for the fitting geometries. This RPM test protocol is not intended for mechanical fittings.

The Rate Process Method (RPM) can also be used to determine the life of heat fusion joints. An example would be butt-fused joints. This could be done in one of two ways:

1) Butt fused joints from an existing system in the ground could be exhumed and subjected to RPM testing. To do the RPM calculation, all of the failure modes would need to be the same - a slit that initiates at the butt fusion notch and propagates through the pipe wall from the ID to the OD. This would indicate remaining life of butt fusion joints in the ground.

2) Pipe could be exhumed and butt fusion joints could be made and then subjected to RPM testing. Again, all failures would have to be the same.

This calculation would indicate how long a butt fusion joint would last if it were done today on the existing system to repair it.

DuPont conducted several RPM experiments on butt-fused joints and also on butt fusion fittings. Generally, the butt fusion joint has a shorter failure time at the laboratory conditions selected for testing. Due to the shallower slope for the butt fusion failure mode compared to control pipe, many times the RPM projected performance for the butt fusion joint is actually longer than the RPM projected performance for the control pipe. This is probably why there are not many field failures for properly made butt fusion joints. DuPont also conducted several RPM experiments on socket fusion and saddle fusion joints.

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After establishing the coefficients, an appropriate single-point elevated temperature stress rupture test may be established for quality control purposes, as discussed in "Rate Process Method as a Practical Approach to a Quality Control Method for Polyethylene Pipe" by Dr. Palermo (7).

RPM Test Procedure

Rate Process Method testing of pipe or fitting assemblies is conducted in accordance with ASTM D 1598, "Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure". Fittings are joined to pipe using standard heat fusion joining procedures, such as butt fusion, socket fusion, saddle fusion or electrofusion.

To do a typical RPM experiment requires a minimum of about 18 to 20 specimens at various temperature/pressure conditions. More specimens would provide greater certainty in making projections. Examples are shown in PPI Technical Note 16 (8).

Using slit failure mode data points, one calculates the A, B and C coefficients for the following three-coefficient Rate Process Method extrapolation equation:

$$Log\, t = A + \frac{B}{T} + \frac{C \,\mathrm{Log}\, S}{T}$$

Where:

t = slit mode failure time, hours

T = absolute temperature, °K

S = hoop stress, psi

Once the A, B and C coefficients are calculated, the RPM equation can be used for various performance projections (average failure time) at typical use temperature (average annual ground temperature) and use pressure conditions.

Mathematically, these RPM projections are sound. However, they are not absolute and are subject to various experimental errors, unknown deviations and judgment factors. Calculations from the RPM equation should be used in conjunction with all other mechanical, performance, and use factors in making judgments as to design, useful life or application suitability.

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Correlating Aldyl "A" and Century PE Pipe Rate Process Method Projections with Actual Field Performance

LDIW Aldyl "A" RPM Projections

Between 1971 and 1972, the DuPont Company produced some Aldyl "A" pipe that had a low ductile inner wall (LDIW) surface. Years later, in the early 1980's, some of their customers started experiencing failures in LDIW Aldyl "A" PE 2306 pipe that had been subjected to rock impingement. They were also experiencing some failures of LDIW Aldyl "A" pipe that had been squeezed-off. In an effort to explain the effect of this phenomenon on projected life performance, the DuPont Company agreed to conduct a major Rate Process Method research project on LDIW Aldyl "A" pipe exhumed from the area where the failures were occurring.

Internal Pressure

DuPont conducted RPM testing on the 2" IPS control (internal pressure only) LDIW Aldyl "A" pipe as received. The selected temperatures were 80°C (176°F) and 60°C (140°F) with the internal pressures selected to assure that the failure mode was slow crack growth. To do the RPM calculation it is imperative that all the data have the same failure mode. In this case all the failures were a crack that initiated at the inside surface and propagated through the wall until failure occurred. The failures times were accelerated due to the LDIW surface.

Based on underground thermocouple testing, the gas utility determined that the average annual service temperature was 21°C (70°F). The use pressure for the gas distribution system was 60 psig. The RPM projected performance for this lot of LDIW Aldyl "A" pipe at the use conditions of 60 psig and 70°F was an average failure time of about 150 years with a 5% lower confidence level (LCL) of 60 years. The RPM program calculates the LCL based on the scatter in the data. These data indicate there is a 95% probability that this lot of LDIW Aldyl "A" pipe would last 60 years at the conditions of 60 psig and an average annual ground temperature of 70°F, and a 50% probability it would last 150 years at the same conditions.

