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HISTORY OF
ALDYL "A" PIPING SYSTEM

By

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HISTORY OF ALDYL "A" PIPING SYSTEM"

I. Summary

As a result of recent Aldyl® "A" pipe failures in the United States, gas companies have requested information on the history of Aldyl "A" and specifically the "Low Ductile Inner Wall" phenomenon that occurred in the early 1970's. This White Paper summarizes a history of the Aldyl® "A" piping system, made from various Alathon® resins, which was marketed by the DuPont Company in the United States from the mid 1960's to the late 1990's. Aldyl "A" pipe was also marketed by DuPont Canada during much of that time period. Included is information on the Alathon PE resins that were used and their properties, Aldyl "A" pipe, Aldyl "A" fittings and the joining methods that were used for the Aldyl "A" piping system. Finally, this report includes detailed information on the Rate Process Method (RPM) as a tool to project expected lifetime for Aldyl "A" pipe and fittings, and also remaining life for exhumed Aldyl "A" PE pipe. RPM is explained in detail and several examples for Aldyl "A" pipe and fittings are included for various Alathon PE materials.

II. Background – Dr. Palermo

Dr. Gene Palermo received a Bachelor of Science in Chemistry from St. Thomas College in St. Paul, MN in 1969 and a Ph.D. in Analytical Chemistry from Michigan State University in 1973.

Dr. Palermo has been in the plastic piping industry for over 35 years. He worked for the DuPont Company from 1976 to 1995 in the Aldyl "A" polyethylene (PE) pipe business for natural gas distribution. During that time, he was involved with research, manufacturing and marketing the Aldyl "A" piping system for natural gas applications. Dr. Palermo then developed the initial use of polyamide (PA) 11 for high-pressure gas distribution, up to 250 psig, to replace metal pipe while with Elf AtoChem during 1995 and 1996.

Dr. Palermo was the Technical Director for the Plastics Pipe Institute (PPI) from 1996 until 2003. As Technical Director, Dr. Palermo was chairman of the Hydrostatic Stress Board (HSB) on which he had served for over 20 years to develop pressure rating methods for plastic pipe; and chairman of the Technical Advisory Group for ISO/TC 138 for international plastic piping systems. Dr. Palermo has developed standards for plastic pipe and fittings in several standards bodies; ASTM F17, CSA B137, AASHTO, and ISO/TC 138.

Most of Dr. Palermo's expertise has been in the natural gas distribution industry. He has been a member of the AGA Plastic Materials Committee for over 25 years, the Gas Pipe Technology Committee for 15 years, an instructor for the DOT inspector training school, and was an original member of the Plastic Pipe Database Committee. Dr. Palermo has also developed a one day Technical Seminar for the gas distribution industry.

Dr. Palermo currently serves as a member of PPI, AGA, GPTC (Chairman of Manufacturers Division), AWWA, ASTM F 17 (Director of Division I), ASTM D 20, CSA B137, CSA Z662 (Chairman of Clause 12 Gas Distribution), and ISO/TC 138. Dr. Palermo is currently president of his consulting firm – Palermo Plastics Pipe Consulting. Dr. Gene Palermo was recently honored with the **ASTM Award of Merit**, which is the highest Society recognition for individual contributions to standards activities, and the **AGA Platinum Award of Merit**, which is the highest award that can be achieved within AGA. Dr. Palermo is the only person to receive both of these very prestigious awards!

III. DuPont Aldyl "A" Resin

A. Polyacetal

The first thermoplastic resin that the DuPont Company used to manufacture plastic pipe for the natural gas distribution industry was polyacetal, with the trade name Delrin®. Manufacturing began at the plant in Tulsa, OK in 1960. Because the polyacetal material was brittle, DuPont then made a coextruded pipe with a polyacetal core and an outer layer of polyethylene (PE). The trade name for DuPont's PE materials was Alathon®. DuPont took the "al" from Alathon and "del" from Delrin and came up with the trade name "Aldel". Apparently, this was too close to an existing trade name, so they changed the "e" to a "y" and came up with Aldyl® as the new trade name for its co-extruded thermoplastic gas pipe. In 1965, DuPont eliminated the polyacetal and began to make their gas pipe as a solid wall PE pipe. The name of this PE pipe was Aldyl "A" pipe.

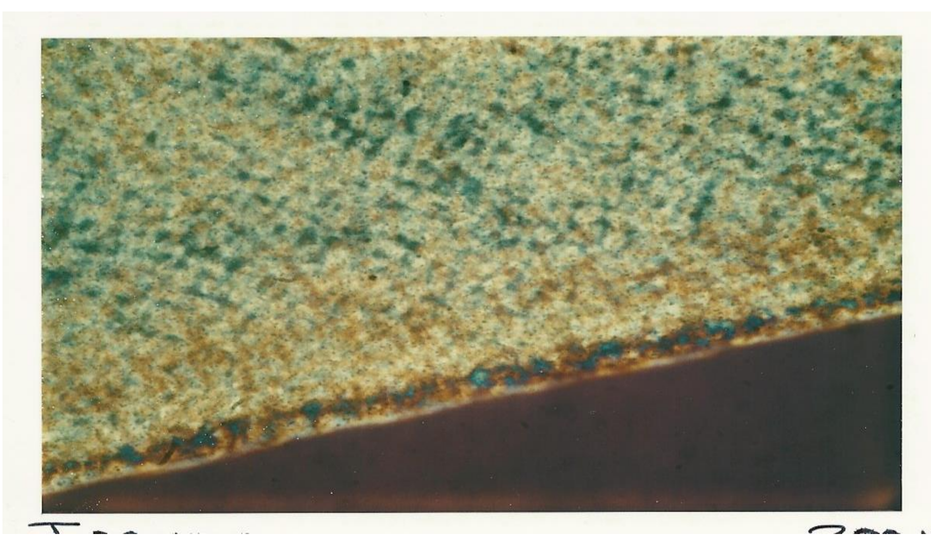
B. Alathon 5040

The PE resin that DuPont initially used for the production of Aldyl "A" pipe from 1965 to 1970 was Alathon 5040. This PE resin used a butene comonomer and had a base resin density of 0.935 g/cc and a melt index (MI) of 2.0 g/10 min. These two properties of melt index and density control many of the other physical properties for PE materials. Most of the other PE materials used for the gas industry at that time had an MI of about 0.2 g/10 min, so Aldyl "A" was not fusion compatible with these other PE materials. With this relatively low molecular weight (high MI), the recommended butt fusion temperature for Aldyl "A" pipe was 310ºF (154ºC), compared to 400ºF (204ºC) to 500ºF (260ºC) for the other PE materials.

C. Alathon 5043

Because some of the small tubing sizes made from the Alathon 5040 resin did not consistently meet the ASTM D 1599 quick burst minimum stress requirement of 2520 psi, DuPont decided to use a higher density PE resin. DuPont changed to Alathon 5043 resin in 1970. This was also a butene comonomer, but with a higher base resin density of 0.939 g/cc to increase the yield strength and more consistently meet quick burst stress requirements. In order to maintain a balance of molecular parameters, the molecular weight was increased when the density was increased, and the corresponding melt index was 1.2 g/10 min. With this higher molecular weight (lower MI) the butt fusion melt temperature was increased to 340ºF (171ºC).

Alathon 5043 was the primary PE resin that DuPont US used for Aldyl “A” pipe from 1970 to 1983. DuPont US also shipped this resin and the corresponding master batch to DuPont Canada for production of Aldyl “A” pipe in Canada at the Huntsville plant. It was also during this time that the LDIW (low ductile inner wall) phenomenon occurred. In the late 1970 to 1971 era, DuPont had a manufacturing issue that resulted in a brittle inside surface. This was finally detected during some elevated temperature stress rupture testing that resulted in premature failures, in which multiple slits were observed as opposed to the normal single slit failure. It was also noted that the spherulites on the inside surface were very large (30 to 40 microns), as shown in the photo below. Because of these large spherulites on the inside surface, this pipe is called “large bore spherulite” pipe, or the term more commonly used is LDIW. The terms "low ductile inner wall" and "large bore spherulites" are synonymous. The brittle inside surface resulted from the manufacturing process that degraded the inner surface. The premature failures were due to an oxidized inner surface that dramatically reduced the initiation time and thus the overall failure time. The effect of this LDIW surface on long-term pipe performance has been determined using the Rate Process Method (RPM), which is discussed in Appendix I, which is a paper I presented at the 2004 AGA Operations Conference, *“Correlating Aldyl ‘A’ and Century PE Pipe Rate Process Method Projections With Actual Field Performance”*. In early 1972 DuPont US changed the manufacturing process to prevent these large spherulites from forming. DuPont estimated that about 30% to 40% of the pipe it produced in 1970 and 1971 had an LDIW inner surface, and it was primarily in pipe sizes 1-1/4” to 4” IPS. It is very likely that DuPont Canada may have also produced LDIW Aldyl “A” in the early to mid 1970’s, but exact details are not known at this time.



During the 1975 to 1980 era, DuPont also produced Aldyl “AAAA” from the same Alathon 5043 resin. The only difference is that the color of the pipe was green instead of tan. Aldyl “AAAA” was SDR 9 pipe that could be used in densely populated areas (called class 4) with an operating pressure of 60 psig. The design factor in a class 4 area was 0.2 instead of the standard 0.25, and thus a thicker wall was required to operate at 60 psig. The green color was used to differentiate this SDR 9 Aldyl “AAAA” pipe from the standard tan SDR 11 Aldyl “A” pipe. Since this green pipe was initially produced in 1975, none of the Aldyl “AAAA” pipe had the LDIW problem.

D. Alathon 5046-C

In 1983 DuPont made a significant change in the PE resin as they switched from a butene comonomer to an octene comonomer. The original octene resin was called Alathon 5046-C, and it had a melt index of 1.1 g/10 min and a base resin density of 0.939 g/cc. This change to octene resulted in a significant improvement in slow crack growth (SCG) resistance and in long-term performance. The octene comonomer has longer side branches than butene (six carbons instead of two carbons), and this improved the efficiency of the tie molecules, which control long-term performance. This is explained in Figure 1. Polyethylene is known as a semi-crystalline polymer, meaning part of the polyethylene is in a crystalline region and part in an amorphous region. In the crystalline region, the molecules form crystals known as “lamellas” – this is also known as “folded chain morphology” for polyethylene, and these crystals are shown in the top photo of Figure 1. When a PE molecule exits the crystal and terminates, it is called a “cilia”. When a PE molecule exits and returns to the same crystal it is called a “loose loop”. When it exits and then enters another crystal it is called a “tie molecule”. These are the long chain molecules that literally “tie” the crystals together. This combination of cilia, loose loops and tie molecules form the “amorphous” portion of PE.

