Reference 10

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Human Chemistry, Human Solutions

Teijin Aramid

Engineering with aramid fibers for RTP applications

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Business Development Manager
Linear Tension Members, Oil & Gas

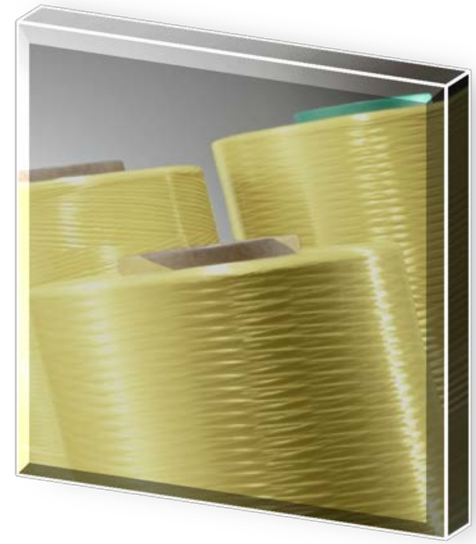
API 15S Meeting
Houston, TX
26^{th} June 2012

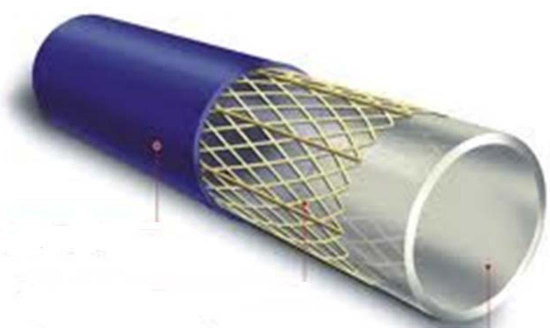
Twaron® | Technora®

The power of Aramid

Content

- Teijin Aramid
- Background - applications
- Quality control properties
- Long-term properties
  - Static loading
  - External influences





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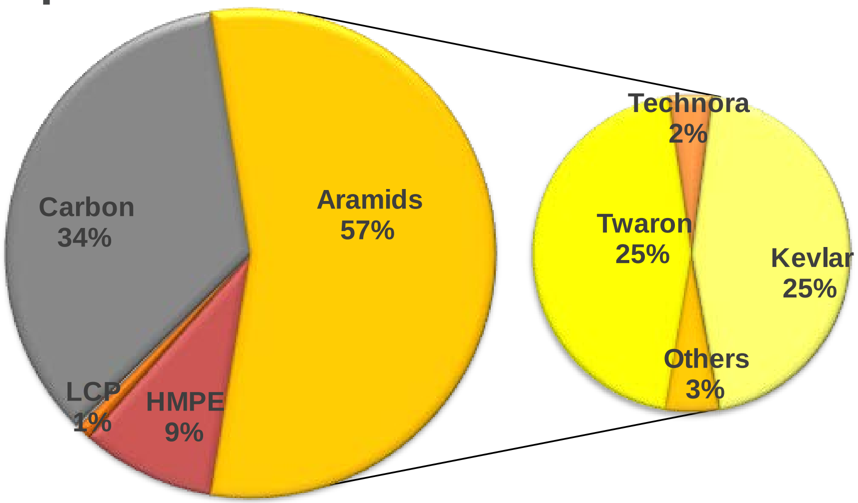
Teijin Aramid BV - Market

Some fiber market volumes:

Glass fiber (E-glass) :	~ 3.000.000 tons / yr (99% composites)
Total synthetic fiber market:	~ 45.000.000 tons / yr (>90% clothing)
Industrial synthetic fibers:	~ 2.500.000 tons / yr (PET, PA66 etc)
High performance fibers:	**~ 100.000 tons / yr**



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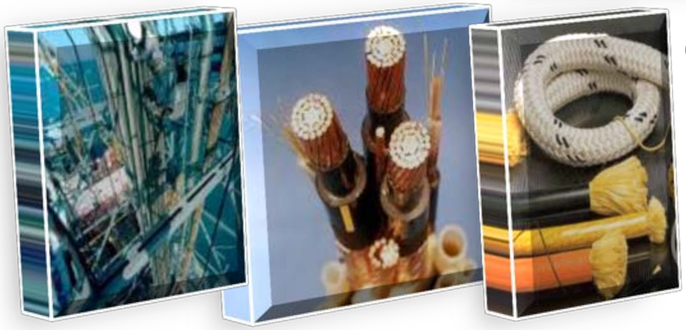
Teijin Aramid BV - Applications

Protection

Telecom

Automotive

Aerospace



Oil&Gas

Leisure

Construction

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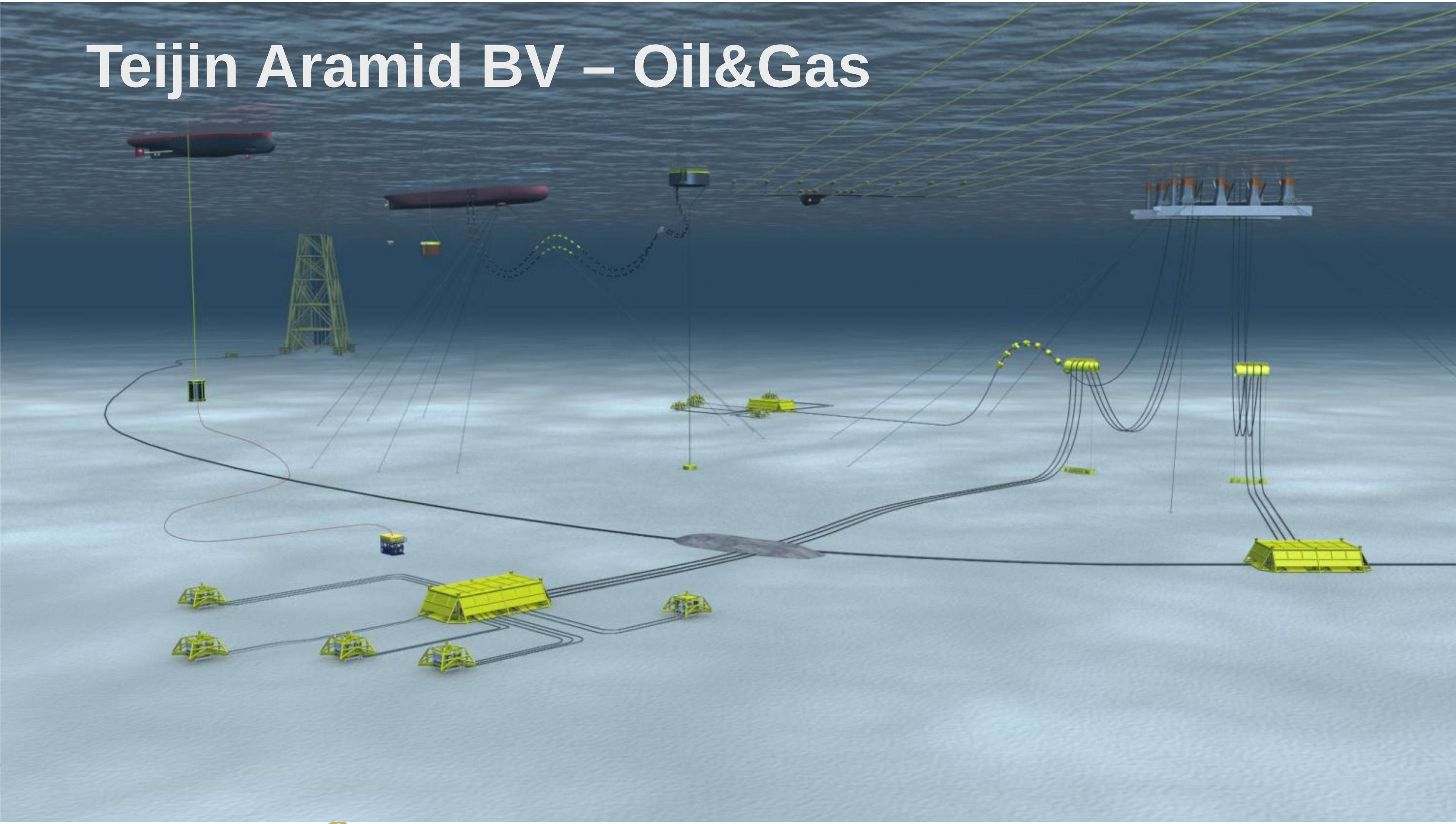
Teijin Aramid BV – Oil&Gas



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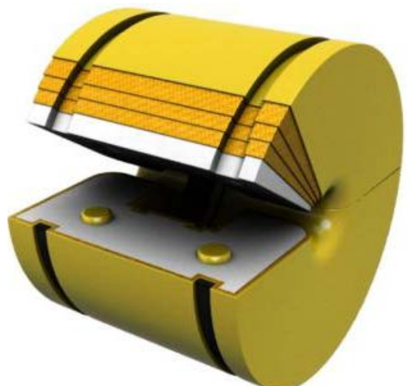
Teijin Aramid BV – Oil&Gas

Seismic streamers

Hoisting ropes

Mooring lines

Buoyancy straps



Buoyancy modules

Static pendants

Marine hoses

Umbilicals

Flexible flowlines

Background (1)

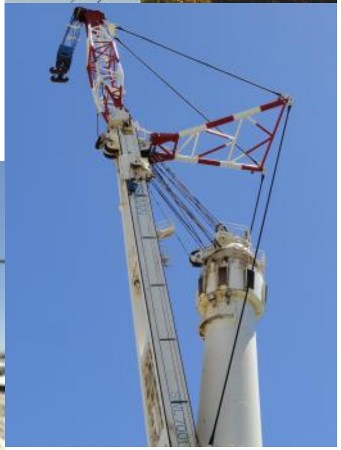
- **Many synthetics move to replacing steel**
  - Steel has history of ~200 years
  - Dataset of material behavior required to compete successfully

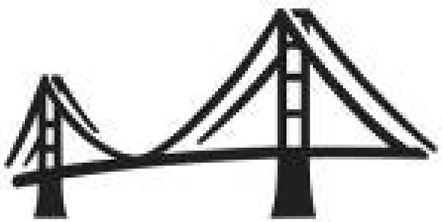
- **High performance synthetics should last long**
  - Offering a reliable and sustainable solution
  - Prediction required how material performs on long term

→Reliability = Predictable performance development over time

Background (2)

- **Prediction important for many applications**
  - **Construction:**
    - Geo-grids
    - Tower guys
    - Antenna guys
    - Crane pendants
    - Bridges
    - Concrete reinforcement





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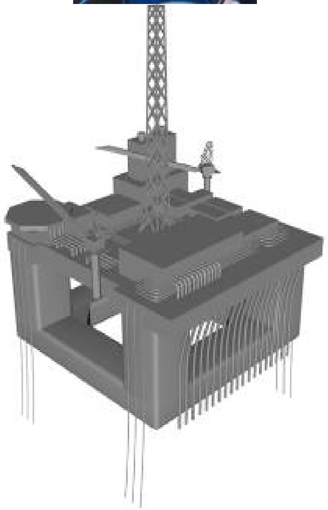
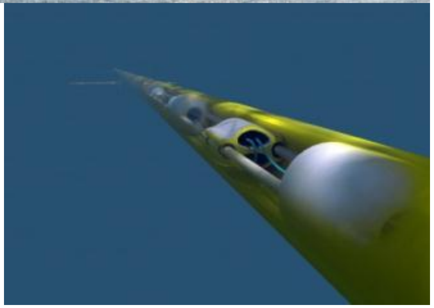
Background (3)

- **Prediction important for many applications**
  - **Oil&Gas:**
    - Ropes & cables
    - Mooring tendons
    - Hoses and pipes
    - Umbilicals
    - Orbit straps

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Background (4)

- **Transmission towers/cables**
  - Collserola tower, Barcelona (1991)
  - Sutro tower, San Francisco (2007)
  - Many smaller others
  - ADSS

Background (5) – hoses/pipes

Riser / flowline anti-birdcaging

- Many years experience, aramids used since 80's as anti-bird-caging material. Typical design life is again 20 years.
- The new **API 17J** is including testing requirements for aramids as one of the polymer materials. (Elevated temperature in low pH-environments).