Rock Impingement

To simulate the rock impingement failures experienced by the gas utility, DuPont developed an indentation jig (**Figure 1**). It consists of a collar with a bolted thread of 28 UNS pitch. Seven turns of the bolt after it is flush with the pipe introduce an indentation of ¼". The bolted collar remains on the pipe the entire time it is subjected to stress rupture testing to simulate the indentation from rock impingement in the field. Testing was again conducted at 80°C and 60°C with the internal pressure selected to assure failure at the indentation. Due to the difference in slopes for the indentation failure mode vs. the control failure mode, if the pressure were too high, failure would occur in the pipe away from the indentation. At the lower pressures, all failures were inside to outside cracks that initiated at the indentation. When the indentation jig was removed, there was residual indentation, which looked identical to the failure mode observed by the gas utility in the field failures. Another characteristic feature of the indentation failures is that they were off axis by a few degrees (a failure due to just internal pressure is exactly in the axial direction). Rock indentation failures exhumed by the gas utility also had off-axis slit failures. At the gas utility use conditions of 70°F and 60 psig the RPM projected performance for the indented LDIW Aldyl "A" pipe was an average failure time of 12 years with an LCL of 8 years.

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This reduction of pipe life due to an LDIW surface was a significant discovery for the DuPont Company and as a result, they notified all Aldyl “A” customers to monitor this pipe with an increased leak survey frequency. This was a letter issued by Don Zerbe of DuPont to its customers on December 17, 1982.

Squeeze-Off

To determine the RPM projected performance of squeezed LDIW Aldyl “A” pipe a similar experiment was conducted. All pipe samples were squeezed-off using DuPont recommended procedures and a single bar squeeze tool. The bar was brought to the gap stop and left there for one hour. The tool was removed and all specimens subjected to stress rupture testing at 80°C and 60°C. Again, due to the difference in slopes for the squeeze failure mode vs. the control failure mode, if the pressure were too high, failure would occur in the pipe away from the squeezed area. At the lower pressures, all failures were inside to outside cracks that initiated at the squeeze-off location. At the gas utility use conditions of 70°F and 60 psig the RPM projected performance for the squeezed LDIW Aldyl “A” pipe was an average failure time of 20 years with an LCL of 10 years.

A projected performance of Aldyl “A” pipe that was properly squeezed of less than 50 years was another significant discovery for the DuPont Company. As a result they notified their Aldyl “A” customers again and recommended reinforcement of squeezed LDIW Aldyl “A” pipe. This was a letter issued by Ed Roddy of DuPont to its customers on August 25, 1986.

Deflection

Excessive earth loading can cause polyethylene pipe to deflect, which is another form of secondary loading. To simulate field deflection from earth loading, DuPont developed a “deflection jig” as shown in Figure 2. With this jig, varying levels of deflection may be achieved, where deflection is defined as the change in OD (ΔY) divided by the OD. For 5% deflection, $\Delta Y/D$ is 0.05. For an RPM experiment, all deflection levels must be the same and all failure modes must be the same. The typical deflection failure mode is an axial slit on the larger radius surface of the oval shaped pipe. DuPont conducted the RPM deflection experiment with 5% deflection on all specimens. At the use conditions of 70°F and 60 psig the RPM projected performance for the 5% deflected LDIW Aldyl “A” pipe was an average failure time of 18 years with an LCL of 9 years.

Bending

The gas utility also experienced a few failures of Aldyl “A” pipe from excessive bending. In this case the field failure mode is a circumferential crack that initiates at the outside surface. To simulate this secondary load of bending, DuPont developed a bending jig (Figure 3). The % bending strain calculation is shown in Figure 4. Again all calculations must be made using the same bending strain and the same failure mode. Due to the different slopes for the control pipe failure mode and the bending failure mode, if the pressure is too high, the failure mode is an axial slit in the pipe away from the bend area. At lower internal pressures, the failure mode is a circumferential slit in the bend area, the same failure mode observed in the field failures. DuPont conducted the RPM bending experiment with 6% bend strain on all specimens. At the gas utility use conditions of 70°F and 60 psig the RPM

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projected performance for the 6% bend strain LDIW Aldyl "A" pipe was an average failure time of 5 years with an LCL of 3 years.