When a high load is applied to PE, the failure that results is a short-term failure; the crystals break apart as shown in the middle photo of Figure 1. These high load or high stress properties are the short-term properties, such as yield strength, and are dependant on the PE base resin density. When a lower load (stress) is applied to PE material the failure mode is a long-term failure. In this case, the amorphous region unravels as the lamellas separate. As they continue to separate, it is the tie molecules that hold these lamellas together, as shown in the bottom photo of Figure 1. When these tie molecules finally break, a crack forms and then advances or grows, which results in the long-term failure mode known as slow crack growth.

When the load is initially applied to the PE material, a craze zone forms at the tip of a small crack or an imperfection. This craze zone is due to the alignment of the tie molecules as the load is applied. Eventually, the tie molecules begin to break, and this causes the crack to grow to the end of the craze zone. At this point, the crack arrests (stops) and a new craze zone forms, and the process continues. The slow crack growth phenomenon thus consists of crack growth followed by crack arrest, then crack growth followed by crack arrest, etc. This growth/arrest pattern results in growth rings on a fracture surface, much like “tree rings” that form on a tree. These growth rings are very apparent in actual PE field failures due to slow crack growth, and they are also very apparent in elevated temperature stress rupture testing of PE pipe or fittings. The duplication of this crack/arrest failure mode in laboratory testing is the reason that prediction models, such as the Rate Process Method, are very good.

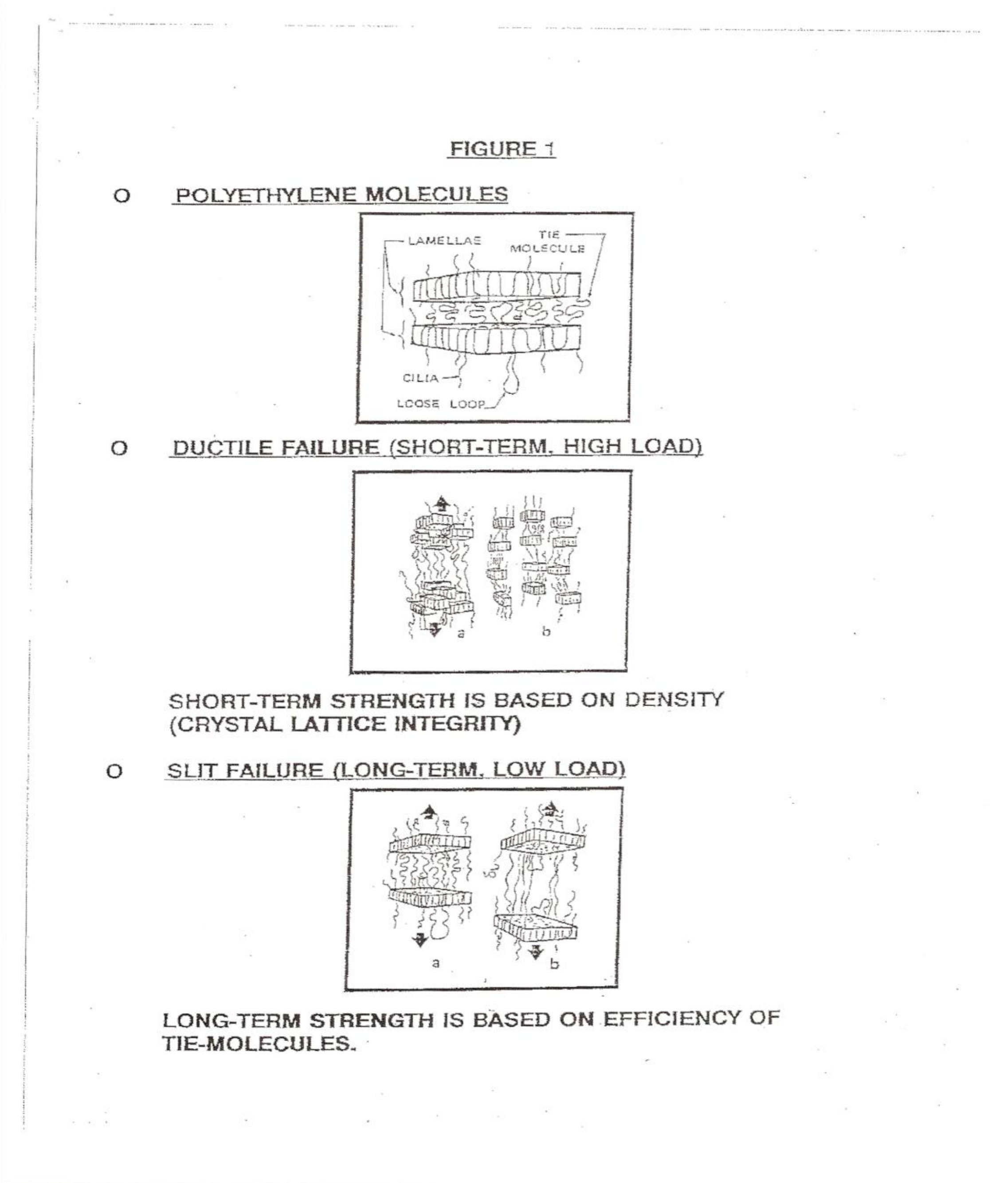
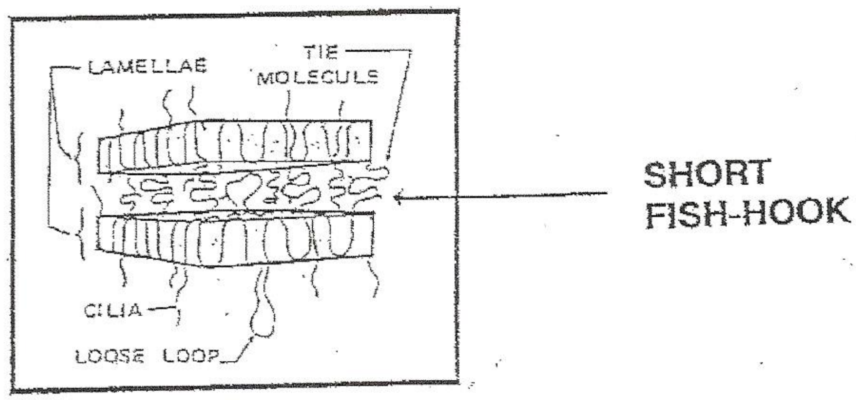


Figure 1 – Tie Molecules in Polyethylene

TIE MOLECULE EFFICIENCY

THE EFFICIENCY OF THE TIE MOLECULES IN KEEPING THE CRYSTAL LATTICES TOGETHER IS BASED ON THE COMONOMER, WHICH ACTS LIKE A "FISH-HOOK".



BY MODIFYING THE COMONOMER AND MAKING THE "FISH-HOOKS" LONGER, THE TIE MOLECULES ARE MORE EFFICIENT.

Figure 2 – Efficiency of Tie Molecules

With the butene comonomer, there are only two carbons as a side branch on the PE molecule, and these act as "short fish hooks" (Figure 2) in trying to prevent the tie molecule from unraveling. With the octene comonomer, there are now six carbons on the side branches, and these act as much longer fish hooks and are more efficient in preventing the tie molecules from unraveling. Since these longer fishhooks are more efficient in keeping the tie molecules from unraveling, it takes a longer time for the tie molecules to break. This increased efficiency of the tie molecules results in a significantly longer time for the crack to grow and thus for a failure to occur, as shown below in a typical 80ºC/120 psig stress rupture test for Aldyl "A" pipe, using test method ASTM D 1598:

- Alathon 5043 resin (butene comonomer) 100 hours
- Alathon 5046C resin (octane comonomer) 1000 hours

With this improvement in long-term performance, DuPont called this new product Improved Aldyl "A".

E. Alathon 5046-U

DuPont recognized the importance of the tie molecules, and the octene comonomer with the longer fishhooks that improved the efficiency of these tie molecules. In 1988 DuPont announced another improvement with the introduction of Alathon 5046-U. They added more octene comonomer to the resin, which decreased the density to 0.933 g/cc. The melt index remained at 1.1 g/10 min. This additional comonomer increased the number of "long fish hooks" and thus increased the efficiency of the tie molecules even more. This resulted in another order of magnitude improvement in slow crack growth resistance, as evidenced by 80ºC/120 psig stress rupture testing for Aldyl "A" pipe:

- Alathon 5043 resin 100 hours
- Alathon 5046-C resin 1000 hours
- Alathon 5046-U resin 10,000 hours

This product was also called improved Aldyl "A". An advantage of the lower density was increased flexibility for the pipe. This made the pipe easier to bend, easier to coil and uncoil – especially in cold weather, and easier to squeeze-off – especially in cold weather. These installation advantages, coupled with the improved SCG resistance, made Alathon 5056-U one of the best PE materials available for the natural gas distribution market.

F. Alathon 5046-O

The last change in the resin for Aldyl "A" pipe came in 1992 with the introduction of Alathon 5046-O. DuPont developed technology whereby the octene comonomer could be selectively placed on the high molecular weight molecules. Since the tie molecules are very high molecular weight, much of the octene comonomer was thus added to the molecules that directly affect long-term performance. Since the amount of comonomer remained the same, the density was still 0.933 g/cc and the melt index was still 1.1 g/10 min. This final change in the PE resin resulted in another improvement in slow crack growth resistance, as evidenced by 80ºC/120 psig stress rupture testing for Aldyl "A" pipe:

- Alathon 5043 resin 100 hours
- Alathon 5046-C resin 1000 hours
- Alathon 5046-U resin 10,000 hours
- Alathon 5046-O resin >30,000 hours

G. Summary of Resins

A summary of the various DuPont Alathon resins used to produce Aldyl "A" pipe is provided in Table 1 below:

Table 1 - DuPont Aldyl® "A" PE Pipe and Alathon® PE Resins

#	Name	Year	Density	Melt Index	Co-monomer	Color	Resin	Comment
1	Aldyl "A"	1966 – 1970	0.935	2.0	Butene	Tan	Alathon® 5040	Original Alathon resin
2	Aldyl "A"	1970 – 1983	0.939	1.2	Butene	Tan	Alathon 5043	Increased density due to quick burst test
	LDIW Aldyl "A"	1971 – 1972	0.939	1.2	Butene	Tan	Alathon 5043	Manufacturing issue
	Aldyl "AAAA"	1975 – 1980	0.939	1.2	Butene	Green	Alathon 5043	DR 9 for class 4 areas
3	Improved Aldyl "A"	1983 – 1988	0.939	1.1	Octene	Tan	Alathon 5046-C	Changed comonomer
4	Improved Aldyl "A"	1988 – 1992	0.933	1.1	Octene	Tan	Alathon 5046-U	Added more comonomer
5	Improved Aldyl "A"	1992 -	0.933	1.1	Octene	Tan	Alathon 5046-O	Placed comonomer on high molecular weight molecules

IV. DuPont Aldyl "A" Pipe

A. Pipe Physical Properties

The two key physical properties for a PE piping material are the 1) melt index, which is a measure of molecular weight, and 2) density, which is a measure of molecular branching. These two properties were described in Section III for all the various Alathon resins used to make Aldyl "A" pipe. Most of the other general physical properties are dependant on these two properties. These physical properties that were published in the Aldyl "A" Product and Technical Bulletins are summarized in Table 2.