Hydraulic hose reinforcement in umbilicals

- Aramids are used since 70's as. Proven track record (20 years design life), typically in contact with water.
- **API 17E** (hydraulic hoses) requirement: cycling 200.000 pressure cycles in a 180° bend at 1.33x MWP.
- Temperature = 55°C (API) up to 90°C (SAE J343)

Background (6) – hydraulic hoses

Transferrable know-how

- >35 years of industry experience
- Big revision of API 17E in 1980s
- Smaller sizes, higher pressures: 35kpsi (1”) / 60kpsi (¼”)
- Safety factor = 4
- Survival test requires very good material fatigue life
- Elevated temperatures, 20 years design life
  - Temperature = 55°C (API 17E) up to 90°C (SAE J343)
- Aramid is the only used/certified material, next to steel

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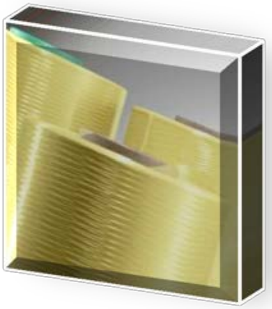
Quality control properties (1)



Standard property determination:

- **Used for quality control & property datasheets**
  - Strength (force at break)
  - Modulus (stiffness between certain stress levels)
  - EAB (Elongation at break)
  - FASE (Force at specified elongation)
  - Miscellaneous (moisture/finish content, yarn count etc)

ASTM D 885

ASTM INTERNATIONAL Designation: D 7269

→ Properties of 'as produced' material

→ According to standards (ASTM, BISFA, company standard)

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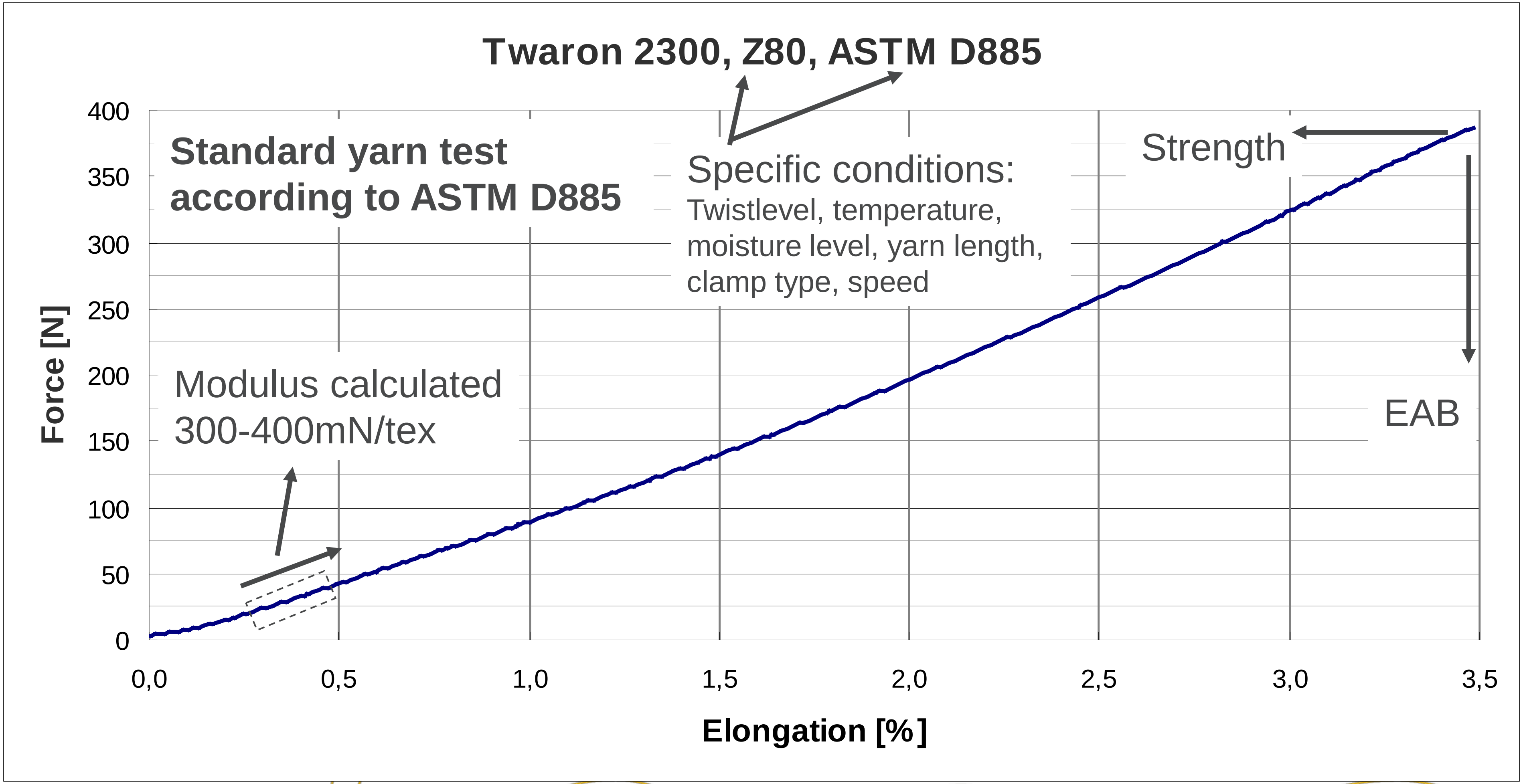
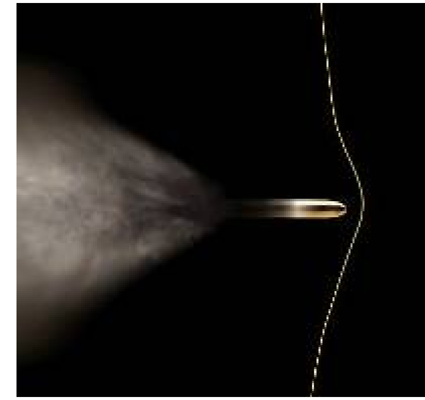
Quality control properties (2)

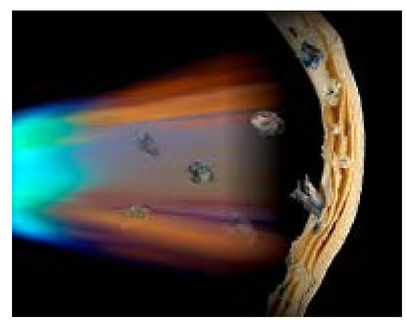


Quality control properties (3)



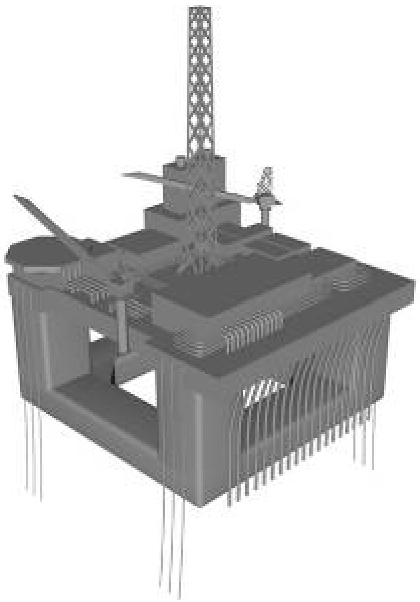
Non-standard properties:

- **Required for engineering purposes**
- **Different conditions** → High / low temp, rate, time
- **Lateral compression** → ‘pin-loop’ strength
- **Dynamic properties** → creep, **modulus**, hysteresis
- **Failure modes** → Time to rupture, tension-tension, chemicals, etc



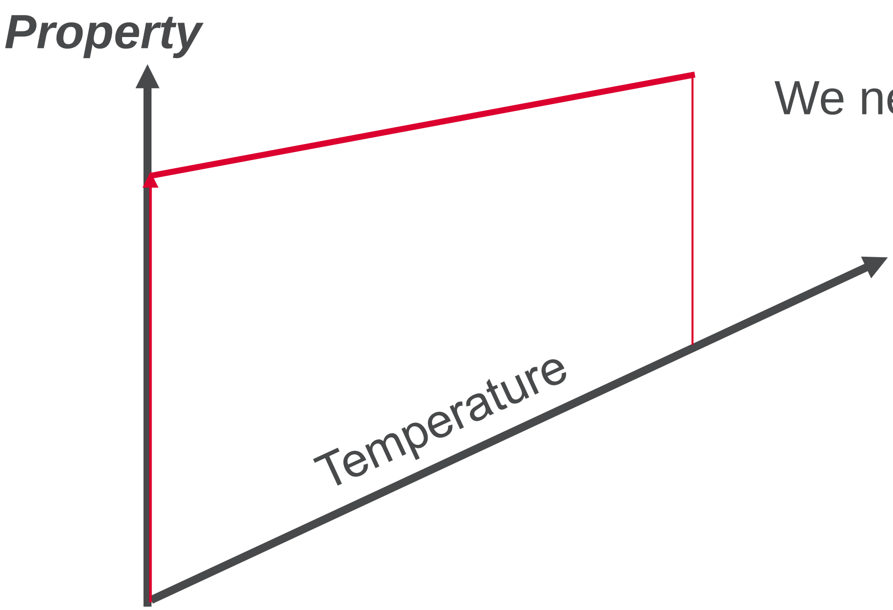
Long-term properties (1)

- **How to perform reliable engineering?**
  - Understanding the materials behavior
  - Temperature and time influence
  - Other influences
  - Translation from raw materials to actual product
  - Many safety rules based on steel material properties

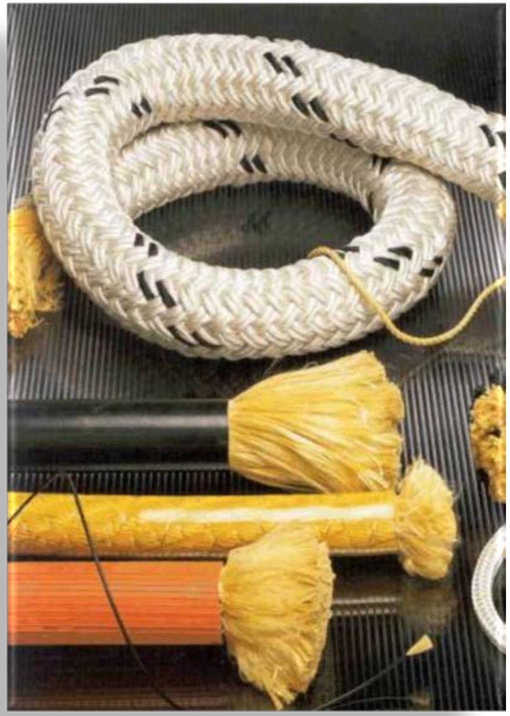


→ **Synthetics have other failure modes than steel!**

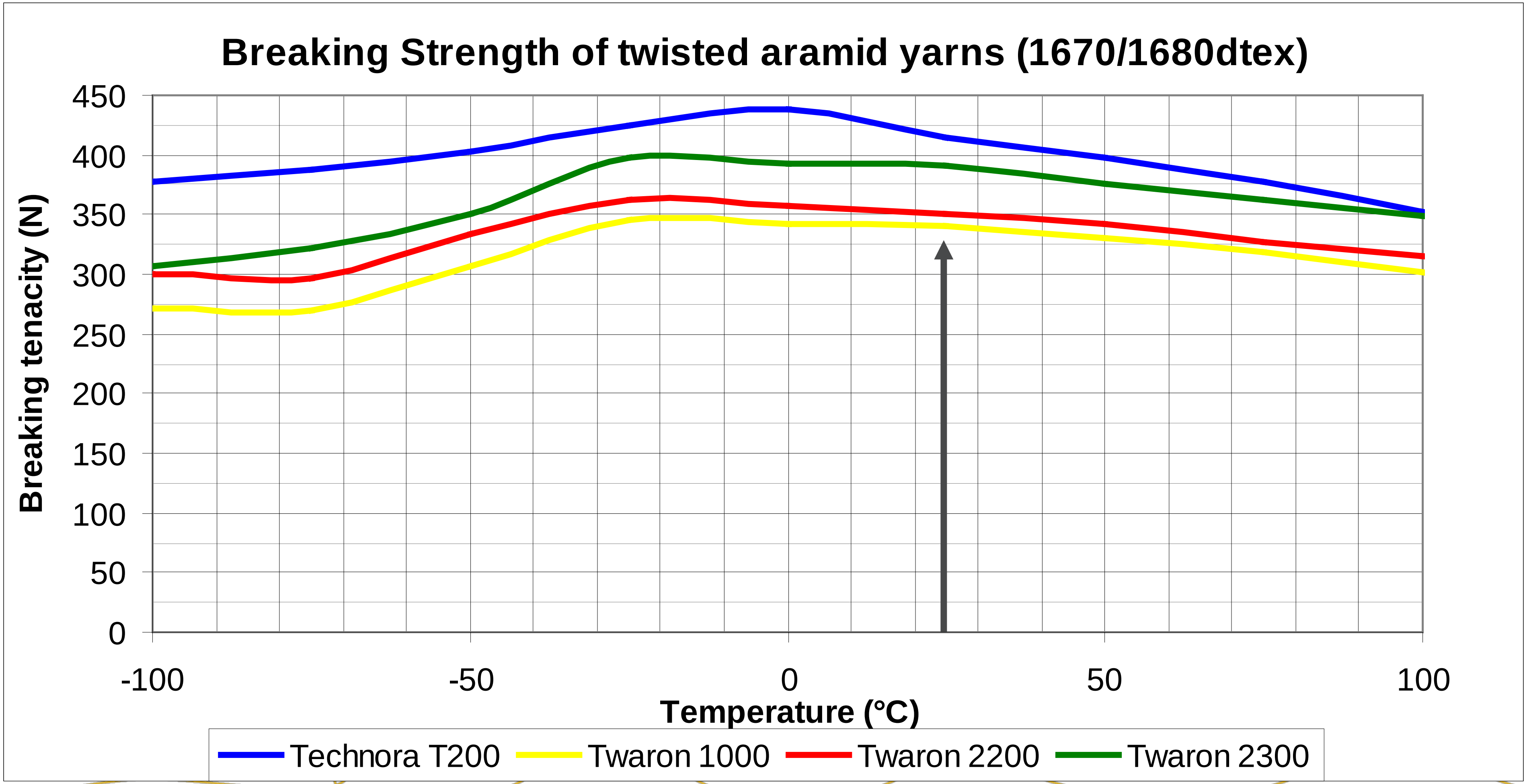
Long-term properties (2)