Figure 5 is a composite plot for LDIW Aldyl "A" pipe summarizing RPM projected slit slopes at the gas utility average temperature of 70°F for control pipe (internal pressure only) and various secondary loads. This composite plot demonstrates the change in slopes for the different failure modes.

One Gas Utility's Field Experience with LDIW Aldyl "A" Pipe

Rock Impingement

The gas utility first started to experience rock impingement failures in LDIW Aldyl "A" pipe after five years of in-ground service. The number of rock impingement failures increased every year and peaked after 12 years of installation. The number of failures then began to decrease every year. This field experience exactly correlates with the RPM projected performance of indented LDIW Aldyl "A" pipe at their use conditions (average failure time of 12 years with a 5% LCL of 8 years).

Squeeze-Off

The first failure in Aldyl "A" pipe experienced by this gas utility due to a squeeze-off was after 12 years of installation. The number of squeeze-off failures has increased slightly. This field experience is consistent with the RPM projections for squeeze-off failures at the use conditions calculated (average failure time of 20 years with a 5% LCL of 10 years).

Deflection

The gas utility did not experience any failures in LDIW Aldyl "A" pipe due to excessive deflection. The RPM projection for 5% deflected LDIW Aldyl "A" pipe at the calculated conditions results in an average failure time of 18 years with an LCL of 9 years. Based on this projection, DuPont had developed installation guidelines to prevent failures due to this excessive deflection.

Bending

Some bending failures were experienced after just a few years of installation, which exhibited a circumferential slit. The RPM projection for LDIW Aldyl "A" pipe bent to a 6% bend strain at the gas utility calculated conditions is an average failure time of 5 years with an LCL of 3 years. Based on this projection, the gas utility installed some LDIW pipe at a bend strain of about 6%, which corresponds to a bend radius of about 10 times the pipe OD. This exceed DuPont's minimum bend radius recommendation of 20 times the OD for Aldyl "A" pipe, but provided valuable feedback for the gas utility to reinforce requirements for installation.

Another Gas Utility's Field Experience with LDIW Aldyl "A" Pipe

Another gas utility also kept very good records of Aldyl "A" PE 2306 pipe and fitting failures. They separated failures into two groups based on year of production. One group was Aldyl "A" pipe produced between 1971 and 1973, which would include LDIW pipe. Recall that not all the pipe produced by DuPont in those years had an LDIW surface. The other group was Aldyl "A" pipe produced between 1974 and 1984. This was all "standard" Aldyl "A" pipe. After 1984, DuPont produced ""improved'" Aldyl "A" pipe. The table below summarizes all their Aldyl "A" failures for the two groups based on failure mode. The units are number of failures per one million feet of pipe per year:

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Failure Mode	Aldyl "A" (1971 – 1973)	Aldyl "A" (1974 – 1984)
Rock impingement	1.26	0.17
Saddle fusion	1.25	0.51
Fitting crack	0.75	0.30
Fitting bend	0.68	0.32
Squeeze-off	0.61	0.32
Socket fusion	0.57	0.49
Pipe crack	0.27	0.11
Pipe bend	0.11	0.06
Other	2.04	0.75
Total	7.54 failures/ MM ft pipe	3.03 failures/ MM ft pipe
	0.040 leaks/mile	0.016 leaks/mile

Several very interesting observations can be made about the failure summary in this table. First of all, the leak rate for every failure mode decreased for the 1974-1984 Aldyl "A" compared to 1971-1973 Aldyl "A". This of course is due to the fact that a portion of the 1971-1973 Aldyl "A" pipe contains an LDIW surface. The overall failure rate for 1971-1973 Aldyl "A" of 0.040 leaks per mile is about an order of magnitude LESS than the leak rate for metal pipe of 0.43 leaks per mile as reported by AGA (9).

The failure mode with the highest failure rate is rock impingement, which is consistent with the first gas utility's field experience. The next highest failure rate is for fittings, which include saddle fittings and socket fittings. This is to be expected since heat fused fittings have notches that act as crack initiators. The next category is squeeze-off and the lowest failure rate is for pipe, which is again to be expected.

Aldyl "A" and Improved Aldyl "A" RPM Projections

During the 1980's the DuPont Company had a major research project to conduct RPM testing on many Aldyl "A" and Improved Aldyl "A" pipe and fitting components. These RPM data can be used to project Aldyl "A" performance at this gas utility's service conditions of an average annual ground temperature of 73°F (23°C) and an operating pressure of 40 psig. These RPM projections are then compared to actual field experience.