Table 2 - DuPont Aldyl® "A" Pipe Physical Properties

Property	ASTM Test Method	Nominal Value
Thermal expansion	E831	9×10^{-5} in/in/ºF
Yield strength	D3350	2500 psi
Ring tensile strength	D2290	2500 psi
Modulus of elasticity	D638	100,000 psi
Thermal conductivity	C177	1.8 BTU/hr/sq ft/ºF/in
Deflection temperature	D648	140ºF
Vicat softening point	D1525	250ºF
Impact brittleness	D746	<-150ºF
Flammability	D635	1 in/min
Flexural modulus	D3350	90,000 psi
Elongation	D638	>900%
Induction temperature (IT)	D3350	>220ºC
PENT (Alathon 5043)	F1473	1 hour
80ºC/120 psig Stress Rupture (Alathon 5043)	D1598	100 hours

The color of Aldyl "A" pipe is tan or ochre. It was intended to be orange, as the pigment was Molybdate Orange. However, the formulation for Aldyl "A" pipe also included a UV stabilizer known as NBC, which was green in color. As a result of this green NBC ingredient, the overall color was tan instead of orange. In addition to the pigment and UV stabilizer, the Aldyl "A" formulation also included an anti-oxidant and titanium dioxide (0.5%) as an opacifier.

B. Ductile Regression Lines and HDB Values

The ASTM method to determine the pressure rating for thermoplastic materials is discussed in detail in ASTM D2837. For Aldyl "A" pipe the typical long-term hydrostatic strength (LTHS) at 73ºF (23ºC) and 100,000 hours is about 1300 psi, as shown in Figure 3 below taken from the *Aldyl "A" Product and Technical Bulletin*.

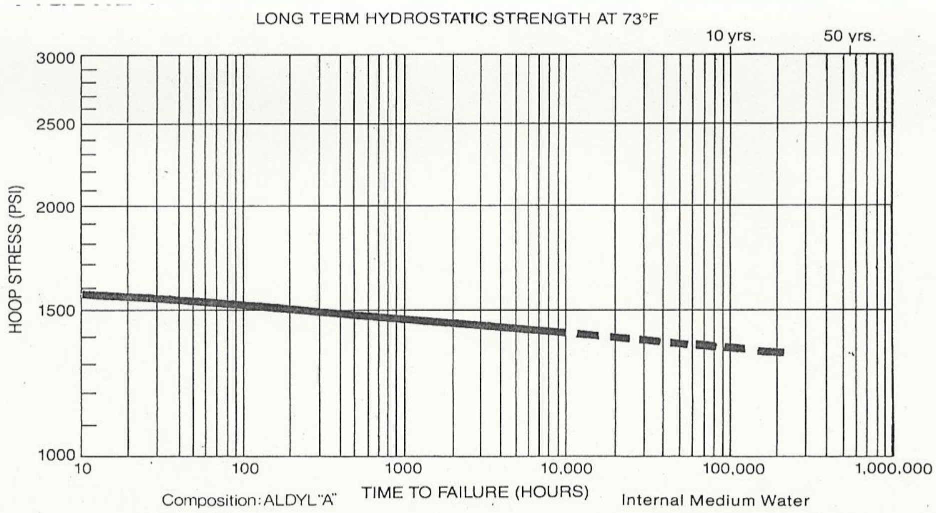


Figure 3 – Typical Aldyl "A" Pipe Ductile Regression Line at 73ºF (23ºC)

Below I have summarized some typical ductile regression data for Aldyl "A" pipe made from Alathon 5043 resin and also made from Alathon 5046 resin. The ductile regression slopes and projections were not very much affected by the resin type. As such, Aldyl "A" pipe always had the same pressure rating, regardless which Alathon resin was used.

1. DuPont Ductile Regression Data for 2" Aldyl "A" Pipe (Alathon 5043 Resin)

Typical stress rupture data for 2" SDR 11 Aldyl "A" pipe made from Alathon 5043 resin are shown below at 23ºC (73ºF). All of these data have a ductile failure mode. In this raw data table the first number is the file number, the second number is the lot code, the third number is the temperature in degrees Celsius, the fourth number is the internal stress in psi or the internal pressure in psig, and the last number is the failure time in hours. In this case, the values are in stress (psi).

File- Lot- Temp- Stress- Hours

168	91	23.	1675.	24.0
168	91	23.	1675.	30.0
168	91	23.	1650.	70.0
168	91	23.	1650.	76.0
168	91	23.	1625.	81.0
168	91	23.	1625.	126.0
168	91	23.	1625.	182.0
168	91	23.	1600.	176.0
168	91	23.	1600.	201.0
168	91	23.	1550.	351.0
168	91	23.	1550.	449.0
168	91	23.	1550.	763.0

168	91	23.	1525.	625.0
168	91	23.	1525.	711.0
168	91	23.	1525.	854.0
168	91	23.	1500.	711.0
168	91	23.	1500.	1119.0
168	91	23.	1500.	2048.0
168	91	23.	1475.	4628.0
168	91	23.	1475.	6218.0
168	91	23.	1475.	11399.0
168	91	23.	1450.	45494.0
168	91	23.	1450.	29768.0
168	91	23.	1450.	41771.0
168	91	23.	1450.	33016.0
168	91	23.	1450.	19366.0

ASTM D 2837 regression analysis of these data at 73ºF (23ºC) results in the following equations and long-term projections.

<u>73ºF (23ºC) ASTM D 2837 analysis</u>

Regression at 23 C : File FILE168.DAT

LOG TIME = A(0) + A(1)* LOG PRESSURE
A(0) = 145.85120
A(1) = -44.81794
Correlation Coef. R = -.96
No. of data points = 26

Input TIME : if Years, input an INTEGER ;
If Hours, input a NON-INTEGER : 100000.01
Please input LOWER Confidence Limit in % : 2.5
The interval between low and high limits is 95. % :

Mean Pressure = 1389. PSI
LCL on Mean value = 1369.
UCL on Mean value = 1410.

The LTHS for this dataset is 1389 psi, which means an HDB of 1250 psi at 73ºF (23ºC). Based on the upper confidence level (UCL) and lower confidence level (LCL), there is a 95% probability that the LTHS at 100,000 hours is between 1369 and 1410 psi.

<u>2. DuPont Ductile Regression Data for 2” Aldyl “A” Pipe (Alathon 5046 Resin)</u>

Typical stress rupture data for 2” SDR 11 Aldyl “A” pipe made from Alathon 5046 resin are shown below at 23ºC (73ºF). All of these data again are for the ductile failure mode. In this case, the data are for pressure (psig).

File-Lot-Temp-Pressure-Hours

173	1	23.	375.	2.7
173	1	23.	375.	2.2
173	1	23.	370.	3.0
173	1	23.	370.	4.0
173	1	23.	365.	5.5
173	1	23.	365.	4.0
173	1	23.	350.	12.2
173	1	23.	350.	12.3
173	1	23.	350.	13.2
173	1	23.	340.	17.5
173	3	23.	306.	53.4
173	3	23.	299.	232.8
173	3	23.	299.	218.8
173	3	23.	297.	433.5
173	3	23.	297.	605.8
173	3	23.	290.	3192.0
173	3	23.	288.	2304.0
173	3	23.	288.	2112.0
173	3	23.	288.	2448.0
173	3	23.	280.	25001.0
173	2	23.	331.	41.8
173	2	23.	330.	23.3
173	2	23.	330.	42.0
173	2	23.	328.	78.5
173	2	23.	321.	683.5
173	2	23.	320.	113.3
173	2	23.	320.	588.7
173	2	23.	319.	461.4
173	2	23.	310.	129.8
173	2	23.	310.	4689.0
173	2	23.	309.	551.9
173	2	23.	309.	654.0
173	2	23.	301.	552.8
173	2	23.	301.	186.5
173	2	23.	301.	2163.6
173	2	23.	300.	558.0
173	2	23.	300.	2048.0
173	2	23.	300.	1119.2
173	2	23.	299.	1173.8
173	2	23.	297.	6164.0
173	2	23.	292.	58001.0
173	2	23.	282.	87001.0

ASTM D 2837 regression analysis of these data at results in the following equations and long-term projections.

73ºF (23ºC) ASTM D 2837 analysis

Regression at 23 C : File FILE173.DAT

LOG TIME = A(0) + A(1)* LOG PRESSURE
A(0) = 75.05049
A(1) = -29.06179
Correlation Coef. R = -.91
No. of data points = 42

Input TIME : if Years, input an INTEGER ;
If Hours, input a NON-INTEGER : 100000.01
Please input LOWER Confidence Limit in % : 2.5
The interval between low and high limits is 95. % :

Mean Pressure = 257. PSI
LCL on Mean value = 249.
UCL on Mean value = 266.

The LTHS for this dataset is 257 psig (1285 psi), which again means an HDB of 1250 psi at 73ºF (23ºC).

C. Pressure Rating

Based on the above LTHS values, the HDB (hydrostatic design basis) for Aldyl "A" pipe is 1250 psi at 73ºF (23ºC). As I mentioned, this HDB value did not change when all the various Alathon resin changes were made. From the HDB, the pressure rating may be determined, and Aldyl "A" pipe always had these same pressure ratings.

The Department of Transportation prescribes the following equation to determine the maximum operating pressure for thermoplastic pipe:

$$MOP = [2\ (HDB)\ (F)\ /\ (DR - 1)]$$

Where: MOP = maximum operating pressure, psig
HDB = hydrostatic design basis, psi
F (design factor) = 0.32 for gas pipe applications
DR = dimension ratio

All thermoplastic piping materials must have an HDB at 73ºF (23ºC) and an elevated temperature HDB. The 140ºF (60ºC) HDB is taken from Aldyl "A" literature and this is the maximum design temperature for PE piping materials. Using the above equation, Table 3 summarizes the maximum operating pressure (MOP) or pressure rating for Aldyl "A" pipe at 73ºF (23ºC) and at 140ºF (60ºC) for various dimension ratios.