We need to know the influence of **temperature**



Long-term properties (3)



Static – Long-term BL (1)

Long-term Breaking Load (LTBL):

- All materials fail after certain time at high sustained load
  - The reason may be different

- Teijin Aramid did extensive tests to study this behavior for aramids.
  - Mathematical model is used to predict longer periods
  - Regression lines are used for engineering

→ **This property is called Long-term Breaking Load (LTBL)**

(also called Time-to-failure)

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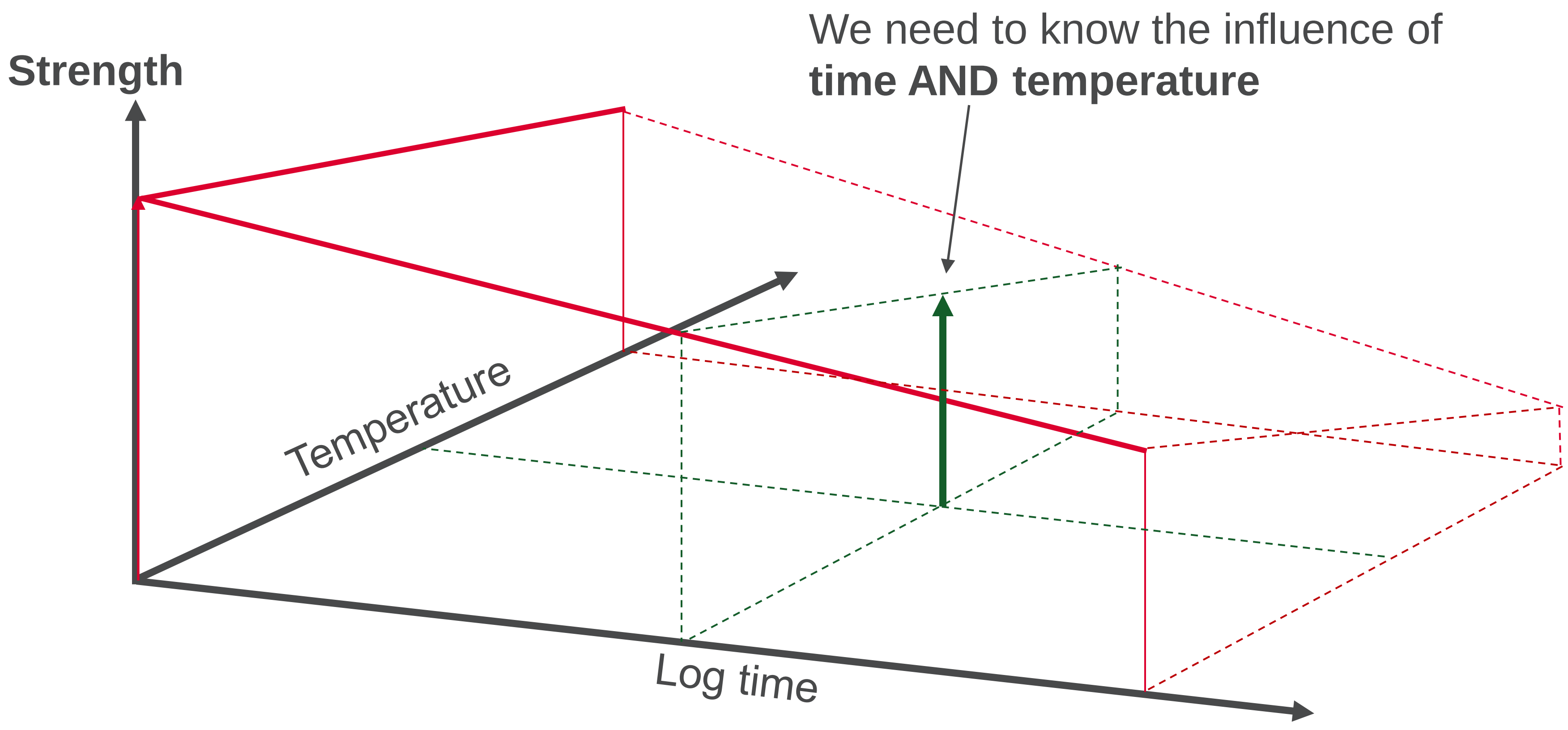
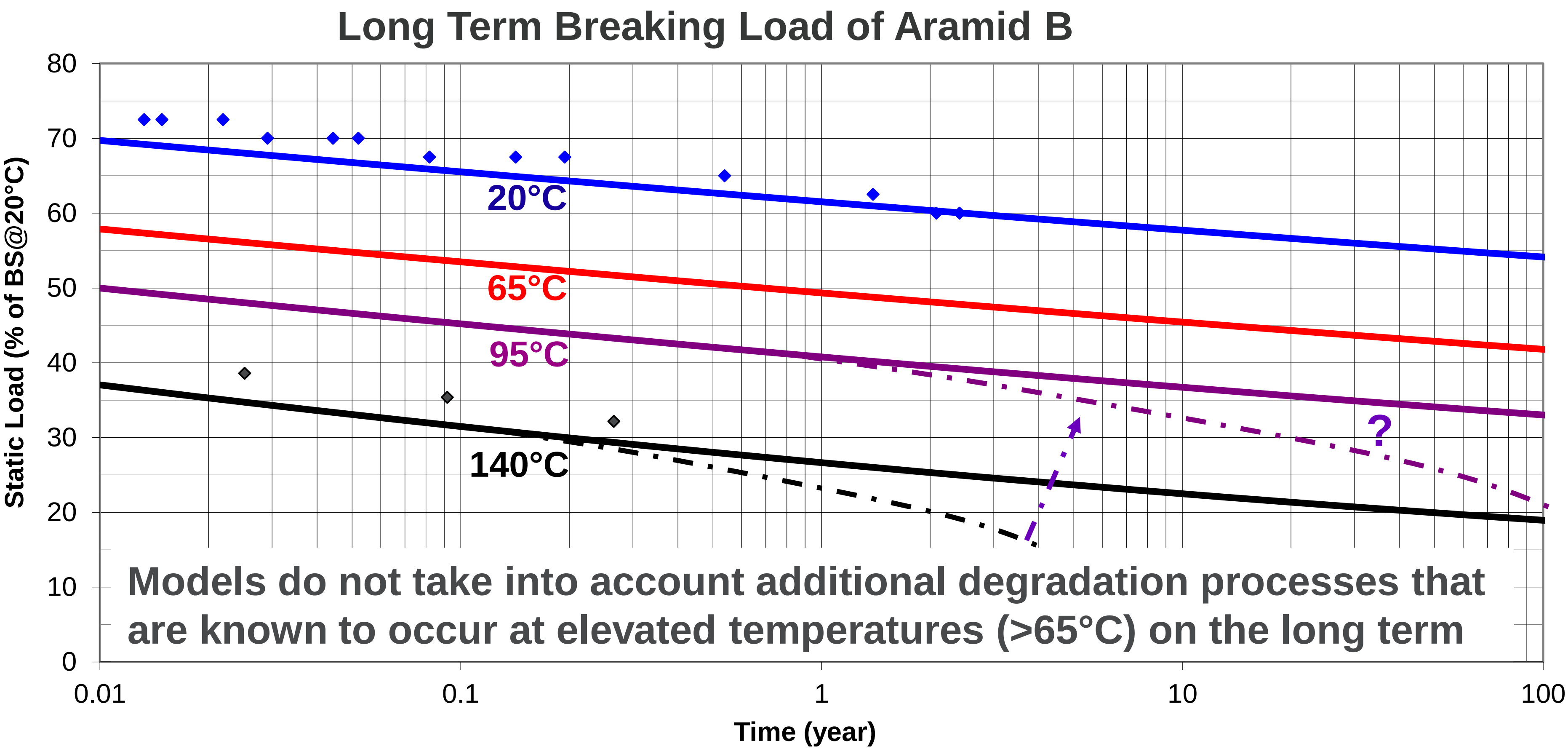
Static – Long-term BL (2)



Static – Long-term BL (3)

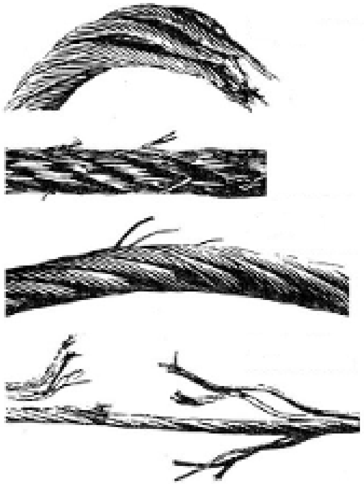


Models do not take into account additional degradation processes that are known to occur at elevated temperatures (>65°C) on the long term

External – Engineering conditions

External factors

- **Chemicals / UV** -> external influences
- **Temperature / Fire** -> heat degradation
- **Mechanical** -> external wear / impact



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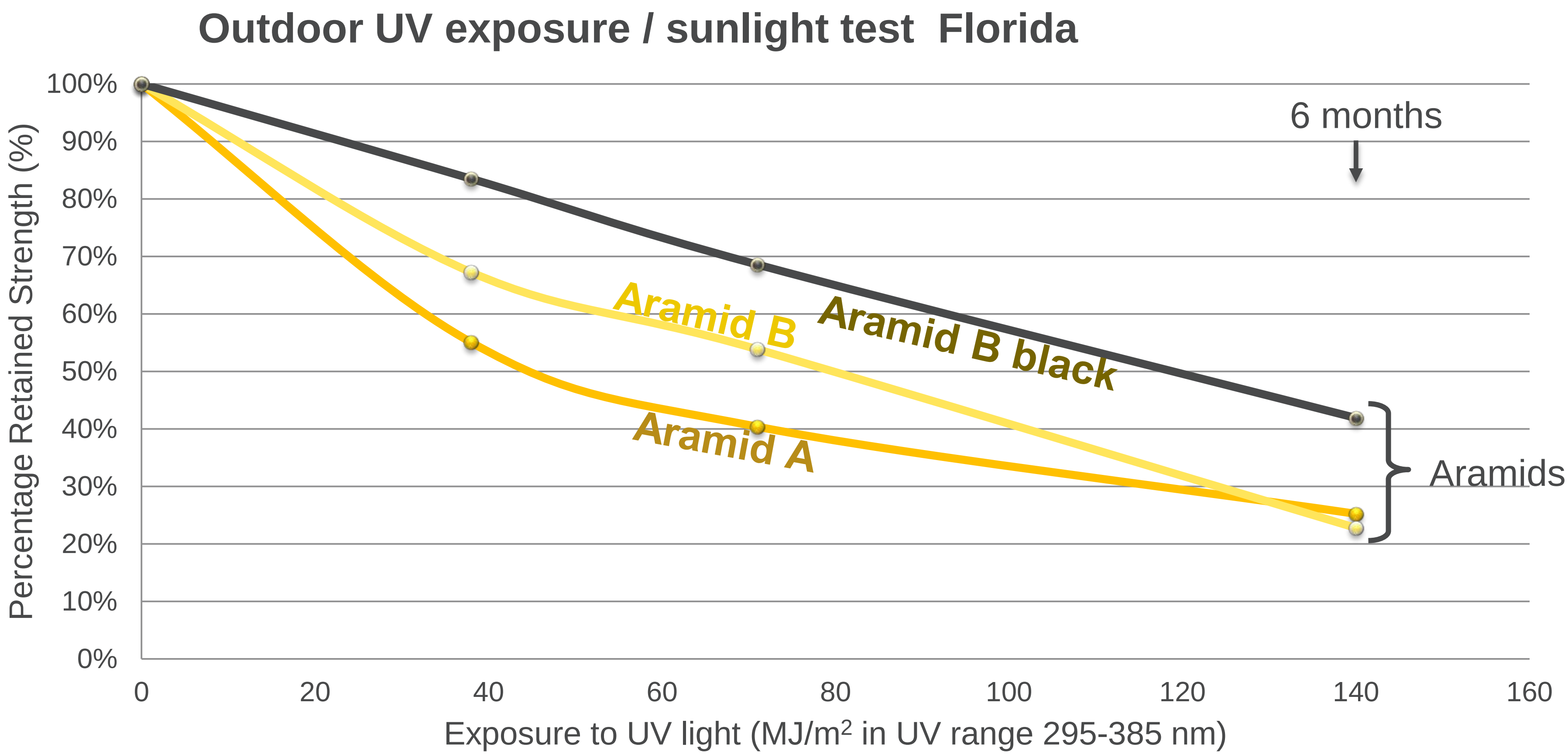
External – UV (1)