Pipe

Figure 6 is a composite plot for control pipe (internal pressure only) comparing LDIW Aldyl "A", standard Aldyl "A" and improved Aldyl "A" at the average annual temperature of 73°F. The table below compares the RPM projected performance for these three generations of control Aldyl "A" pipe at 73°F and 40 psig with the gas utility's actual field experience.

Control Aldyl "A" Pipe	RPM Projection at 73°F/40 psig (Years)	Field Experience (Failures/MM ft/year)
LDIW	267	0.27
Standard	3408	0.11
Improved	9693	0.0

The RPM projected performance is consistent with this gas utility's field experience for pipe. As the RPM projected lifetime at their use conditions increases, the number of field failures experienced decreases.

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Indented Pipe

Figure 7 is a composite plot for indented pipe (indentation jig with ¼" indentation) comparing LDIW Aldyl "A", standard Aldyl "A" and improved Aldyl "A" at the gas utility's average annual temperature of 73°F. For improved Aldyl "A" all failures occurred away from the indentation jig. All failure modes were axial slits in the pipe. The table below compares the RPM projected performance for these three generations of indented Aldyl "A" pipe at 73°F and 40 psig with this gas utility's field experience.

Indented Aldyl "A" Pipe	RPM Projection at 73°F/40 psig (Years)	Field Experience (Failures/MM ft/year)
LDIW	23	1.26
Standard	88	0.17
Improved	9693	0.0

Again, the RPM projected lifetime at this gas utility's use conditions correlates well with actual field experience for rock impingement failures.

Squeezed Pipe

Figure 8 is a composite plot for squeezed pipe (standard squeeze-off procedures) comparing LDIW Aldyl "A", standard Aldyl "A" and improved Aldyl "A" at the gas utility average annual temperature of 73°F. For improved Aldyl "A" all failures occurred away from the squeeze-off location. All failure modes were axial slits in the pipe. The table below compares the RPM projected performance for these three generations of squeezed Aldyl "A" pipe at 73°F and 40 psig with the gas utility field experience.

Squeezed Aldyl "A" Pipe	RPM Projection at 73°F/40 psig (Years)	Field Experience (Failures/MM ft/year)
LDIW	46	0.61
Standard	420	0.32
Improved	9693	0.0

Once again, the RPM projected lifetime at this gas utility's use conditions correlates well with actual field experience for squeeze-off failures.

A Gas Utility's Field Experience with Century Pipe

A gas utility installed Century PE 2306 pipe in their gas distribution system in the mid 1970's. Century pipe was a tan colored pipe, marketed primarily in the Midwest, made to look like Aldyl "A" pipe. In the late 1980's, the gas utility noted that in one area of their system they were experiencing several rock impingement failures in Century pipe after only a few years of service. In another area, they were not experiencing any failures with Century pipe. They noted that the Century pipe in the two areas had been installed at different times and also the Century pipe had two different production lots.

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Correlating Aldyl "A" and Century PE Pipe Rate Process Method Projections with Actual Field Performance

The gas utility planned to remove Century pipe (bad) from the area where they were experiencing failures, but they felt they did not need to remove Century pipe (good) from the area where they were not experiencing any failures. The gas utility contacted DuPont to see if they could conduct RPM testing on the two lots of Century pipe, and then use the results to justify to their Public Service Commission leaving the "good" Century pipe in the ground. They exhumed several feet of "good" and "bad" Century pipe and sent it to DuPont for RPM testing.

Century Pipe RPM Testing

The DuPont Company conducted Rate Process Method testing on the exhumed Century PE 2306 pipe in a similar fashion, as was done for Aldyl "A" pipe. Both the "good" and "bad" lots of Century pipe were tested at conditions that result in slit failures.

experience for rock impingement failures.

Control Pipe

Control pipe samples (primary internal pressure only) were tested at selected temperatures and internal pressures to produce axial slit failures. At the gas utility conditions of an average annual ground temperature of 60°F (15°C) and an average internal pressure of 60 psig, the RPM projected mean failure time for both lots of Century pipe was over 10,000 years and the 5% LCL was over 1000 years. These RPM projections would indicate good performance for the control (internal pressure only) Century pipe. The gas utility did not have any failures in control pipe for either pipe lot, which correlates well with the RPM projection.