Table 3 – Maximum Operating Pressure (MOP) for Aldyl "A" Pipe

SDR	73ºF (23ºC)	140ºF (60ºC)
7.0	100	86
9.3	96	61

10.0	88	56
11.0	80	51
11.5	76	49
12.5	69	44
13.5	64	40
15.3	56	36
21.0	40	25

In most cases, gas utilities use the HDB established at the higher temperature to determine the pressure rating at that higher temperature. Most of the PE pipe manufacturers published HDB values at 140ºF (60ºC) so that gas companies could make these calculations. In other industries, such as water pipe, a temperature derating factor is used instead of the elevated temperature HDB. In the gas industry, these temperature-derating factors are not used. In fact, ASTM D 2513 requires that the pipe manufacture publish the elevated temperature HDB on the pipe print line using a code system described in D 2513.

D. Squeeze-Off

a). Gas Industry Practice

Gas companies have used squeeze-off as a means of controlling the flow in PE gas pipe since the 1970's. Within the gas industry, there are many resources for information and guidance on proper squeeze-off of PE gas pipe.

Many of the major PE pipe manufacturers provided squeeze-off procedures for proper squeeze-off of their product. Examples of this are Bulletin #661 "Pressure Control by Squeeze-Off" (1974) and Installation Bulletin 104 "Aldyl Flow Control by Squeeze-Off" (1991) that were available from the DuPont Company.

ASTM standards were also available for the squeeze-off procedure. These include:

- ASTM F 1041, "Standard Guide for Squeeze-Off of Polyolefin Gas Pressure Pipe and Tubing", issued in 1987.
- ASTM F 1563, "Standard Specification for Tools to Squeeze-Off Polyethylene (PE) Gas Pipe or Tubing", issued in 1993.
- ASTM F 1784, "Standard Practice for Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-Off Procedures to Avoid Long-Term Damage in Polyethylene (PE) Gas Pipe, issued in 1996.

In addition, the Gas Research Institute (GRI) published three reports on squeeze-off of PE gas pipe:

- Volume 1: User's Guide on Squeeze-Off of Polyethylene Gas Pipe, February 1992
- Volume 2: Technical References on Squeeze-Off of Polyethylene Gas Pipes, October 1992
- Guidelines and Technical Reference on Gas Flow Shut-Off in Polyethylene Pipes Using Squeeze Tools, June 1994

b). Properly Squeezed PE Pipe

When PE pipe is squeezed-off using a standard round bar squeeze-off tool, the pipe is flattened and the area on each side is called an “ear” or “squeeze cheek”. In this squeeze cheek area, there will be several parallel folds or grooves that form as the pipe is compressed during the squeeze-off process. These grooves just represent folding of the PE material during the squeeze-off process, and generally do not cause any long-term damage to the pipe. DuPont testing has shown that these folds in the pipe generally do not affect long-term performance, based on 80ºC stress rupture testing, although there are some instances where even proper squeeze-off of pipe affects long-term performance.

It is possible that even when PE 2306 or PE 2406 pipe is squeezed-off properly, the life of the pipe may be reduced somewhat, as these folds may act as initiation points for slow crack growth (SCG) to occur. I observed this when conducting Rate Process Method (RPM) experiments on MDPE pipe while I was with the DuPont Company. For properly squeezed improved Aldyl “A” pipe (5046 resin), failures occurred in the pipe away from the squeeze-off location. For properly squeezed standard Aldyl “A” pipe (5043 resin) the RPM projection was a failure time of several years after the squeeze-off, and the failure location was at the squeeze-off. It is important to note that these projected failure times for **properly** squeezed Aldyl “A” pipe are much less than the projected failure times for the control pipe. For the LDIW (low ductile inner wall) Aldyl “A” pipe that had been **properly** squeezed, the RPM projected failure time was reduced even further, and the failure location was also at the squeeze-off location. The crack initiated in the degraded inside surface area in the squeeze cheek area and propagated slowly through the pipe wall.

c). Improperly Squeezed PE Pipe

When PE pipe is over-squeezed, and the pipe is compressed beyond the industry recommendation of 30%, damage may occur at the squeeze cheek area. It is possible for ductile tearing to occur in the fold area as a result of the over-compression (over-squeeze). An SCG crack will initiate in this area and grow through the pipe wall. This will result in a squeeze-off failure after a few years, depending on the SCG resistance of the PE material.

E. Rate Process Method Data and RPM Equations/Projections

The DuPont Company conducted many Rate Process Method (RPM) experiments on Aldyl “A” pipe and fittings and several other competitive pipe and fittings. RPM as an analytical tool is explained in more detail in Appendix I. A typical data set and RPM equation is provided here for standard Aldyl “A” pipe made from Alathon 5043 resin, LDIW Aldyl “A” control pipe and LDIW Aldyl “A” indented pipe to simulated rock impingement, and for Aldyl “A” pipe made from Alathon 5046 resin. All of these RPM data are for the brittle or slit failure mode. It is very important when conducting an RPM experiment or calculation that all the failure modes are the same. The correlation between these RPM projections with actual field performance is discussed in Appendix I.

1. DuPont RPM Data for 2” Aldyl “A” Pipe (Alathon 5043 Resin)

File-Lot-Temp-Pressure-Hours

106	4	80.	175.	38.0
106	4	80.	170.	26.2
106	4	80.	170.	32.9
106	4	80.	170.	28.4
106	4	80.	170.	28.5
106	4	80.	170.	25.9
106	4	80.	170.	43.0
106	4	80.	165.	40.0
106	4	80.	165.	31.0
106	1	80.	150.	74.0
106	1	80.	150.	100.0
106	1	80.	150.	88.0
106	1	80.	150.	102.0
106	1	80.	150.	101.0
106	1	80.	150.	96.0
106	1	80.	150.	139.0
106	1	80.	120.	188.0
106	1	80.	120.	166.0
106	3	80.	120.	147.0
106	3	80.	120.	93.0
106	3	80.	120.	147.0
106	8	80.	120.	211.0
106	4	80.	120.	310.0
106	4	80.	120.	309.0
106	1	80.	60.	788.0
106	1	80.	60.	841.0
106	2	80.	60.	934.0
106	2	80.	60.	1077.0
106	2	80.	60.	1032.0
106	3	80.	60.	1042.0
106	3	80.	60.	831.0
106	3	80.	60.	552.0
106	3	80.	60.	1195.0
106	3	80.	60.	1989.0
106	3	80.	60.	1704.0
106	3	80.	60.	1614.0
106	3	80.	60.	879.0
106	3	80.	60.	1416.0
106	3	80.	60.	835.0
106	4	80.	60.	693.0
106	4	80.	60.	622.0
106	4	80.	60.	882.0
106	4	80.	60.	792.0
106	4	80.	60.	803.0
106	4	80.	60.	926.0
106	4	80.	60.	923.0
106	4	80.	60.	954.0
106	4	80.	60.	1229.0
106	4	80.	60.	2112.0
106	1	80.	30.	972.0

106	1	80.	30.	1561.0
106	2	80.	30.	1948.0
106	1	80.	30.	2339.0
106	2	80.	30.	2511.0
106	2	80.	30.	1994.0
106	1	80.	30.	2758.0
106	1	80.	30.	2612.0
106	1	80.	30.	3126.0
106	2	80.	30.	4458.0
106	4	80.	30.	3307.0
106	4	80.	30.	3883.0
106	4	80.	30.	5935.0
106	6	80.	15.	16430.0
106	5	80.	15.	16054.0
106	6	80.	15.	18382.0
106	6	80.	15.	19900.0
106	5	80.	15.	35384.0
106	6	80.	15.	92423.0
106	4	60.	210.	201.6
106	4	60.	210.	182.8
106	4	60.	210.	253.3
106	4	60.	210.	268.0
106	4	60.	210.	220.0
106	1	60.	180.	489.0
106	1	60.	180.	927.0
106	3	60.	150.	1130.0
106	3	60.	150.	2242.0
106	3	60.	150.	1068.0
106	3	60.	150.	3224.0
106	3	60.	150.	3488.0
106	4	60.	150.	2250.0
106	4	60.	150.	2748.9
106	1	60.	120.	1822.0
106	1	60.	120.	2302.0
106	3	60.	120.	1509.0
106	3	60.	120.	2169.0
106	3	60.	120.	2486.0
106	3	60.	120.	2855.0
106	3	60.	120.	2728.0
106	3	60.	120.	3333.0
106	3	60.	120.	4104.0
106	3	60.	120.	4158.0
106	4	60.	120.	3601.0
106	4	60.	120.	4288.0
106	4	60.	120.	5153.0
106	4	60.	120.	5455.0
106	4	60.	120.	7160.0
106	4	60.	120.	4856.0
106	4	60.	120.	7616.0
106	4	60.	120.	7742.0
106	2	60.	60.	24098.0
106	2	60.	60.	32522.0
106	2	60.	60.	11194.0

```
106  3  60.   60.  16595.0
106  3  60.   60.  38348.0
106  3  60.   60.  44004.0
106  1  60.   60.  75152.0
106  1  60.   60.  79276.0
106 13  50.   60.  52970.0
106 13  50.   60.  46298.0
106  3  45.  180.   7522.0
106  3  45.  180.   8826.0
106  3  45.  180.  14002.0
106  4  45.  120.   8434.0
106  4  45.  120.  11122.0
106  4  45.  120.  17918.0
106  4  45.  120.  22232.0
106  4  45.  120.  23380.0
106  4  45.  120.  28298.0
```

Here is the RPM equation for the control Aldyl “A” pipe (5043 resin) pipe data set:

Data File FILE106.DAT

```
LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.
                A(0) =  -17.617
                A(1) =   8857.3
                A(2) =  -898.54
       Multp.Correl.Coef. =    .95
       No. of data points =    122
```

Note there are 122 data points and the correlation coefficient is 0.95, which is quite good. Once the three RPM coefficients are known, the projected time (years) at a particular temperature (degrees Centigrade) and at a particular internal pressure (psig) may be determined. For the following data sets, I will use 20ºC (68ºF) as the average annual ground temperature and 60 psig as the average annual internal pressure to project the mean (50%) failure time in years. Note that the 2.5% LCL and 97.5% UCL are also calculated.

```
            FORECAST OF SERVICE LIFE :

   Input Temperature, Centigrade     : 20
   Input Pressure, PSI               : 60
   Input Lower Confidence Limit in % :  2.5
   For result in Hours, input h; for result in Years, input y : y
 For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

     The interval between low and high limits is  95. % :

     MEAN TIME TO FAIL =     1599.3 YEARS
        LOWER LIMIT ON MEAN =      887.2 YEARS
```

UPPER LIMIT ON MEAN = 2882.8 YEARS

The mean or average projected failure time for Aldyl "A" pipe made from Alathon 5043 PE resin at this condition of 20ºC/60 psig is 1599 years. There is a 95% probability that the failure time will occur between 887 years and 2883 years.