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External – Chemicals (1)

Aramid long term strength is influenced by:

- Strong acids and bases
- Long term UV exposure (should be protected)
- Hydrolysis → Water + temperature or H_2O + >80°C

    - **Hydrolysis Aramid B at** 50°C **is negligible**
    → Residual BS is >97% after 2 years in 50°C water

    → Hydrolysis is no issue at ambient temperatures,
    even for design life of >50 years

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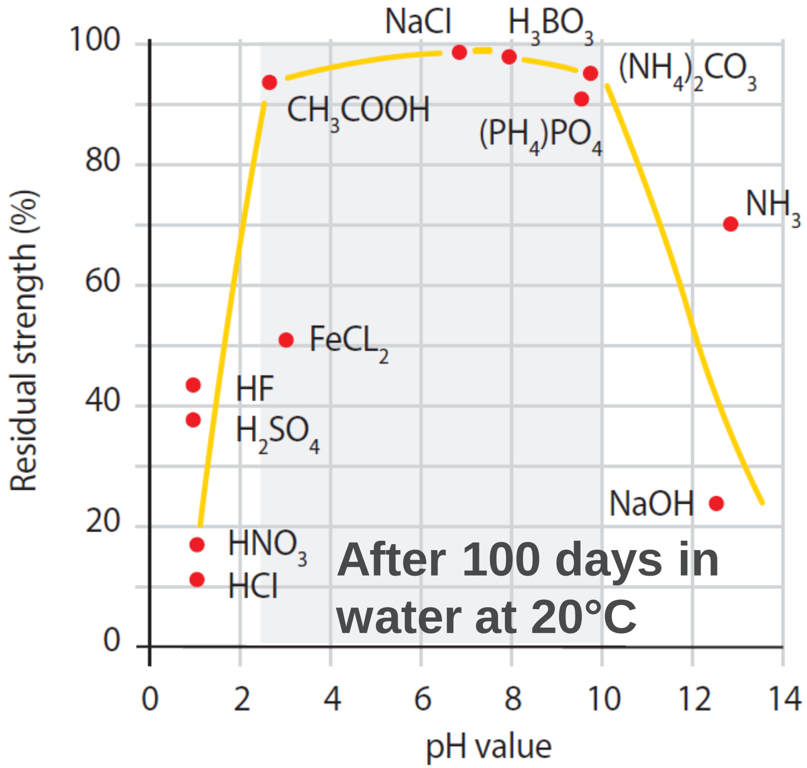
External – Chemicals (2)

Chemical resistance of Aramid B:



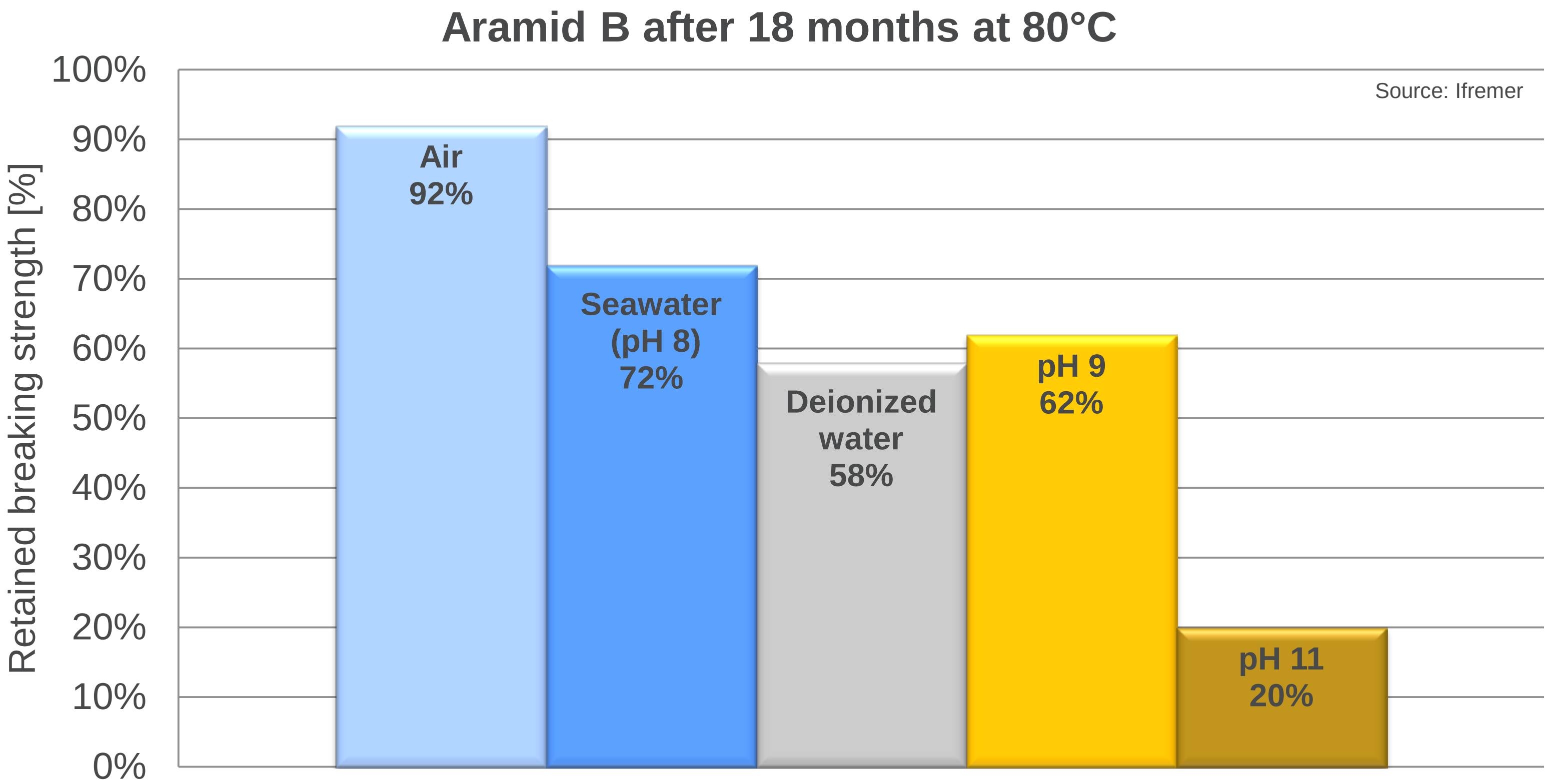
Crude Brent at 60°C:
Twaron immersed in Crude Brent:

- 60°C
- 30% load of its BS

→ no measureable degradation after 240 days (0,66 years)

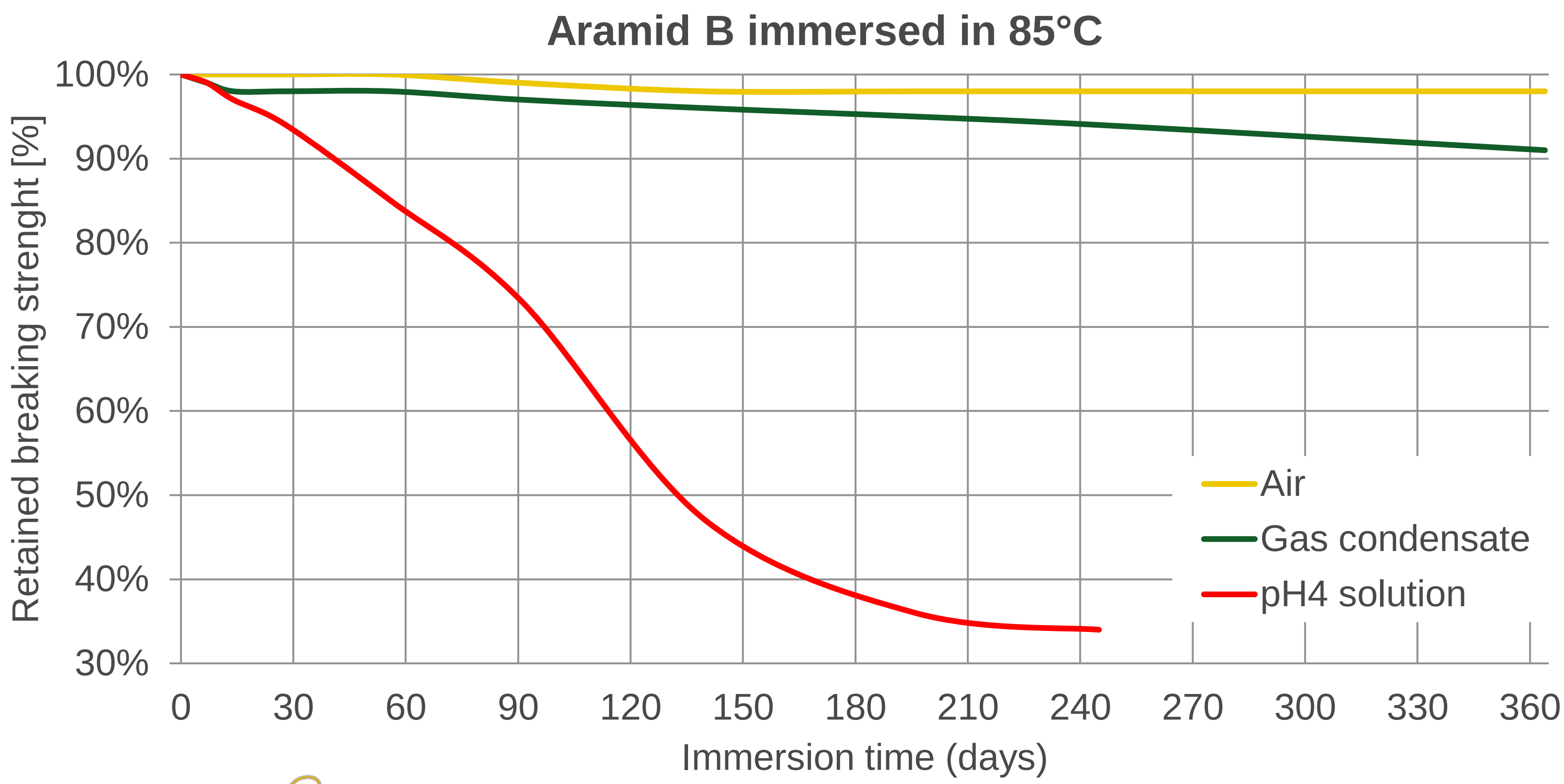
External – Chemicals (3)

Hydrolysis resistance of aramid:



External – Chemicals (4)

Hydrolysis resistance of aramids at low pH:



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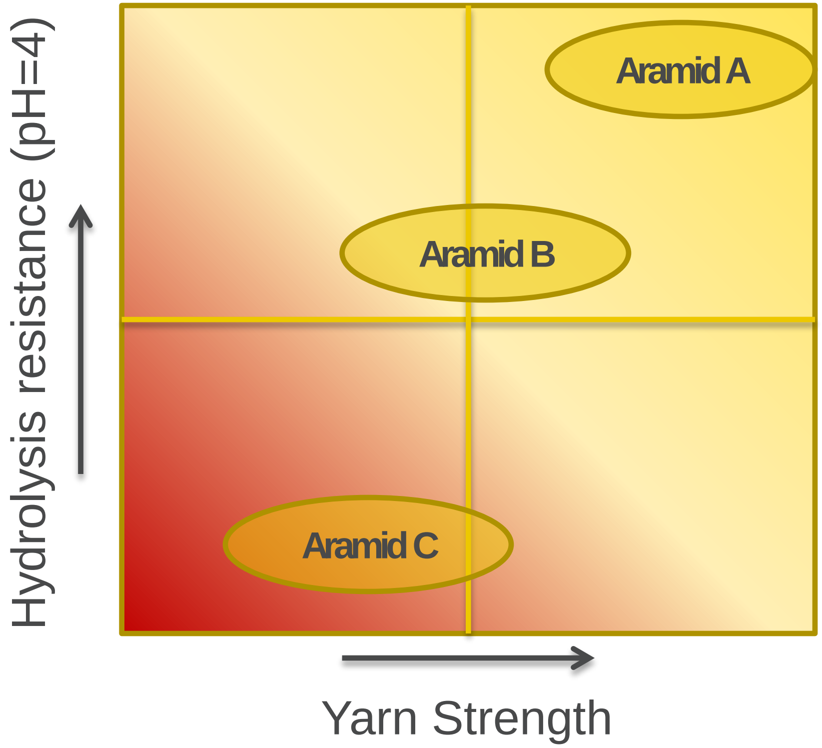
External – Chemicals (5)

Hydrolysis resistance of aramids at low pH:



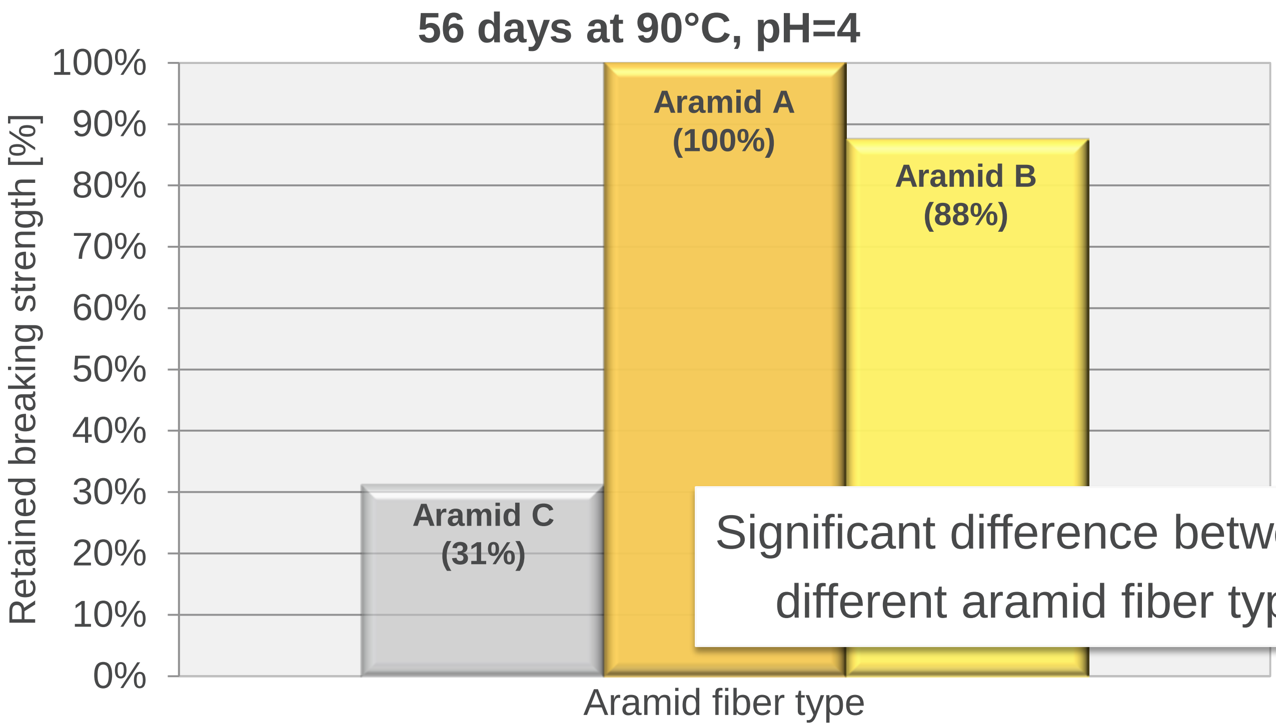
Acidic conditions:
Yarn immersed in sour fluid (pH=4) at elevated temperature

→ Aramid B <u>significantly</u> outperforms other p-aramids

→ Aramid A significantly outperforms Aramid B

External – Chemicals (6)

Hydrolysis resistance of aramids at low pH:



Significant difference between different aramid fiber types

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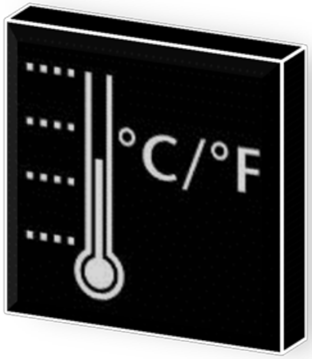
External – Temperature / Fire

Breaking strength at 250°C:

→ ~50% of BS@20°C for Aramid A&B



Residual BS@20°C after 550 hours @150°C (e.g. heat):

- Aramid B: 80%

Residual BS@20°C after 1 hour @250°C (e.g. fire):

- Aramid A: 99%
- Aramid B: 87%

Residual BS@20°C after 1 hour @350°C (e.g. fire):

- Aramid A: 80%
- Aramid B : 65%

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Conclusions

Aramids are durable, but some are more durable

- Aramid types can significantly differ on long-term performance
- Aramids are widely used in long-term applications

Aramids have long-term track record in pipes/hoses

- >30 years experience in hydraulic hoses, aramids are the only synthetic material used in umbilical hoses
- >20 years experience in flowline applications
- >10 years experience in RTP applications

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Human Chemistry, Human Solutions

Safety – Reliability – Confidence

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Reference 11

SPECIALTY RTP

Technology to Flow Mature Wells

Jay,

I understand you are looking for some information on Abrasion testing of nylon(s) vs. polyethylene and steel. I did a little digging and here is what I found out:

Based on the attached pdf chart and the table below, I would surmise that:

a) a) nylon 6 has a similar Taber abrasion result to Nylon 6-10
b) b) nylon 6's Taber abrasion does not degrade upon equilibrium exposure to humidity in the atmosphere (23C and 50%RH).
c) c) For both nylon 6 and nylon 6-10 the Taber abrasion value is similar to UHMW PE and an order of magnitude better than 304SS steel.

One widely referenced test method is the Taber Abrasion Test, in which the weight loss of a material is measured after being exposed to an abrasive wheel for 1000 cycles. While the Taber test cannot predict actual performance of a material to a given application, it does provide a relative measure to compare materials.
Loadings of 250, 500, and 1000 grams may be used.

12-3 South Bacton Hill Rd, Malvern, PA 19355
www.specialtyrtp.com

TABER ABRASION TESTER

(Abrasion Ring CS-10, Load 1 kg)

Nylon 6-10	5mg/1000 cycles
UHMW PE	5
PVDF	5 - 10
PVC (rigid)	12 - 20
PP	15 - 20
CPVC	20
CTFE	13
PS	40 - 50
Steel (304 SS)	50
ABS	60 - 80
PTFE	500 - 100

Source: Industrial and High Purity Piping Systems

Engineering Handbook, George Fischer +GF+, 2002.

Typical Taber abrasion tests for plastics are DIN 53754 and ASTM D1242 (withdrawn):

DIN 53754, Publication date:1977-06, Testing of plastics; determination of abrasion, abrasive disk method, manuscript, English

WITHDRAWN STANDARD: D1242-95a Standard Test Methods for Resistance of Plastic Materials to Abrasion (Withdrawn 2004)

These test methods (D1242-95a) covers the determination of the resistance to abrasion of flat surfaces of plastic materials, measured in terms of volume loss, by two different types of abrasion-testing machines.

Formerly under the jurisdiction of Committee D20 on Plastics, these test methods (D1242-95A) were withdrawn in December 2003 in accordance with section 10.6.3.1 of the *Regulations Governing ASTM Technical Committees*, which requires that standards shall be updated by the end of the eighth year since the last approval date.

Other Taber Abrasion tests:

ASTM D3389 – Taber abrasion of coated Fabrics

ASTM D4060 – Taber abrasion of organic coatings by weight loss

ASTM D1044 – Haze resulting from Taber abrasion

ASTM D3884 – Taber abrasion of textile fabrics

ASTM D1044 – Taber abrasion of transparent fabrics

Please let me know if you need additional information.

Kind regards,
John

Reference 12

SPECIALTY RTP

Technology to Flow Mature Wells

Petronas Abrasion Testing

Purpose

Test reinforced thermoplastic pipes and the associated termination fittings for abrasion resistance to sand and fluid flow at high velocities

Method

Target Flowing Velocities: Over 8ft/sec (Critical Steel Velocity)
Target % Sand: 10%
Sections of Reinforced Thermoplastic Pipe (RTP) is looped around the exit and entrance of a pump suitable to provide the acceptable flow rates for testing. End terminations should be raw steel and Fortron lined steel to see the impact of the sand on both surfaces as well as the pipe itself.
The pumps should be run with a water slurry with sand at the desired concentration. The pump impeller will witness severe erosion and the test should be performed until slippage of fluid around the impeller dramatically slows the flow and the test is stopped
Nylon and Fortron Lined Samples of Pipe were inserted in the test loop and Fortron lined and raw steel couplings were inserted

Results

Inch pipe was used for the test and ran a a flow rate of 4 gallons per minute which equates to just over 8ft/sec velocity

After 72 hours of flow the pump impeller became so eroded that it no longer would flow. The pipe was split open and inspected and there was no indication of wear in either the nylon of Fortron lined pipe samples

The impeller was completely eroded (aluminum construction) and the raw steel couplings indicated severe wear. The Fortron lined coupling experienced very little wear

Conclusion

Nylon and Fortron liners do not exhibit any significant abrasion wear. Raw steel couplings did exhibit abrasion wear and Fortron lined couplings.

Specialty RTP suggests in areas of high velocity and high sand or solids the couplings should be constructed from Stainless Steel because coatings (zinc Chromate or Fortron) will eventually wear and cannot be relied on for long term corrosion resistance

Pump Set Up

Test Loop with Nylon and Fortron Liners

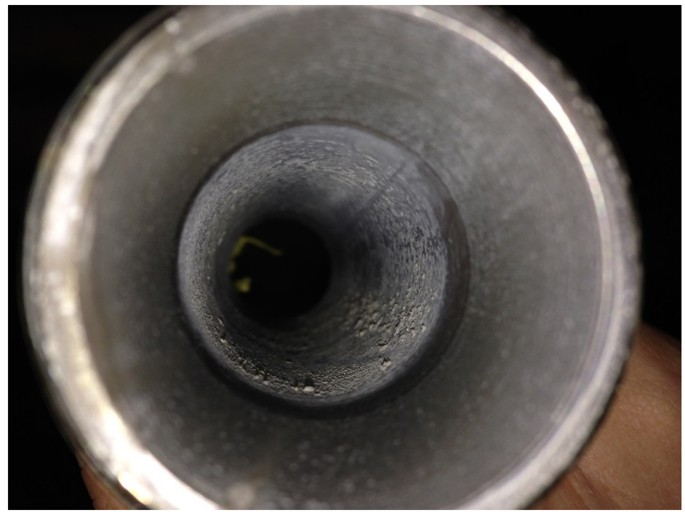
Eroded Pump Impeller

Nylon Before

Nylon After

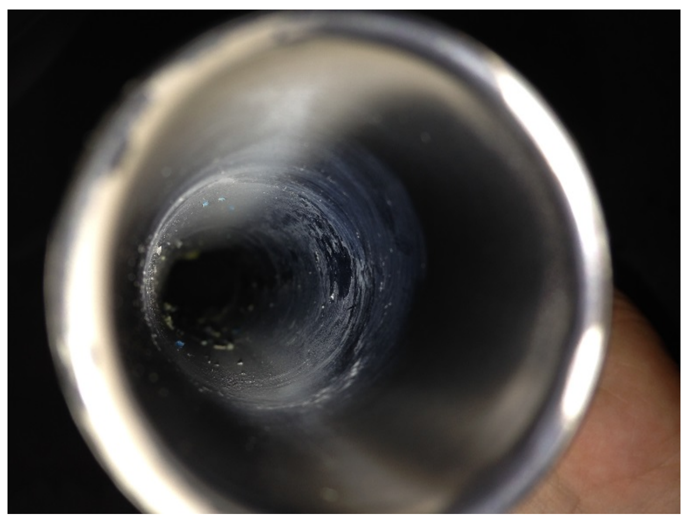
Fortron Remained Un-affected after Testing

New Coupling



Eroded Coupling after Testing

Fortron Coated Coupling New



Fortron Coated Coupling after Testing
Slight Erosion

Reference 13

Washington Penn Plastic Co., Inc.
450 Racetrack Road • P.O. Box 236
Washington, Pennsylvania 15301-6183
Phone (724) 228-1260
Fax (724) 223-9300
Website www.washpenn.com

A 4 melt flow medium impact copolymer polypropylene.