Squeezed Pipe

Squeezed pipe RPM projections are based on testing the same lot of 2" Century pipe that has been squeezed-off using standard squeeze-off procedures. Dupont used a single bar squeeze tool with a gap stop of 0.340", which is the standard for Aldyl "A" pipe. After reaching the gap stop, each pipe specimen was left in the squeeze tool for one hour. Specimens tested at too high an internal pressure resulted in an axial slit failure away from the squeeze location. At lower pressures, all failures occurred at the squeeze location for the "bad" pipe lot with a slit initiating at the inside surface. At the gas utility conditions of an average annual ground temperature of 60°F and an average internal pressure of 60 psig, the RPM projected mean failure time for the "bad" lot of squeezed Century pipe was 300 years and the 5% LCL was 20 years. The "good" pipe lot failed away from the squeeze location at all test conditions. Although the gas utility did not experience any squeeze-off failures, the Rate Process Method does show a distinct difference in the slit or long-term performance of these two pipe lots.

Indented Pipe

Indentation is the laboratory method developed by DuPont of simulating point loading such a rock impingement. Indentation jigs were place on both the "good" and "bad" Century pipe lots and tightened to introduce ¼" of indentation. This indentation jig remains on the pipe for the duration of the test.

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Again, at higher internal pressures, failure occurred in the pipe away from the indentation jig. This is due to the different slope for the indentation failure mode. At the gas utility conditions of an average annual ground temperature of 60°F and an average internal pressure of 60 psig, the RPM projected mean failure time for the "bad" lot of indented Century pipe was 30 years and the 5% LCL was 8 years. The "good" pipe lot failed away from the indent location at all test conditions. This RPM projection for indented pipe correlates very well with this gas utility's field experience. They experience several indent failures after a few years for the "bad" pipe and no indent failures for the "good" pipe.

Based on these RPM projections developed by the DuPont Company, in 1990 gas utility requested the state Public Service Commission allow them to leave the "good" Century pipe in service. The PSC granted their request because the RPM projections correlated so well with their field experience. To date, after 14 more years of service, the "good" Century pipe is still in their distribution system and they still have not experienced any slit failures – just as predicted by the Rate Process Method.

Conclusion

The Rate Process Method is a very powerful tool that can be used to determine the projected life of old generation polyethylene pipe that is in service for natural gas distribution. RPM can project not only the life of control pipe based on internal pressure, but also the life of the pipe subjected to secondary loads such as rock impingement, squeeze-off, bending and deflection. RPM can also project the life of heat fusion fittings, such as butt fusion, socket fusion, saddle fusion and electrofusion. In addition, based on scatter of the data, RPM can project the mean or average failure time at use conditions and the lower confidence level at use conditions.

RPM can be used for older generation PE materials like Aldyl "A", Century, PE 2306, PE 3306, PE 3406 and PE 3408 materials. Because the new PE materials have such improved resistance to slow crack growth, RPM is not practical for modern PE 2406 or PE 100 materials because the slit failures simply take too long to generate in laboratory conditions.