2. DuPont RPM Data for 2" Control LDIW Aldyl "A" Pipe (5043 resin)

File-Lot-Temp-Pressure-Hours

691	1	80.	120.000	34.2
691	1	80.	120.000	33.7
691	1	80.	120.000	26.5
691	1	80.	120.000	35.8
691	1	80.	120.000	34.3
691	1	80.	90.000	49.2
691	1	80.	90.000	50.4
691	1	80.	90.000	74.9
691	1	80.	90.000	78.2
691	1	80.	90.000	79.4
691	1	80.	90.000	80.6
691	1	80.	60.000	133.0
691	1	80.	60.000	255.2
691	1	80.	60.000	266.5
691	1	80.	60.000	409.5
691	1	80.	60.000	615.8
691	1	60.	150.000	151.1
691	1	60.	150.000	159.1
691	1	60.	150.000	159.1
691	1	60.	150.000	173.8
691	1	60.	150.000	178.5
691	1	60.	120.000	150.9
691	1	60.	120.000	184.4
691	1	60.	120.000	212.4
691	1	60.	120.000	240.8
691	1	60.	120.000	253.3
691	1	60.	90.000	468.2
691	1	60.	90.000	489.2
691	1	60.	90.000	503.6
691	1	60.	90.000	620.1
691	1	60.	60.000	3619.2
691	1	60.	60.000	3635.6
691	1	60.	60.000	4769.9
691	1	60.	60.000	7477.0
691	1	60.	60.000	13485.0
691	1	80.	120.000	30.0

691	1	80.	120.000	30.0
691	1	80.	120.000	32.0
691	1	80.	120.000	23.0
691	1	80.	120.000	19.0
691	1	80.	120.000	27.0
691	1	80.	120.000	22.0
691	1	80.	60.000	280.0
691	1	80.	60.000	222.0
691	1	80.	60.000	198.0
691	1	80.	60.000	379.0
691	1	80.	60.000	194.0
691	1	80.	60.000	243.0
691	1	80.	35.000	728.0
691	1	80.	35.000	1413.0
691	1	80.	35.000	1485.0
691	1	80.	35.000	985.0
691	1	80.	35.000	1548.0
691	1	80.	35.000	996.0
691	1	80.	30.000	1767.0
691	1	80.	30.000	1339.0
691	1	80.	30.000	3946.0
691	1	80.	30.000	4918.0
691	1	80.	30.000	5297.0
691	1	60.	150.000	132.0
691	1	60.	150.000	162.0
691	1	60.	150.000	130.0
691	1	60.	150.000	168.0
691	1	60.	120.000	207.0
691	1	60.	120.000	163.0
691	1	60.	120.000	390.0
691	1	60.	120.000	348.0
691	1	60.	120.000	170.0
691	1	60.	120.000	399.0
691	1	60.	120.000	547.0
691	1	60.	120.000	308.0
691	1	60.	120.000	416.0
691	1	60.	120.000	130.0
691	1	60.	60.000	3472.0
691	1	60.	60.000	3198.0
691	1	60.	60.000	2672.0
691	1	60.	60.000	3936.0
691	1	60.	60.000	2790.0

Here is the RPM equation for the control Aldyl “A” LDIW pipe data set:

Data File FILE691.DAT

LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.
A(0) = -15.955
A(1) = 8563.6
A(2) = -1167.3
Multp.Correl.Coef. = .97
No. of data points = 78

FORECAST OF SERVICE LIFE :

Input Temperature, Centigrade : 20
Input Pressure, PSI : 60
Input Lower Confidence Limit in % : 2.5
For result in Hours, input h; for result in Years, input y : y
For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

The interval between low and high limits is 95. % :

MEAN TIME TO FAIL = 171.6 YEARS
LOWER LIMIT ON MEAN = 90.7 YEARS
UPPER LIMIT ON MEAN = 324.7 YEARS

The mean or average projected failure time for LDIW Aldyl “A” pipe at this condition of 20ºC/60 psig is 171 years. There is a 95% probability that the failure time will occur between 90 years and 325 years.

3. DuPont RPM Data for 2” Indented LDIW Aldyl “A” Pipe (5043 resin)

File-Lot-Temp-Pressure-Hours

693	1	80.	60.000	104.4
693	1	80.	60.000	111.0
693	1	80.	60.000	127.7
693	1	80.	30.000	164.4
693	1	80.	30.000	191.0
693	1	80.	30.000	191.7
693	1	60.	90.000	498.0
693	1	60.	90.000	511.0
693	1	60.	90.000	603.8
693	1	60.	60.000	588.6
693	1	60.	60.000	642.0
693	1	60.	60.000	719.6
693	1	60.	60.000	835.9
693	1	60.	60.000	869.0
693	1	80.	60.000	91.0
693	1	80.	60.000	90.0
693	1	80.	60.000	78.0
693	1	80.	60.000	75.0
693	1	80.	60.000	97.0
693	1	80.	60.000	102.0

```
693  1  80.   60.000    110.0
693  1  80.   60.000    110.0
693  1  80.   35.000    179.0
693  1  80.   35.000    159.0
693  1  80.   35.000    156.0
693  1  80.   35.000    189.0
693  1  80.   35.000    223.0
693  1  80.   35.000    165.0
693  1  60.   60.000    955.0
693  1  60.   60.000    928.0
693  1  60.   60.000    885.0
693  1  60.   60.000    893.0
693  1  60.   60.000    850.0
693  1  60.   60.000    892.0
693  1  60.   60.000    791.0
693  1  60.   60.000    693.0
693  1  60.  120.000    390.0
693  1  60.  120.000    348.0
```

Here is the RPM equation for the above Aldyl "A" LDIW indented pipe data set:

Data File FILE693.DAT

LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.

A(0) = -13.166
A(1) = 5983.1
A(2) = -353.86
Multp.Correl.Coef. = .99
No. of data points = 38

FORECAST OF SERVICE LIFE :

Input Temperature, Centigrade : 20
Input Pressure, PSI : 60
Input Lower Confidence Limit in % : 2.5
For result in Hours, input h; for result in Years, input y : y
For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

The interval between low and high limits is 95. % :

MEAN TIME TO FAIL = 14.3 YEARS
LOWER LIMIT ON MEAN = 10.2 YEARS
UPPER LIMIT ON MEAN = 20.0 YEARS

The mean or average projected failure time for indented LDIW Aldyl "A" pipe at this condition of 20ºC/60 psig is 14 years. There is a 95% probability that the failure time will occur between 10 years and 20 years.

4. <u>DuPont RPM Data for 2" Aldyl "A" Pipe (Alathon 5046 Resin)</u>

File-Lot-Temp-Pressure-Hours

126	1	80.	160.	856.0
126	1	80.	120.	742.0
126	1	80.	120.	835.0
126	1	80.	120.	614.0
126	1	80.	120.	834.0
126	1	80.	120.	929.0
126	1	80.	90.	1056.0
126	1	80.	90.	2799.0
126	1	80.	90.	3106.0
126	1	80.	90.	5127.0
126	1	80.	90.	4985.0
126	1	80.	75.	3882.0
126	1	80.	75.	6215.0
126	1	80.	60.	3840.0
126	1	80.	60.	6038.0
126	1	80.	60.	8712.0
126	1	80.	60.	9045.0
126	1	80.	60.	8712.0
126	1	80.	60.	12741.0
126	1	80.	60.	13987.0
126	1	80.	60.	17223.0
126	1	80.	60.	18073.0
126	1	80.	60.	17779.0
126	1	80.	60.	8479.0
126	1	80.	60.	24564.0
126	1	80.	60.	12592.0
126	1	80.	60.	10896.0
126	1	80.	60.	28724.0
126	1	80.	60.	14192.0
126	1	80.	60.	3351.0
126	1	80.	60.	20287.0
126	1	80.	60.	19103.0
126	1	80.	60.	26177.0
126	1	80.	60.	24207.0
126	1	80.	60.	25148.0
126	11	80.	40.	14491.0
126	1	60.	190.	7535.0
126	1	60.	190.	9035.0
126	1	60.	120.	14532.0
126	1	60.	120.	15377.0
126	1	60.	120.	5006.0
126	1	60.	120.	7918.0
126	1	60.	120.	11784.0
126	1	60.	120.	17779.0

Here is the RPM equation for the above Aldyl “A” pipe (Alathon 5046) data set:

Data File FILE126.DAT

LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.

A(0) = -14.899
A(1) = 8675.5
A(2) = -1115.6
Multp.Correl.Coef. = .86
No. of data points = 45

FORECAST OF SERVICE LIFE :

Input Temperature, Centigrade : 20
Input Pressure, PSI : 60
Input Lower Confidence Limit in % : 2.5
For result in Hours, input h; for result in Years, input y : y
For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

The interval between low and high limits is 95. % :

MEAN TIME TO FAIL = 9677.5 YEARS
LOWER LIMIT ON MEAN = 1124.3 YEARS
UPPER LIMIT ON MEAN = 83300.7 YEARS

The mean or average projected failure time for Aldyl "A" pipe made from Alathon 5046-C PE resin at this condition of 20ºC/60 psig is 9677 years. There is a 95% probability that the failure time will occur between 1124 years and 83300 years.

Below in Table 4, I have summarized the RPM projected performance at an average annual ground temperature of 20ºC and average operating pressure of 60 psig for these four data sets for Aldyl "A" pipe from the above calculations. I have also included the RPM projected performance at three other average annual ground temperatures (15ºC, 10ºC, 5ºC) that may be appropriate for Enbridge Gas in the gas distribution system. These RPM projections can also be made at any other temperature requested by Enbridge Gas.