Typical Applications:
Injection molding applications

Product Description:
The properties shown below are typical for medium impact copolymer polypropylene. This basic product satisfies the needs of many applications.

Features and Options:
- Excellent cleanliness
- Excellent processing stability
- Good melt strength
- Cold temperature impact
- Tested at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5% relative humidity unless otherwise noted

Physical Properties	Typical Values*	Test Method
Melt Flow	4 g/10min	ASTM D1238
Notched Izod Impact @ 23°C	2 ft-lbs/in	ASTM D256
Gardner Impact @ -30°C	100 in-lbs	ASTM D5420
Tensile Strength @ Yield (2”/minute)	3,900 psi	ASTM D638
Flexural Modulus (0.50”/minute)	186,000 psi	ASTM D790

NOTE: Custom colors available upon request.

* Values given are typical and should not be interpreted as product specification. To obtain values for specific application purposes, contact your Washington Penn Plastic representative.

Reference 14

Long term creep and stress rupture of aramid fibre

G. M. Fallatah, N. Dodds and A. G. Gibson

The present paper describes a creep rupture investigation on aramid fibre yarns (Twaron 1000 and Kevlar 29) supplied by Teijin and Du Pont respectively. The ISO 9080 extrapolation procedure, which was developed for thermoplastic pipe materials, was used to model and interpret the results. The 4 parameter version of this procedure fitted the results well and gave useful predictions of the long term stress rupture behaviour, lending confidence to existing qualification procedures for the use of aramid fibre in reinforced thermoplastic pipe (RTP), and other applications involving continuous high tensile loads. Creep strain measurements on yarns showed a near constant degree of creep deformation per decade. Although they may involve some of the same mechanisms the creep and stress rupture processes appear to operate independently and on different time scales. It was found that creep deformation in aramid yarns is unlikely to be a significant problem at stress levels corresponding to a 20 year lifetime.

Keywords: Aramid, Creep, Stress rupture

Introduction

Aramid is the most successful member of a range of ultrahigh strength polymer fibres developed over the last forty years. Frank[1] in 1970 discussed routes by which high strength and stiffness might be achieved in polymers by making use of the fully chain extended conformation, where the intrinsic properties of the carbon–carbon covalent bond could be exploited. Successful research in the 1970s (Ref. 2) resulted in the manufacture of high strength polymers by virtually all of the routes proposed in that paper, including polyethylene fibres manufactured by ultradrawing and gel spinning. Rigid rod polymers, however, which have been widely studies in the last three decades[3–14] provide stability up to higher temperatures than extended chain thermoplastics, but are much more challenging to process because of their intractability to melt processing. Use must be made instead of their solubility in highly polar media, in which they show lyotropic liquid crystal behaviour. This phenomenon, and the effects of orienting flows, enable aramids to be processed by wet spinning into fibres with a high level of crystallinity and molecular orientation. The molecular structure of para-aramid[2,4,12,13] is shown in Fig. 1.

Aramid fibre successfully penetrated a wide range of markets, including tyres, tension members, composite products and ballistic protection fabrics. However, an important new market that has emerged in the last 15 years is reinforced thermoplastic pipe (RTP).[15] This fulfils of the need of the oil and gas industry for flexible high pressure pipework with greatly improved resistance to oilfield fluids, especially those containing dissolved H_2S and CO_2 which are highly corrosive to steel. While unreinforced thermoplastic pipe can only offer working pressures up to ~15 bar, RTP is capable of offering working pressures of 80 bar and much higher. An advantage of aramid in this application is that, unlike glass and carbon fibre, aramid does not need to be fully impregnated with and protected by resin in order to work effectively. This is because, along with its sizing system, aramid provides yarns with a low friction coefficient that are much more resistant to damage by fibre–fibre abrasion than the other fibres.

Reinforced thermoplastic pipe, as shown in Fig. 2, comprises a thermoplastic liner and cover, reinforced by an even number of aramid fibre reinforcing layers, wrapped at $\pm 55^\circ$ to the pipe axis, the optimum angle to resist internal hydrostatic pressure. The product is manufactured in diameters up to 6" (150 mm), with working pressures, depending on the application, up to 12 MPa (120 bar). There are currently two manufacturers, Pipelife bv and Technip. The first applications were in onshore transport of oilfield fluids, as shown in Fig. 3, as well as in gas transmission. Despite being significantly more expensive than steel, RTP has the advantages of corrosion resistance and flexibility, which provides ease of deployment, as shown in Fig. 4. More recently, subsea applications have arisen, as shown in Fig. 5.

The possible use of large volumes in RTP represents a technical challenge for aramid because this is one of the fibre's most highly continuously stressed applications. This has generated renewed interest in its long term creep rupture behaviour. To promote the wider

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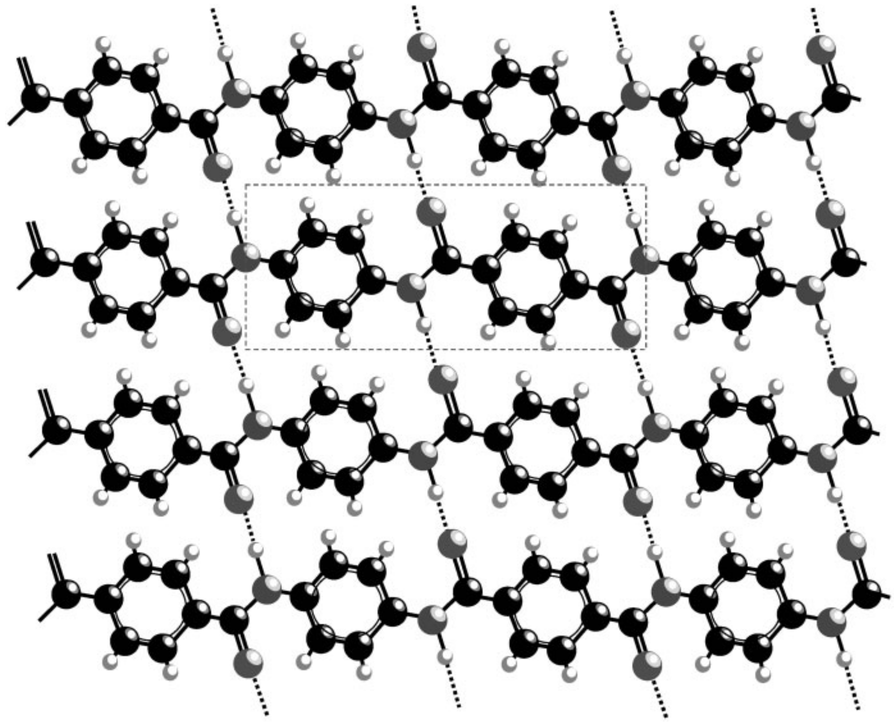
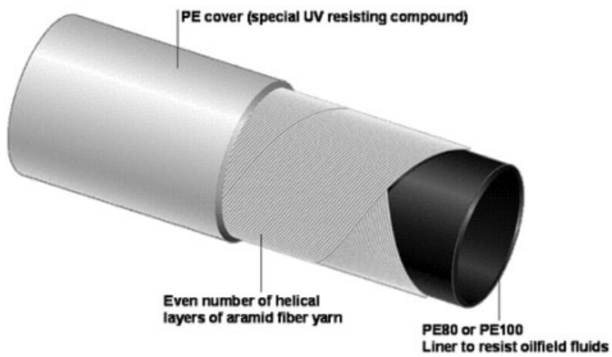


1 Crystalline structure of aramid fibre, showing *b–c* plane: unit cell dimensions[9–14] are *c* (chain direction)=1·29 nm and *b* (transverse direction)=0·518 nm, *a* direction dimension, not shown, is 0·787 nm



2 Schematic structure of RTP, showing liner, reinforcement and cover (Courtesy of Technip)

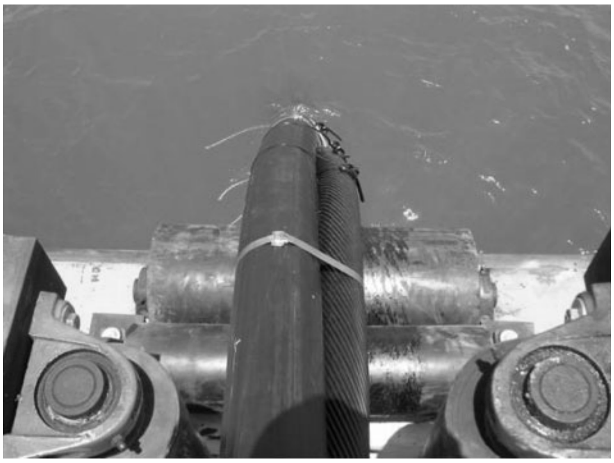
application of RTP, the principal manufacturers, together with Teijin, Du Pont and a group of end users formed a joint industry project (JIP), which was recently successfully completed.[16,17] The JIP outputs comprised guidelines for the qualification and use of product,[16] including an API Guideline[18] for oilfield applications and an ISO Technical Specification for its use in gas transmission.[19]

Qualification of reinforced thermoplastic pipe

All non-metallic pipe systems are prone to long term failure under load, through processes involving creep

3 Aramid fibre RTP in use for transport of oilfield fluids: photograph shows white pigmented, UV stabilised cover for exposed use in hot climates, as well as electrofusion coupler technology, which is one of jointing options (Courtesy Pipelife bv)

4 Flexibility of RTP permits coiling on drum: continuous lengths, up to 1 km between joints, may be deployed (or retrieved) by this simple means (Courtesy of Technip and Petroleum Directorate Oman)



5 Piggyback deployment of underwater RTP, alongside steel cable (Courtesy of Technip)

and/or damage accumulation, the process generally referred to as stress rupture or static fatigue. The main financial burden in the qualification of non-metallic piping products is the cost of this long term stress rupture testing, which involves the application of constant pressure and the measurement of failure times exceeding 10 000 h, as shown schematically in Fig. 6. This enables a relationship to be established between the applied pressure and the time to failure. A statistical lower prediction limit (LPL) is then calculated for the product, as shown, and extrapolated to the design life, to enable a long term pressure rating to be established for the pipe. Using the LPL, rather than the mean line enables some allowance to be made for the variability of the product, as manufactured. Most non-metallic pipe systems, including thermoplastic and fibreglass pipe, employ similar procedures.[20,21]

The JIP investigated a number of ways in which the burden of long term testing might be reduced. A key task was to characterise the long term failure behaviour of aramid yarns, representative of the reinforcement used in RTP. The outcome of this task is reported here, along with an interpretation of aramid fibre creep behaviour.