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Figure 1 – Indentation Jig

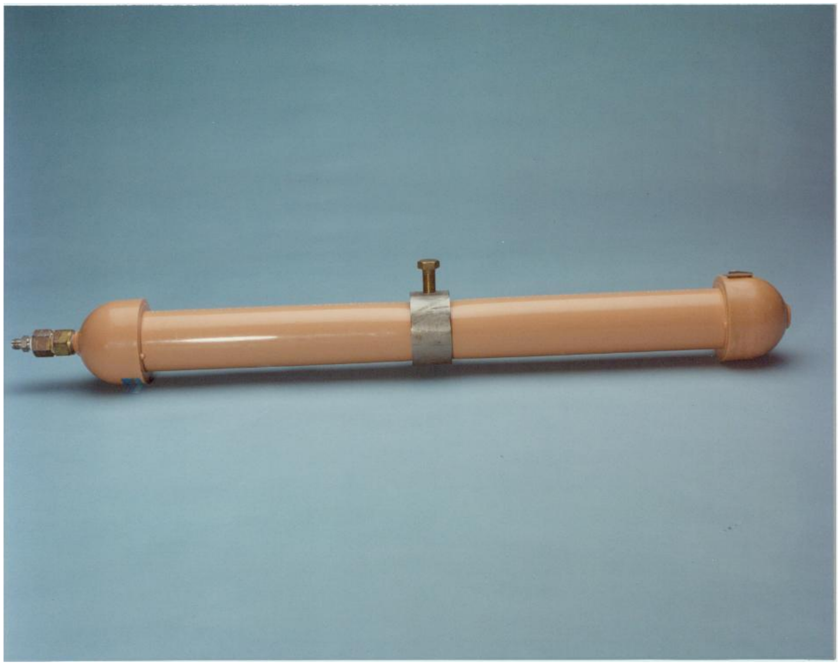

Figure 2 – Deflection Jig

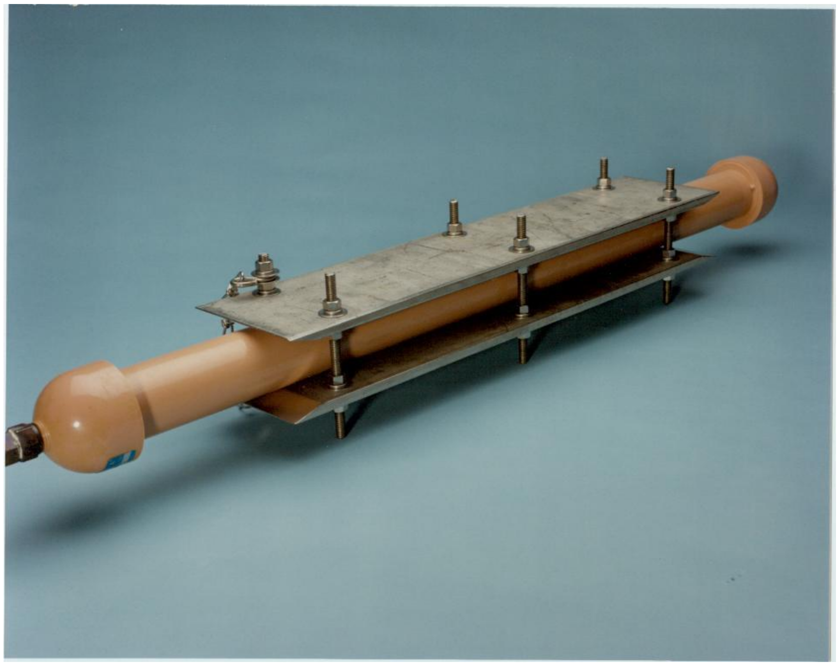

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Figure 3 – Bending Jig

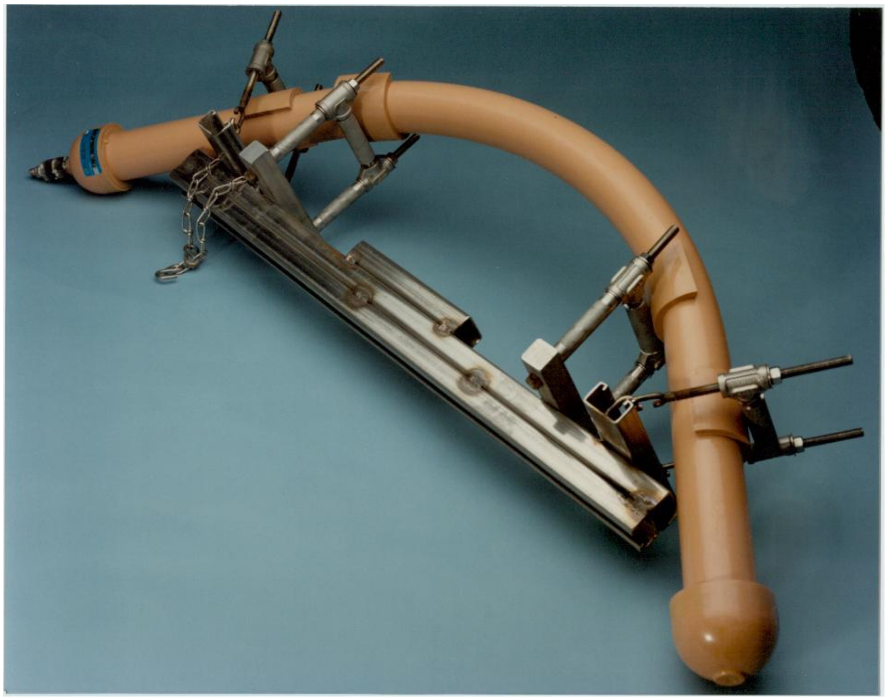
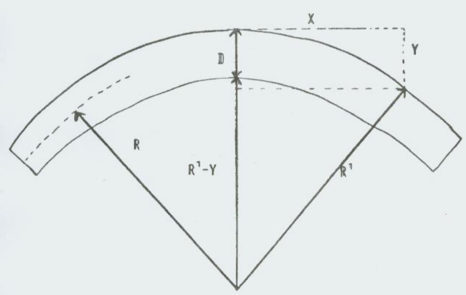