Table 4 – RPM Projected Performance for Aldyl "A" Pipe at 60 psig

PE Material	**Temperature (ºC)**	**RPM Projection (years)**	**2.5% LCL (years)**
Alathon 5046	20	9677	1124
	15	24,091	2254
	10	61,937	4632
	5	164,733	9766
Alathon 5043	20	1600	887
	15	4300	2238
	10	11,981	5833
	5	34,625	15,729
Alathon 5043 LDIW	20	171	90

	15	415	204
	10	1037	475
	5	2679	1137
Alathon 5043 LDIW – indented (rock impingement)	20	14.3	10.2
	15	29.6	20.3
	10	63.0	41.4
	5	137.8	86.7

In this RPM projection summary, one can see there is about an order of magnitude difference in the RPM projected performance between Alathon 5043 (1600 years at 20ºC/60 psig) and Alathon 5046 (10,000 years at 20ºC/60 psig), in this case, Alathon 5046-C. Note that these RPM projections correlate very well with typical 80ºC/120 psig stress rupture testing for Aldyl "A" pipe, using test method ASTM D 1598, which also shows an order of magnitude difference:

- Alathon 5043 resin 100 hours
- Alathon 5046C resin 1000 hours

This RPM projection summary also shows the effect of the LDIW inner surface on long-term performance – about an order of magnitude decrease from 1600 years to 170 years at 20ºC/60 psig. This summary also shows the effect of rock impingement on RPM projected performance – another order of magnitude decrease from 170 years to 14 years, again at 20ºC/60 psig. Finally, this summary shows the effect of the average annual ground temperature. A decrease in average annual ground temperature from 20ºC to 5ºC results in about an order of magnitude increase in RPM projected failure time for the LDIW rock impingement Aldyl "A" pipe – 14.3 years at 20ºC/60 psig to 137.8 years at 5ºC/60 psig.

V. <u>DuPont Aldyl "A" Fittings</u>

A. Rate Process Method Data and RPM Equations/Projections

In addition to RPM experiments on pipe, the DuPont Company also conducted many RPM experiments on Aldyl "A" fittings and several other competitive fittings. RPM as an analytical tool is explained in more detail in Appendix I. A typical data set and RPM equation is provided here for several Aldyl "A" fittings made from Alathon 5043 resin (6043 compound), and also for Aldyl "A" fittings made from Alathon 5046 resin (6046 compound). All of these RPM data are for the brittle or slit failure mode in the fitting. In the case of socket fittings, the failure mode is a crack that initiates at the internal fusion notch and propagates through the coupling. In the case of saddle fittings, the failure mode is a crack that initiates at the external fusion notch at the base of the saddle fitting and propagates through the pipe wall.

Below are RPM data sets and projections for Aldyl “A” socket caps, tees, and couplings and Aldyl “A” saddle fittings made from Alathon 5043 resin, along with Aldyl “A” socket caps, tees, and couplings made from Alathon 5046 resin.

1. <u>DuPont RPM Data for 2” Aldyl “A” Socket Caps (Alathon 5043 Resin)</u>

<u>File-Lot-Temp-Pressure-Hours</u>

107	12	80.	175.	16.6
107	12	80.	170.	22.2
107	12	80.	170.	20.7
107	12	80.	170.	13.9
107	12	80.	170.	30.4
107	12	80.	170.	20.5
107	8	80.	150.	25.0
107	0	80.	150.	23.0
107	8	80.	150.	32.0
107	10	80.	150.	39.0
107	8	80.	150.	36.0
107	8	80.	150.	44.0
107	3	80.	120.	21.5
107	2	80.	120.	27.6
107	3	80.	120.	28.2
107	3	80.	120.	23.0
107	3	80.	120.	29.2
107	13	80.	120.	65.0
107	13	80.	120.	57.0
107	13	80.	120.	45.0
107	13	80.	120.	76.0
107	18	80.	100.	51.0
107	18	80.	100.	51.0
107	18	80.	100.	55.0
107	18	80.	100.	63.0
107	18	80.	100.	63.0
107	18	80.	100.	68.0
107	18	80.	100.	72.0
107	18	80.	100.	55.0
107	18	80.	100.	60.0
107	18	80.	100.	60.0
107	18	80.	100.	65.0
107	18	80.	100.	65.0
107	18	80.	100.	67.0
107	18	80.	100.	69.0
107	18	80.	100.	74.0
107	18	80.	100.	58.0
107	18	80.	100.	58.0
107	18	80.	100.	62.0
107	2	80.	60.	307.0
107	2	80.	60.	320.0
107	2	80.	60.	554.0
107	2	80.	60.	560.0
107	2	80.	60.	594.0

107	2	80.	60.	531.0
107	0	80.	60.	692.0
107	2	80.	60.	683.0
107	2	80.	60.	723.0
107	9	80.	60.	358.0
107	3	80.	60.	1077.0
107	6	80.	60.	1071.0
107	8	80.	60.	1184.0
107	2	80.	60.	381.0
107	2	80.	60.	717.0
107	6	80.	60.	3518.0
107	2	80.	60.	229.0
107	2	80.	40.	3337.0
107	2	80.	40.	6837.0
107	8	80.	40.	11620.0
107	8	80.	40.	11620.0
107	12	60.	220.	90.2
107	12	60.	210.	173.8
107	14	60.	210.	154.3
107	13	60.	210.	80.2
107	12	60.	210.	99.0
107	13	60.	210.	83.2
107	12	60.	210.	119.4
107	12	60.	210.	75.4
107	9	60.	180.	199.0
107	9	60.	180.	186.0
107	2	60.	180.	177.0
107	2	60.	180.	204.0
107	0	60.	180.	164.0
107	0	60.	180.	139.0
107	9	60.	180.	213.0
107	2	60.	180.	210.0
107	14	60.	150.	468.0
107	12	60.	150.	616.0
107	12	60.	150.	1467.0
107	14	60.	150.	2350.0
107	2	60.	120.	555.0
107	2	60.	120.	240.0
107	2	60.	120.	360.0
107	2	60.	120.	669.0
107	2	60.	120.	555.0
107	2	60.	120.	821.0
107	9	60.	120.	526.0
107	0	60.	120.	537.0
107	9	60.	120.	483.0
107	2	60.	120.	576.0
107	2	60.	120.	1113.0
107	2	60.	120.	358.0
107	17	60.	120.	496.0
107	17	60.	120.	2320.0
107	12	60.	120.	6118.0
107	2	60.	60.	2584.0
107	2	60.	60.	4168.0

107	2	60.	60.	4406.0
107	9	60.	60.	3130.0
107	2	60.	60.	34244.0
107	9	60.	60.	46074.0
107	9	45.	180.	1203.0
107	2	45.	180.	1022.0
107	9	45.	180.	1278.0
107	2	45.	180.	1442.0
107	2	45.	180.	1312.0
107	9	45.	180.	1312.0
107	2	45.	120.	2234.0
107	2	45.	120.	2306.0
107	2	45.	120.	2925.0
107	2	45.	120.	3078.0
107	2	45.	120.	3630.0
107	0	45.	120.	2969.0
107	0	45.	120.	2482.0
107	0	45.	120.	2485.0
107	2	45.	120.	9181.0
107	0	45.	120.	6854.0
107	0	45.	120.	3490.0
107	2	45.	120.	5080.0
107	2	45.	120.	7600.0
107	2	45.	120.	8483.0
107	0	45.	120.	7310.0

Here is the RPM equation for the above 2” Aldyl “A” Socket Caps (Alathon 5043 Resin) data set:

Data File FILE107.DAT

LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.
A(0) = -16.590
A(1) = 9004.1
A(2) = -1219.0
Multp.Correl.Coef. = .94
No. of data points = 122

Note for this socket fitting data set there are 122 data points and the correlation coefficient is 0.94, which is quite good. It is very important that a data set contain only a given fitting type and a fitting size, and preferably the same fitting production lot number. Also, all the failure modes must be the same. As with the pipe RPM, once the three RPM coefficients are known for a particular fitting geometry, the projected time (years) at a particular temperature (degrees Centigrade) and at a particular internal pressure (psig) may be determined. For the following data sets for various Aldyl “A” fittings, I will use 20ºC as the average annual ground temperature and 60 psig as the average annual internal pressure to project the mean (50%) failure time in years. These are the same conditions that I selected for the pipe RPM projections. Again, note that the 2.5% LCL and 97.5% UCL are also calculated.

FORECAST OF SERVICE LIFE :

Input Temperature, Centigrade : 20
Input Pressure, PSI : 60
Input Lower Confidence Limit in % : 2.5
For result in Hours, input h; for result in Years, input y : y
For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

The interval between low and high limits is 95. % :

MEAN TIME TO FAIL = 614.4 YEARS
LOWER LIMIT ON MEAN = 317.8 YEARS
UPPER LIMIT ON MEAN = 1187.8 YEARS

The mean or average projected failure time for 2" Aldyl "A" socket caps made from Alathon 5043 resin (Alathon 6043 compound) at this condition of 20ºC/60 psig is 614 years. There is a 95% probability that the failure time will occur between 317 years and 1187 years.

2. DuPont RPM Data for 2" Aldyl "A" Socket Tees (Alathon 5043 Resin)

File-Lot-Temp-Pressure-Hours

108	2	80.	150.	21.0
108	0	80.	150.	19.0
108	2	80.	150.	17.0
108	0	80.	150.	13.0
108	5	80.	120.	64.0
108	6	80.	120.	62.0
108	5	80.	120.	60.0
108	5	80.	120.	60.0
108	2	80.	120.	48.5
108	5	80.	120.	49.0
108	6	80.	120.	46.0
108	5	80.	120.	43.0
108	2	80.	120.	38.8
108	2	80.	120.	35.9
108	6	80.	120.	47.0
108	0	80.	120.	33.0
108	0	80.	120.	30.0
108	0	80.	120.	25.0
108	0	80.	120.	36.0
108	0	80.	120.	40.0
108	0	80.	120.	31.0
108	0	80.	120.	33.0
108	4	80.	120.	19.0
108	4	80.	120.	21.0
108	4	80.	120.	22.0

108	4	80.	120.	28.0
108	4	80.	85.	83.0
108	4	80.	85.	124.0
108	2	80.	60.	913.0
108	1	80.	60.	275.0
108	5	80.	60.	238.0
108	1	80.	60.	237.0
108	5	80.	60.	235.0
108	0	80.	60.	226.0
108	1	80.	60.	190.0
108	6	80.	60.	310.0
108	6	80.	60.	581.0
108	6	80.	60.	299.0
108	0	80.	60.	429.0
108	5	80.	60.	470.0
108	6	80.	60.	661.0
108	5	80.	60.	801.0
108	6	80.	60.	369.0
108	0	80.	60.	258.0
108	7	80.	40.	1657.0
108	7	80.	40.	3779.0
108	7	80.	40.	6818.0
108	0	80.	40.	3129.0
108	0	80.	40.	4802.0
108	0	80.	40.	10156.0
108	0	80.	40.	10156.0
108	3	80.	30.	3125.0
108	3	80.	30.	1132.0
108	2	60.	120.	642.0
108	2	60.	120.	563.0
108	2	60.	120.	538.0
108	2	60.	120.	284.0
108	2	60.	120.	422.0
108	5	60.	120.	318.0
108	8	60.	120.	284.0
108	5	60.	120.	348.0
108	5	60.	120.	348.0
108	5	60.	120.	384.0
108	5	60.	120.	442.0
108	5	60.	120.	378.0
108	5	60.	120.	436.0
108	5	60.	120.	405.0
108	2	60.	120.	486.0
108	1	60.	60.	14917.0
108	1	60.	60.	2936.0
108	0	60.	60.	2728.0
108	0	60.	60.	2516.0
108	0	60.	60.	2192.0
108	2	60.	60.	10380.0
108	2	60.	60.	11138.0
108	2	60.	60.	13360.0
108	1	60.	60.	33623.0
108	0	60.	60.	20663.0