Theory for qualification tests

Reinforced thermoplastic pipe qualification tests assume an empirical power law relationship between time to failure and pressure (at constant temperature). In other words, a linear relationship is assumed between these quantities when plotted on a log–log basis, as in Fig. 6. This form of relationship is assumed in almost all types of non-metallic pipe qualification procedures, including Refs. 18–21. Since, for RTP, fibre failure is the key failure mechanism, the aramid yarns are also assumed to behave in the same way, so the following relationship was assumed between the applied stress σ and the time to failure t_f

$$\sigma = F t_f^{-G} \tag{1}$$

so the equation of the stress rupture curve is

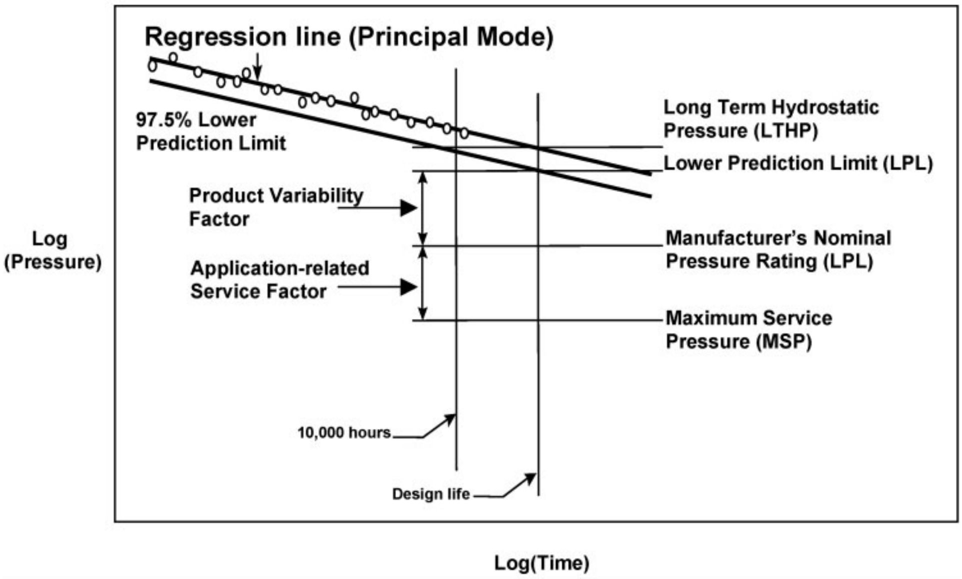
$$\log \sigma = \log F - G \log t_f \tag{2}$$

where F and G are power law constants, $-G$ being the regression line slope.

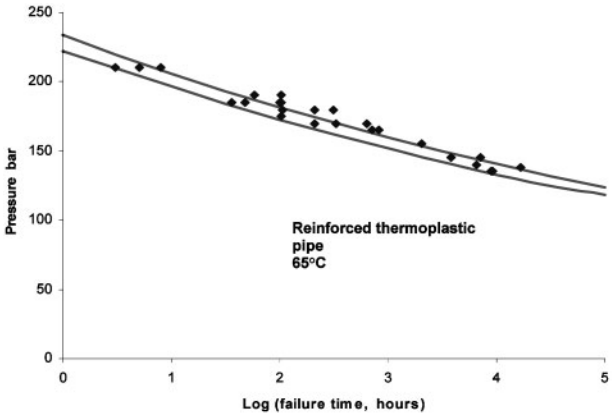
Alternatively, in terms of time to failure

$$t_f = \left(\frac{F}{\sigma}\right)\frac{1}{G} \tag{3}$$

In the case of RTP[16,18,19] the regression relationship for the stress rupture behaviour is determined at the 'design temperature', the maximum temperature at which the product will be used and failure points are required up to times exceeding 10 000 h, somewhat more than one year. The LPL for the results is the lower 95% confidence limit for individual experimental points. This represents the line above which 97·5% of all individual measurement points should lie. The design basis and pressure rating of the pipe is then determined by extrapolating the LPL to the design life, which in the case of most oilfield pipework, is 20 years. This value is the manufacturer's nominal pressure rating (MNPR). It



6 Schematic of pressure rupture relationship for reinforced thermoplastic pipe, showing experimental results, mean line and extrapolation of the LPL to design life



7 Pressure versus log time to failure relationship for Pipelife RTP at 65°C (Courtesy, Pipelife bv)

is regarded as reasonable practice to extrapolate such failure data by up to ~1·5 decades. Generally, depending on the individual application and the fluid being handled, a further safety factor will be applied to the MNPR to determine the working pressure, but the MNPR is the key factor determining the rating of the pipe. Extrapolating the LPL, rather than the mean line takes into account the manufacturing variability of the product, which is assumed to be the main factor determining the scatter on the failure points.

Figure 7 shows an example of one manufacturer's regression data, along with the mean line and the LPL, for a particular RTP product. In this case the scatter on the data is fairly small, so the LPL is quite close to the mean line.

Temperature dependence

The ISO 9080 procedure[21] requires measurements to be taken at different temperatures. If Arrhenius dependence is assumed for the time to failure, equation (3) can be amended to

$$t_f = A \exp\left(\frac{H}{kT}\right)\sigma^{-\frac{1}{G}} \tag{4}$$

where H is the activation energy of the process and k is Boltzmann's constant.

This model makes no assumptions about the physical mechanisms involved in the creep and failure of the fibres. The alternative approach would be the widely used model due to Eyring,[22] which assumes creep deformation to consist of a series of thermally activated events. In this case the failure time would be

$$t_f = A \exp\left(\frac{H - V\sigma}{kT}\right) \tag{5}$$

where the constant V is the activation volume.

Eyring has been employed with some success to model the creep and failure of aramid fibre.[6,7,12] The model predicts a linear relationship between stress and log time to failure, instead of the power law relationship of equation (1).

The plastic pipes industry has considerable experience of modelling the stress rupture of pipe materials at long times, over a range of temperatures. Standards and qualification procedures invariably use the power law model rather than Eyring, although in most cases each would fit the results equally well. The reason for preferring the power law model is simple: extrapolation of failure data assumed to be linear in log–log space gives a slightly more favourable life prediction than the equivalent extrapolation in lin–log space.

ISO 9080[21] contains a useful modelling and extrapolation protocol for modelling failure data. The same approach has been recommended for modelling other types of failure data. ISO 9080 assumes that the time to failure is given by an expression of the form

$$\log(t_f) = c_1 + \frac{c_2}{T} + c_3 \log(\sigma) + \frac{c_4 \log(\sigma)}{T} \tag{6}$$

where c_1,c_2,c_3 and c_4 are fitting constants, and T is the absolute temperature. Comparing this with equation (4) it can be seen that the constants are related by

$$\log A = c_1 \tag{7}$$

$$H = 2{\cdot}302585kc_2 \tag{8}$$

$$G = -\frac{1}{c_3 + \frac{c_4}{T}} \tag{9}$$

Finally

$$\log F = \frac{-c_1 - \frac{c_2}{T}}{c_3 + \frac{c_4}{T}} \tag{10}$$

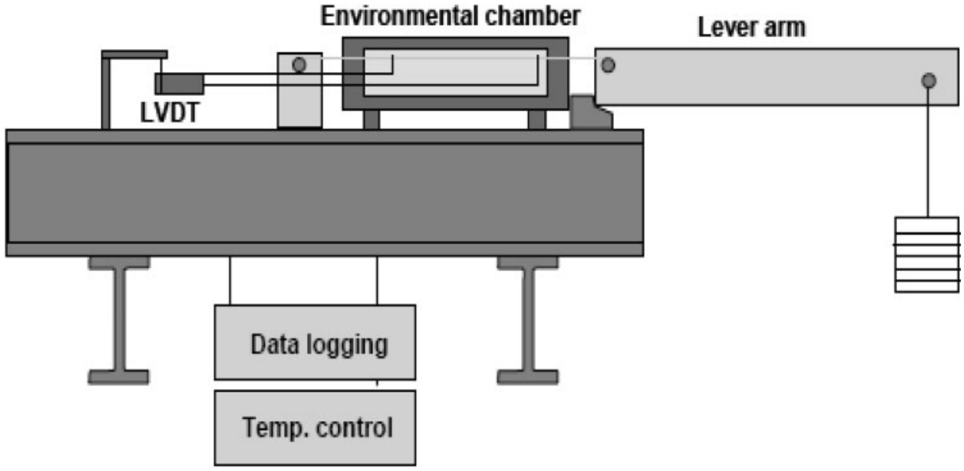
In terms of temperature dependence the rupture curves are taken to be proportionally spaced depending on the reciprocal of the absolute temperature. This is consistent with creep and failure being governed by an Arrhenius type thermally activated process, as implied in equation (4). The regression procedure obtains the best least squares fit for the constants based on the scatter in $\log t_f$, i.e. on the scatter in the 'ordinate' direction. This has been shown to be more conservative than using the vertical scatter (i.e. the scatter in logσ). Two versions of the protocol are available: the three parameter model ($c_4 = 0$) where all the regression lines have the same slope in log–log space, and the 4 parameter model ($c_4 \neq 0$) where the slope varies with temperature.

Calculation procedures for the least squares fit and the LPL are explained in ISO 9080[21] and will not therefore be discussed here. In addition to curve fitting and extrapolation, the standard also provides methods for checking possible changes of slope due to changes in failure mode of the material. Such a change, which would be indicated by a 'knee' in the curve, would indicate undesirable long term performance. Including test data at temperatures higher than the intended design temperature is very important in this respect, because undesirable failure mechanisms tend to move to shorter times as the test temperature is increased.

Experimental

Creep rupture tests at constant load were carried out on aramid fibre yarn in air at 25, 65, 95 and 120°C. At 25 and 60°C, failure times exceeding 10 000 h were achieved. For the other temperatures, failure times were limited to ~1000 h.

The principal aim was to establish values of the regression line gradient and 20 year design parameters for the fibre yarns, especially at the most frequently used design temperature of 65°C. A secondary aim was to look for any evidence of any long term changes in failure



8 Schematic of dead loading stress rupture testing machine

mode that would affect the suitability of the fibre for long term use.

The two yarn types in the study were Kevlar 29 (1670 dtex) and Twaron 1000 (1680 dtex). Although the manufacturing processes employed by Teijin and Du Pont differ in certain details these yarn products are acknowledged to be very similar in performance and have been regarded as effectively interchangeable. It is worth pointing out that Kevlar 29 differs from Kevlar 49, the fibre type most widely used in composite materials and the material for which most long term performance data arecurrently available. Kevlar 49 is subjected to a more prolonged stretching treatment to improve orientation, as a result of which it possesses a higher Young's modulus than Kevlar 29, but similar strength.

Behaviour of yarns is influenced by the level of twist. There is a statistical variation of strength along each fibre, due to a distribution of flaws or weak points in the constituting filaments of the fibre (in this case 1000 filaments). With untwisted fibres, therefore, test results depend on the gauge length, and a Weibull analysis of the results would be required. Twisted yarns largely eliminate this variation by allowing stress to be shared, through friction, between adjacent filaments when a particular filament fails. This is similar to the 'composite' effect achieved when fibres are impregnated by a rigid resin matrix. Both yarns were supplied with the same twist level of 'z80' (i80 turns per metre), which was representative of the yarns currently employed to reinforce RTP.

Stress rupture tests were carried out using seven temperature controlled dead loading rigs, designed for testing aramid fibre, as in Fig. 8. In addition a computer controlled mechanical testing machine, equipped with a temperature controlled oven, was used in constant load mode for a number of the short term tests, lasting up to ~100 h. In all cases, cylindrical grips of the capstan type were employed, to minimise grip damage to the yarn and grip failure. There were a small number of results involving grip failure and these were discarded.

Once sufficient data were available to determine the approximate shape of the regression relationships for the yarns, some further experiments to measure creep strain were put in place. The strain within a 100 mm gauge length was measured using a linear voltage differential transformer (LVDT) transducer, in the arrangement shown in Fig. 8. These measurements were carried out at just two temperatures, 25 and 65°C. The LVDT was held on a compliant suspension, which allowed frictionless lateral movement. The LVDT body and core were connected to respective ends of the gauge length by lightweight carbon fibre rods and steel pins. The pins were carefully inserted between the fibres in the yarn, to avoid fibre damage and, with the yarn under a small pretension, anchored in position with a very small bead of cyanoacrylate adhesive. This arrangement was found to work well for the most part. Some difficulties were found in establishing a reproducible level of initial elastic strain after the first application of the load. These were largely overcome by applying and removing small loads until the strain zero position could be accurately and reproducibly established. The other experimental difficulty, which was not overcome, was the problem of accurately measuring the very small residual creep rate that occurred at lower loads, when measurement times exceeded 1000 h. For this reason and for reasons of available time the period of measured creep strain seldom exceeded 1000 h.