Figure 4 – Percent Bend

RATE PROCESS METHOD EXPERIMENT

EFFECT OF SECONDARY LOAD

BENDING



$$(R')^2 = (R' - Y)^2 + X^2$$

$$R' = \frac{X^2 + Y^2}{2Y} = \text{BEND RADIUS (OUTSIDE)}$$

$$R' = R + \frac{D}{2} = \frac{D}{2}\left(\frac{1}{E} + 1\right)$$

$$E = \left[\frac{2}{D}\left(\frac{X^2 + Y^2}{2Y}\right) - 1\right]^{-1} = \text{BEND STRAIN}$$

$$R = \frac{D}{2E} = \text{BEND RADIUS (CENTERLINE)}$$

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Figure 5 – Composite Showing Control Pipe and Secondary Loading Effects

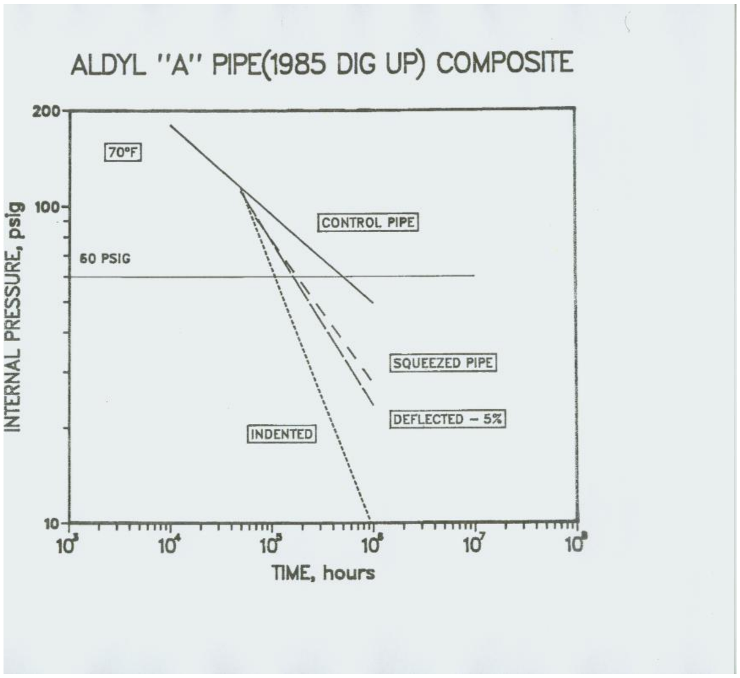

Figure 6 – Composite of Three Generations of Control Aldyl "A" Pipe

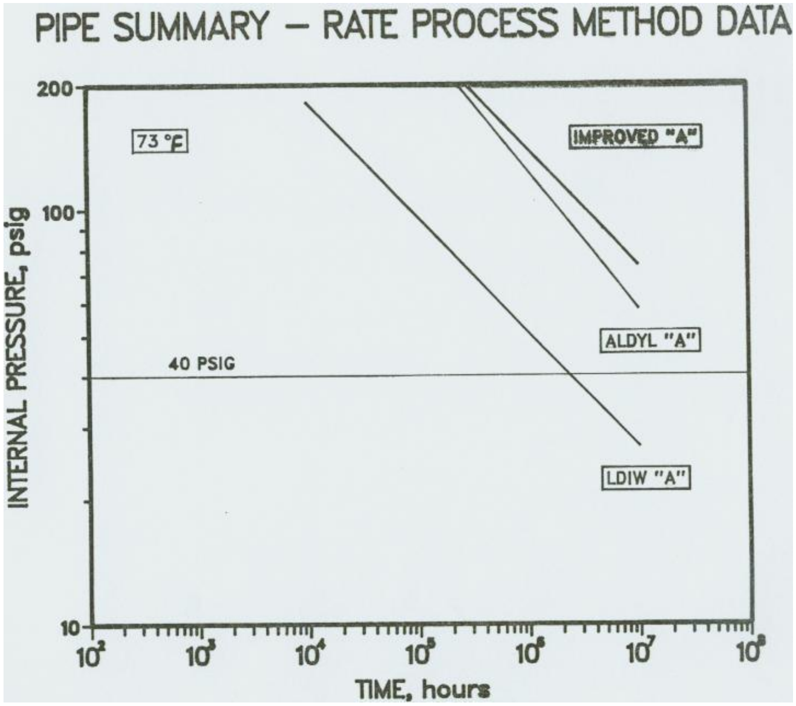

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Figure 7 - Composite of Three Generations of Indented Aldyl “A” Pipe