108	0	60.	60.	30413.0
108	2	45.	120.	3678.0
108	0	45.	120.	2293.0
108	1	45.	120.	2116.0
108	0	45.	120.	1617.0
108	0	45.	120.	1582.0
108	0	45.	120.	1513.0
108	0	45.	120.	1417.0
108	0	45.	120.	1405.0
108	2	45.	120.	6257.0

Here is the RPM equation for the above 2" Aldyl "A" Socket Tees (Alathon 5043 Resin) data set:

Data File FILE108.DAT

LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.
A(0) = -15.660
A(1) = 8900.3
A(2) = -1357.9
Multp.Correl.Coef. = .95
No. of data points = 88

FORECAST OF SERVICE LIFE :

Input Temperature, Centigrade : 20
Input Pressure, PSI : 60
Input Lower Confidence Limit in % : 2.5
For result in Hours, input h; for result in Years, input y : y
For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

The interval between low and high limits is 95. % :

MEAN TIME TO FAIL = 332.0 YEARS
LOWER LIMIT ON MEAN = 163.2 YEARS
UPPER LIMIT ON MEAN = 675.1 YEARS

The mean or average projected failure time for 2" Aldyl "A" socket tees made from Alathon 5043 resin (Alathon 6043 compound) at this condition of 20ºC/60 psig is 332 years. There is a 95% probability that the failure time will occur between 163 years and 675 years.

3. DuPont RPM Data for 2" Aldyl "A" Socket Couplings (Alathon 5043 Resin)

File-Lot-Temp-Pressure-Hours

120	2	80.	120.	58.0
120	2	80.	120.	75.0

120	2	80.	120.	83.0
120	8	80.	120.	35.0
120	6	80.	85.	162.0
120	6	80.	85.	157.0
120	2	80.	60.	932.0
120	2	80.	60.	836.0
120	2	80.	60.	861.0
120	0	80.	60.	669.0
120	8	80.	60.	260.0
120	8	80.	60.	404.0
120	8	80.	60.	591.0
120	1	60.	180.	281.0
120	1	60.	180.	210.0
120	1	60.	180.	365.0
120	1	60.	120.	1347.0
120	1	60.	120.	3180.0
120	6	60.	120.	500.0
120	6	60.	120.	600.0
120	6	60.	120.	691.0
120	6	60.	120.	696.0
120	6	60.	120.	1250.0
120	0	60.	120.	447.0
120	0	60.	120.	429.0
120	6	60.	120.	1078.0
120	6	60.	120.	842.0
120	6	60.	120.	1134.0
120	6	60.	120.	1404.0
120	1	45.	180.	1312.0
120	1	45.	180.	2273.0
120	1	45.	180.	2558.0
120	5	45.	120.	4229.0
120	5	45.	120.	7169.0
120	5	45.	120.	8780.0
120	0	45.	120.	1986.0
120	2	45.	120.	18513.0
120	4	80.	15.	41398.0

Here is the RPM equation for the above 2” Aldyl “A” Socket Couplings (Alathon 5043 Resin) data set:

Data File FILE120.DAT

LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.

A(0) = -16.588
A(1) = 8744.2
A(2) = -1077.0

Multp.Correl.Coef. = .94
No. of data points = 38

FORECAST OF SERVICE LIFE :

Input Temperature, Centigrade : 20
Input Pressure, PSI : 60
Input Lower Confidence Limit in % : 2.5
For result in Hours, input h; for result in Years, input y : y
For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

The interval between low and high limits is 95. % :

MEAN TIME TO FAIL = 581.9 YEARS
LOWER LIMIT ON MEAN = 200.6 YEARS
UPPER LIMIT ON MEAN = 1688.2 YEARS

The mean or average projected failure time for 2" Aldyl "A" socket couplings made from Alathon 5043 resin (Alathon 6043 compound) at this condition of 20ºC/60 psig is 582 years. There is a 95% probability that the failure time will occur between 200 years and 1688 years.

4. DuPont RPM Data for 2" Aldyl "A" Multi-saddle Tees (Alathon 5043 Resin)

File-Lot-Temp-Pressure-Hours

121	71	80.	120.	32.0
121	71	80.	120.	39.0
121	71	80.	120.	41.0
121	71	80.	120.	40.0
121	71	80.	120.	16.0
121	71	80.	90.	207.0
121	71	80.	90.	34.0
121	71	80.	90.	76.0
121	71	80.	90.	198.0
121	71	80.	60.	553.0
121	71	80.	60.	644.0
121	71	80.	60.	737.0
121	71	65.	150.	188.0
121	71	65.	150.	170.0
121	71	65.	150.	184.0
121	71	65.	150.	209.0
121	71	65.	150.	329.0
121	71	65.	105.	642.0
121	71	65.	105.	256.0
121	71	65.	105.	843.0
121	71	65.	105.	919.0
121	71	65.	105.	1240.0
121	71	65.	60.	1618.0

```
121 71  50.  180.    290.0
121 71  50.  180.    763.0
121 71  50.  180.   1180.0
121 71  50.  180.   1455.0
121 71  50.  180.    791.0
121 71  50.  120.   3464.0
121 71  50.  120.   5261.0
121 71  50.  120.   5907.0
121 71  50.  120.   4570.0
121 71  50.  120.   5847.0
```

Here is the RPM equation for the above 2" Aldyl "A" Multi-saddle tees (Alathon 5043 Resin) data set:

Data File FILE121.DAT

```
LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.
                 A(0) =  -20.493
                 A(1) =   10393.
                 A(2) =  -1246.8
          Multp.Correl.Coef. =    .95
          No. of data points =     33

            FORECAST OF SERVICE LIFE :

   Input Temperature, Centigrade     : 20
   Input Pressure, PSI               : 60
   Input Lower Confidence Limit in % :  2.5
   For result in Hours, input h; for result in Years, input y : y
For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

        The interval between low and high limits is  95. % :

      MEAN TIME TO FAIL =     2849.9 YEARS
           LOWER LIMIT ON MEAN =      655.7 YEARS
           UPPER LIMIT ON MEAN =    12386.4 YEARS
```

The mean or average projected failure time for 2" Aldyl "A" multi-saddle tees made from Alathon 5043 resin (Alathon 6043 compound) at this condition of 20ºC/60 psig is 2849 years. There is a 95% probability that the failure time will occur between 655 years and 12,386 years.

5. <u>DuPont RPM Data for 2" Aldyl "A" Socket Caps (Alathon 5046 Resin)</u>

<u>File-Lot-Temp-Pressure-Hours</u>

```
111 11  80.  150.    133.0
```

111	11	80.	150.	134.0
111	3	80.	120.	875.0
111	3	80.	120.	1138.0
111	3	80.	120.	737.0
111	3	80.	120.	668.0
111	3	80.	120.	643.0
111	3	80.	120.	733.0
111	3	80.	120.	932.0
111	0	80.	120.	264.0
111	0	80.	120.	815.0
111	12	80.	120.	134.0
111	12	80.	120.	292.0
111	13	80.	120.	297.0
111	12	80.	120.	502.0
111	12	80.	120.	553.0
111	13	80.	120.	894.0
111	4	80.	100.	657.0
111	4	80.	100.	1623.0
111	3	80.	90.	932.0
111	4	80.	90.	2678.0
111	3	80.	90.	4548.0
111	3	80.	90.	4979.0
111	4	80.	75.	6250.0
111	4	80.	75.	8877.0
111	1	80.	60.	6312.0
111	1	80.	60.	11304.0
111	0	80.	60.	8789.0
111	3	80.	60.	23804.0
111	3	80.	60.	2368.0
111	3	80.	60.	3438.0
111	3	80.	60.	22407.0
111	3	80.	60.	30559.0
111	11	60.	180.	465.0
111	11	60.	180.	661.0
111	11	60.	180.	1156.0
111	13	60.	180.	1596.0
111	0	60.	180.	1228.0
111	13	60.	180.	2139.0
111	4	60.	150.	4133.0
111	0	60.	120.	4226.0
111	4	60.	120.	12290.0
111	4	60.	120.	4185.0
111	4	60.	120.	11763.0
111	3	45.	180.	11014.0
111	4	45.	180.	20388.0
111	4	45.	180.	23835.0
111	4	45.	180.	23217.0
111	3	45.	180.	26812.0
111	4	45.	180.	27344.0

Here is the RPM equation for the above 2” Aldyl “A” Socket Caps (Alathon 5046 Resin) data set:

Data File FILE111.DAT

LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.
A(0) = -18.955
A(1) = 10978.
A(2) = -1600.8
Multp.Correl.Coef. = .92
No. of data points = 50

FORECAST OF SERVICE LIFE :

Input Temperature, Centigrade : 20
Input Pressure, PSI : 60
Input Lower Confidence Limit in % : 2.5
For result in Hours, input h; for result in Years, input y : y
For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

The interval between low and high limits is 95. % :

MEAN TIME TO FAIL = 69483.7 YEARS
LOWER LIMIT ON MEAN = 13671.8 YEARS
UPPER LIMIT ON MEAN = 353135.3 YEARS

The mean or average projected failure time for 2" Aldyl "A" socket caps made from Alathon 5046 resin (Alathon 6046 compound) at this condition of 20ºC/60 psig is 69,483 years. There is a 95% probability that the failure time will occur between 13,671 years and 353,135 years.

6. DuPont RPM Data for 2" Aldyl "A" Socket Tees (Alathon 5046 Resin)

File-Lot-Temp-Pressure-Hours

114	1	80.	120.	410.0
114	0	80.	120.	347.0
114	1	80.	120.	460.0
114	0	80.	120.	340.0
114	1	80.	90.	922.0
114	1	80.	90.	997.0
114	1	80.	75.	2031.0
114	1	80.	75.	3336.0
114	1	80.	60.	12569.0
114	1	80.	60.	4008.0
114	1	80.	60.	4102.0
114	1	80.	60.	30222.0
114	1	60.	180.	1573.0
114	1	60.	180.	1775.0
114	1	60.	180.	2037.0
114	1	60.	180.	2172.0

114 1 60. 120. 3317.0
114 1 60. 120. 3941.0
114 0 60. 120. 3462.0
114 0 60. 120. 3710.0
114 0 60. 120. 2880.0
114 0 60. 120. 4766.0
114 1 45. 180. 9752.0
114 1 45. 180. 11940.0
114 1 45. 180. 10375.0
114 0 45. 180. 12712.0
114 1 45. 120. 36725.0
114 1 45. 120. 57895.0

Here is the RPM equation for the above 2" Aldyl "A" Socket Tees (Alathon 5046 Resin) data set:

Data File FILE114.DAT

LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.
A(0) = -15.734
A(1) = 9174.0
A(2) = -1288.0
Multp.Correl.Coef. = .93
No. of data points = 28

FORECAST OF SERVICE LIFE :

Input Temperature, Centigrade : 20
Input Pressure, PSI : 60
Input Lower Confidence Limit in % : 2.5
For result in Hours, input h; for result in Years, input y : y
For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

The interval between low and high limits is 95. % :

MEAN TIME TO FAIL = 6390.6 YEARS
LOWER LIMIT ON MEAN = 1260.7 YEARS
UPPER LIMIT ON MEAN = 32394.4 YEARS

The mean or average projected failure time for 2" Aldyl "A" socket tees made from Alathon 5046 resin (Alathon 6046 compound) at this condition of 20ºC/60 psig is 6390 years. There is a 95% probability that the failure time will occur between 1260 years and 32,394 years.

7. <u>DuPont RPM Data for 2" Aldyl "A" Socket Couplings (Alathon 5046 Resin)</u>

<u>File-Lot-Temp-Pressure-Hours</u>
127 1 80. 120. 593.0

127	1	80.	120.	437.0
127	1	80.	120.	464.0
127	0	80.	120.	598.0
127	1	80.	100.	665.0
127	1	80.	100.	768.0
127	1	80.	75.	2098.0
127	1	80.	75.	5760.0
127	1	80.	60.	4644.0
127	0	80.	60.	3661.0
127	1	80.	60.	12061.0
127	1	60.	150.	3830.0
127	1	60.	150.	4229.0
127	0	60.	120.	7395.0
127	1	60.	120.	8375.0
127	1	60.	120.	9239.0
127	1	60.	120.	9734.0
127	1	60.	120.	11338.0
127	1	60.	120.	11231.0
127	1	60.	120.	13623.0
127	1	60.	120.	13506.0
127	1	60.	120.	11677.0
127	1	60.	120.	19185.0

Here is the RPM equation for the above 2" Aldyl "A" Socket Couplings (Alathon 5046 Resin) data set:

Data File FILE127.DAT

LOG TIME = A(0) + A(1)/Abs.TEMP. + A(2)*(Log PRESSURE)/Abs.TEMP.
A(0) = -19.966
A(1) = 10746.
A(2) = -1322.6
Multp.Correl.Coef. = .97
No. of data points = 23

FORECAST OF SERVICE LIFE :

Input Temperature, Centigrade : 20
Input Pressure, PSI : 60
Input Lower Confidence Limit in % : 2.5
For result in Hours, input h; for result in Years, input y : y
For limits on a SINGLE specimen, input s; for limits on MEAN, input m : m

The interval between low and high limits is 95. % :

MEAN TIME TO FAIL = 53403.3 YEARS

LOWER LIMIT ON MEAN = 11648.4 YEARS
UPPER LIMIT ON MEAN = 244833.2 YEARS

The mean or average projected failure time for 2" Aldyl "A" socket couplings made from Alathon 5046 resin (Alathon 6046 compound) at this condition of 20ºC/60 psig is 53,503 years. There is a 95% probability that the failure time will occur between 11,648 years and 244,833 years.

Below in Table 5, I have summarized the RPM projected performance at an average operating pressure of 60 psig for these seven data sets for Aldyl "A" fittings and at the same four average annual ground temperatures (20ºC, 15ºC, 10ºC and 5ºC):

Table 5 – RPM Projected Performance for Aldyl "A" Fittings at 60 psig

PE Material	PE Fitting	Temperature (ºC)	RPM Projection (years)	2.5% LCL (years)
Alathon 5043	2" socket cap	20	614	317
		15	1560	756
		10	4093	1857
		5	11,119	4705
Alathon 5043	2" socket tee	20	332	163
		15	803	366
		10	2006	846
		5	5178	2014
Alathon 5043	2" socket coupling	20	582	200
		15	1476	455
		10	3868	1064
		5	10,498	2563
Alathon 5043	2" multi-saddle	20	2850	655
		15	8685	1747
		10	27,532	4814
		5	90,973	13,749
Alathon 5046	2" socket cap	20	69,483	13,671
		15	210,483	35,923
		10	663,060	97,614
		5	2,176,726	274,829
Alathon 5046	2" socket tee	20	6390	1260
		15	16,330	2780
		10	43,138	6299

		5	118,000	14,692
Alathon 5046	2” socket coupling	20	53,403	11,648
		15	167,672	31,783
		10	548,159	89,799
		5	1,870,018	263,248

In this RPM projection summary for fittings, one can see there is a significant difference in the RPM projected performance between Alathon 5043 fittings and Alathon 5046 fittings. Note that these RPM projections for 5043/5046 fittings correlate very well with the RPM projections comparing Alathon 5043 pipe and Alathon 5046 pipe.

This RPM projection summary also shows the effect of geometry. For both Alathon 5043 and 5046, the socket tee has the lowest RPM projected time, which correlates well with the fact that a socket tee has the most complex geometry and stress risers.

Finally, this RPM projection summary for fittings shows the effect of the average annual ground temperature, as all the RPM projections increase significantly as the temperature decreases.

VI. DuPont Aldyl “A” Joining Techniques

A. Socket Fusion

Socket fusion was the original method for joining DuPont Delrin® polyacetal pipe in the 1960’s. In fact, all the molds used to make Aldyl “A” socket fusion fittings were originally designed to make Delrin polyacetal socket fusion fittings.

Socket fusion was used to join Aldyl “A” pipe and tubing sizes from ½” CTS to 4” IPS, and it was the preferred method for joining ½” CTS tubing through 2” IPS pipe. The recommended socket fusion temperature for Aldyl “A” pipe and fittings was 500ºF (260ºC).

In addition to offering socket fusion fittings, DuPont also sold all the necessary tools for socket fusion. This included the heating irons (both electric and gas), heater faces, cold rings, chamfering tools and depth gauges. In addition, DuPont sold accessories for socket fusion such as fitting pullers, coil joiners and the KGT Joiner, which was named in honor of Karl G. Toll.

DuPont decided to stop selling tools in the early 1980’s, as all the required tools were available from P&S Rigid Tool Company, McElroy Manufacturing and other tool manufacturers.

The *“DuPont Aldyl “A” Heat Fusion Installer Qualification Manual”* describes the socket fusion procedure for Aldyl “A” pipe and fittings and provides photos of a properly made socket fusion joint.

B. Butt Fusion

Butt fusion was primarily used to join Aldyl "A" pipe and fitting sizes from 1-1/4" IPS to 16" IPS pipe, and it was the preferred method for joining 4" IPS through 16" IPS. Although some Aldyl "A" pipe and tubing in smaller diameters down to ½" CTS were joined by butt fusion, it is difficult to do because of the low molecular weight and the thin walls. McElroy Manufacturing sold a hand held butt fusion machine for these smaller sizes and some gas companies joined Aldyl "A" tubing using this small hand-held butt fusion machine.

The original recommended butt fusion temperature for Aldyl "A" pipe made from Alathon 5040 (2.0 g/10 min melt index) was 310ºF (154ºC). The recommended butt fusion temperature was increased to 340ºF (171ºC) in 1970 when DuPont switched from Alathon 5040 to Alathon 5043 (1.2 g/10 min melt index). Although some gas companies used 500ºF (260ºC) to butt fuse Aldyl "A" pipe, DuPont felt this temperature was too high due to the low molecular weight.

The *"DuPont Aldyl "A" Heat Fusion Installer Qualification Manual"* describes the butt fusion procedure for Aldyl "A" pipe and fittings and provides photos of a properly made butt fusion joint.

C. Saddle Fusion

Saddle fusion was primarily used to join Aldyl "A" tapping tees, service punch tees and branch saddles to pipe sizes ranging from 1-1/4" IPS to 16" IPS. Most Aldyl "A" saddle fusions for tapping tees and service punch tees were originally done by hand, and some gas companies prefer to saddle fuse by hand even today! Eventually saddle assist tools were developed, but most Aldyl "A" customers preferred to do saddle fusion by hand. All branch saddle fusions were done with a saddle fusion assist tool.

The recommended saddle fusion temperature for Aldyl "A" saddle fusions was 500ºF (260ºC).

The *"DuPont Aldyl "A" Heat Fusion Installer Qualification Manual"* describes the saddle fusion procedure for Aldyl "A" pipe and fittings and provides photos of a properly made saddle fusion joint.

D. Electrofusion

DuPont introduced an electrofusion system for Aldyl "A" pipe in the late 1980's. Electrofusion fittings were made in Europe at the Hilcote plant in the UK and also at the George Fischer location in Switzerland. The trade name for the DuPont electrofusion system was SUMMIT. The EF system consisted of electrofusion fittings from 2" to 8", pipe alignment clamps, pipe scrapers – both rotary and hand, and an electrofusion control box.

By the early 1990's, the electrofusion system expanded to include small diameter couplings, service punch tees, reducers, and spigot fittings.

E. Mechanical Fittings

There were several types of mechanical fittings that were used with Aldyl "A" pipe and tubing, but DuPont did not manufacture or market mechanical fittings. Due to some premature failures of Aldyl "A" pipe and tubing pulling out of mechanical fittings, DuPont published an article, "Pull-Out Forces on Joints in Polyethylene Pipe Systems" by Jack Husted and Dexter Thompson. In this report, DuPont stated that for socket fusion joints, butt fusion joints and transition fittings, the joint strength is equal to or greater than the pipe strength; whereas, for compression fittings larger than 1", the joint strength is less than the pipe strength. As a result, DuPont emphasized that for compression (mechanical) fittings used on Aldyl "A" pipe, either the joint needed to be anchored or a fitting designed to prevent pullout should be used. DuPont supported the use of Category 1 mechanical fittings, which provide both a leak-free joint and pullout restraint.

J. References

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