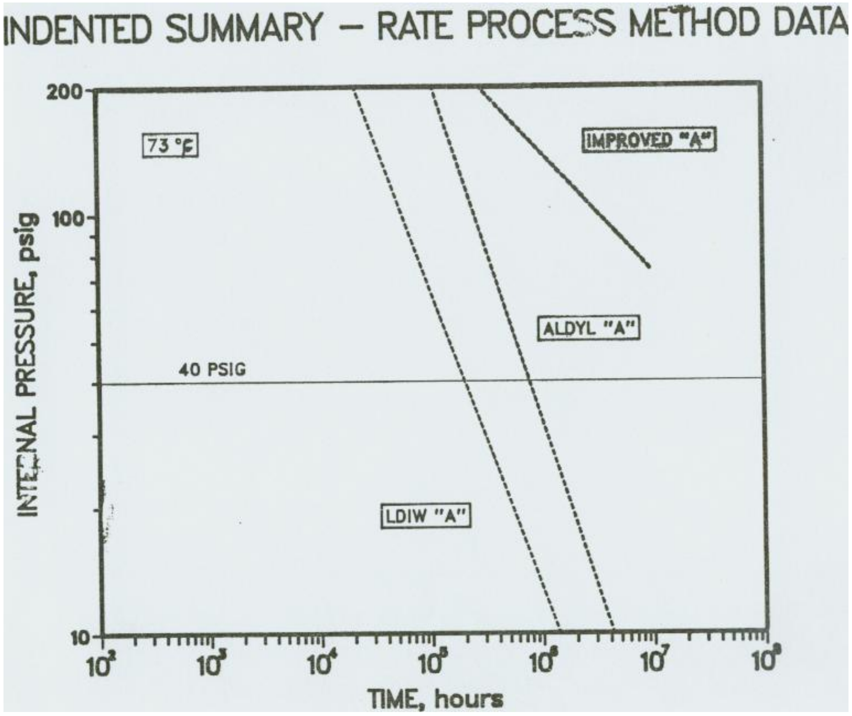
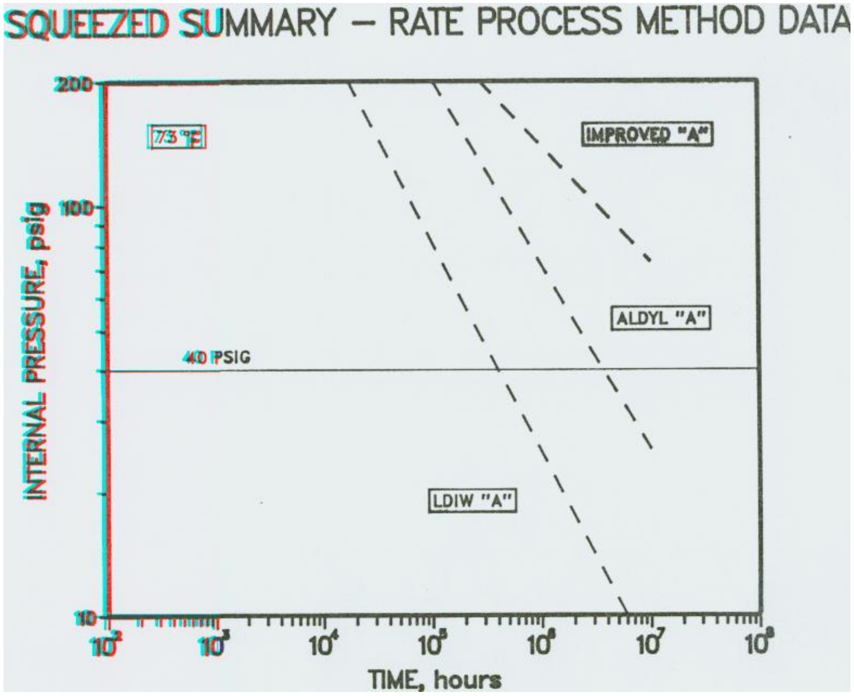


Figure 8 - Composite of Three Generations of Squeezed Aldyl “A” Pipe



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