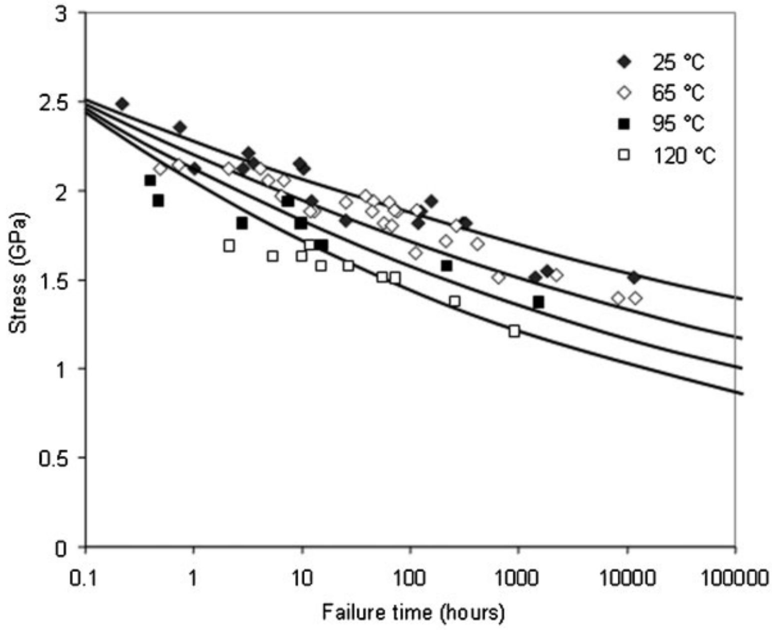
Results

Figures 9 and 10 show the stress rupture results on the two different yarns in air. The slopes of the curves varied with temperature, so the 4 parameter model was required. The procedure was effective in correlating the behaviour at different times and temperatures. The regression constants and the 20 year LPL values were calculated and are given in Table 1. It can be seen, from comparison with Fig. 7, that the scatter of the failure

Table 1 Regression results for aramid fibre yarns: ISO 9080 prediction parameters*

	25°C		65°C	
	G	*F*	*G*	*F*
Kevlar	0·03682	2·2085	0·04919	2·0958
Twaron	0·04237	2·2278	0·05402	2·1961
	95°C		120°C	
	G	*F*	*G*	*F*
Kevlar	0·06179	1·9867	0·07569	1·8730
Twaron	0·06485	2·1228	0·07573	2·0518

*Numerical values of *F* correspond to stresses in GPa and failure times in hours. Values accurate to 2–3 significant figures, but further figures are given to assure similarity of calculations.

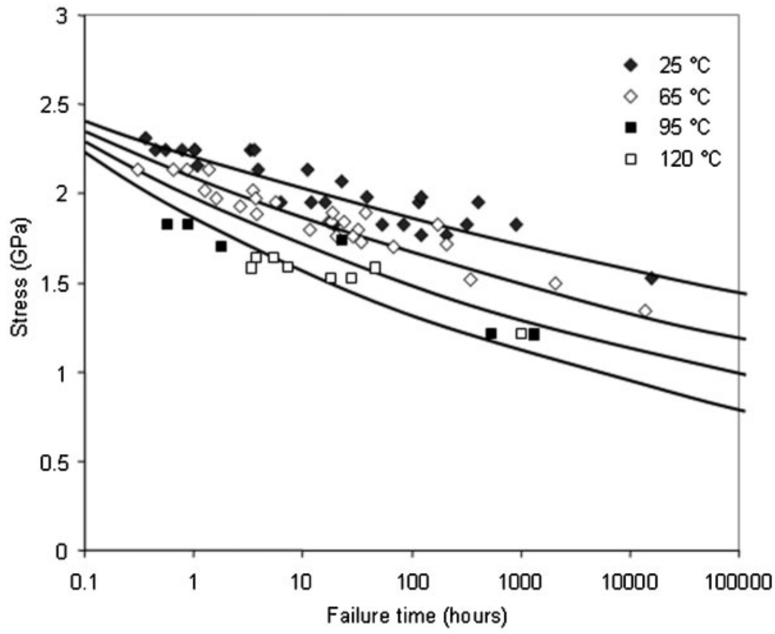


9 Twaron 1000 yarn results: continuous lines are predictions of ISO 9080 4 parameter model

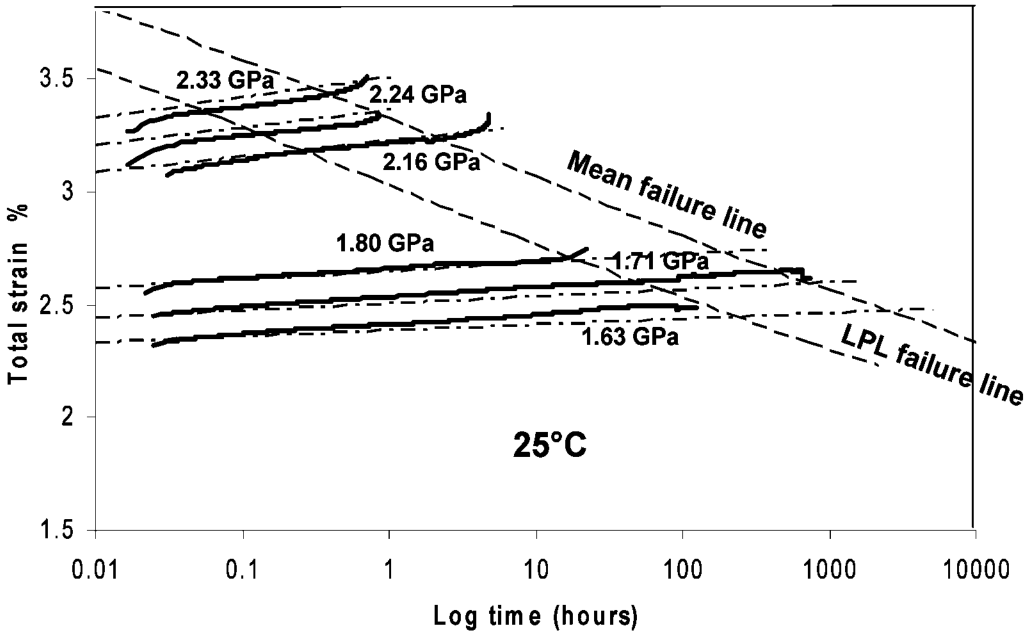
points for the yarns in tension is significantly greater than that observed when testing RTP spool samples under pressure. In hindsight it was realised that this was because, when a pipe was tested, the behaviour of several hundred yarns was effectively averaged, which greatly reduced the scatter. Despite the scatter problem, however, the actual failure parameters are rather similar for the two different yarn types, confirming that the products are effectively interchangeable.

The values of the regression line slope *G* are close to the values measured on pipes and used by RTP manufacturers in rating their products. This is interesting, as it had been anticipated that the regression line slopes for the yarns themselves might be a little shallower than those for pipe samples. The implication is that the manufacturing processes used to convert the yarns into reinforcing tapes and to incorporate the tapes into the RTP must be very effective in achieving an even distribution of strain between all the yarns. The view of the RTP JIP was that one of the consequences of strain imbalances between yarns would be an increase in the regression line slope. The similarity seen here between the yarn data and pipe data supports the idea that these products were well manufactured, from the viewpoint of strain balance, and the pressure regression test is therefore a good test of RTP quality. It may be that future qualification procedures could avoid the 10 000 h regression test sequence, replacing it with a test for conformity of the regression line slope.

Applying the test criteria of ISO 9080, there is no evidence at all of any 'knee' in the curves, either at long times or higher temperatures. This was checked both visually and using the mathematical procedure provided



10 Kevlar 29 yarn results: continuous lines are predictions of ISO 9080 4 parameter model



11 Creep behaviour for aramid yarn at 25°C, at stresses of 2·33, 2·24, 2·16, 1·8, 1·71 and 1·63 GPa: continuous lines are experimental data: predictions of equation (12) are shown, along with mean and LPL failure lines

in the standard. This useful result suggests that there will be no change of failure mechanism at long times at the maximum design temperature of 65°C, giving confidence in the use of aramid reinforcement.

The ISO 9080 procedure was rewritten, to incorporate the Eyring[22] rather than the power law model. It was found that the fit to the data was very similar to that observed in Figs. 9 and 10 for the power law model. For comparison purposes the 20 year mean failure stresses and 20 year LPL stresses are shown in Table 2. It can be seen that, as mentioned previously, the extrapolated values are slightly more favourable in the power law case, which appears to be the main justification for using this procedure.

Table 2 Comparisons between 20 year mean failure stress and 20 year LPL from power law (log–log) and Eyring (lin–log) models, using mathematical procedure of ISO 9080

Power law (log–log)		
Kevlar, °C	Mean, GPa	LPL, GPa
25	1·416	1·283
65	1·157	1·018
95	0·942	0·774
120	0·751	0·521
Twaron, °C	Mean, GPa	LPL, GPa
25	1·365	1·226
65	1·144	1·001
95	0·970	0·801
120	0·822	0·600
Eyring (lin–log)		
Kevlar, °C	Mean, GPa	LPL, GPa
25	1·328	1·135
65	1·016	0·790
95	0·762	0·453
120	0·534	0·073
Twaron, °C	Mean, GPa	LPL, GPa
25	1·277	1·068
65	0·995	0·757
95	0·773	0·456
120	0·580	0·125

Values accurate to 2–3 significant figures, but further figures are given to assure similarity of calculations.

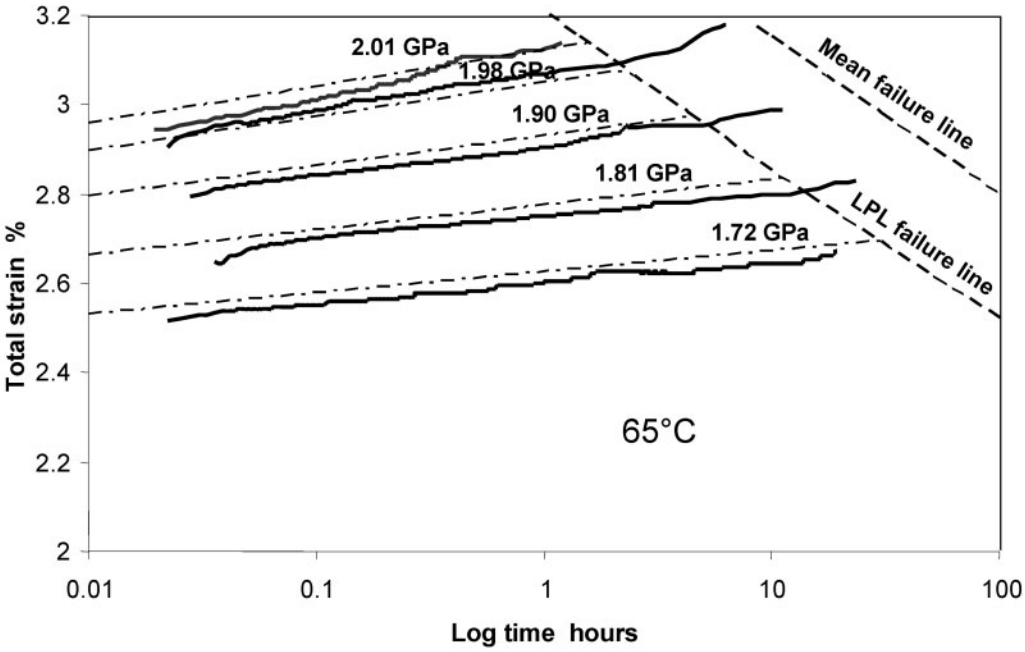
Figures 11 and 12 show the measured creep strains at 25 and 65°C respectively. The general features, as reported previously[5,6,14,22] for Kevlar 49, are a rapid, mainly elastic response, followed by a low rate of creep deformation. It does appear that a short relaxation process may take place in the first minutes after loading, as it takes some minutes for the curves to level out. After this, the creep rate, per decade appears to be almost constant, as has been noted before.[5] A constant creep rate in linear time, which is observed with many materials in the secondary stage of creep, would imply an upwardly curving creep response in logarithmic time, which does not appear to occur in the present case. This, of course, implies the existence of some 'hardening' process, as the creep rate is, in effect slowing down with time. The creep rate per decade appears to be a strong function of stress, as it reduces to a very low rate for stresses that would cause failure at times of 10 h and beyond.

It seems probable, observing the differences in time-scale between the stress rupture data and the creep data, that mechanisms involved in the two different processes may be different.

Discussion

Structure and properties of aramid fibre

The structure and properties of aramid fibre have been widely investigated.[2–14,23] Unlike thermoplastic fibres, aramid has a structure that is close to 100% crystalline. Poly *p*-terephthalamide (PPTA) possesses a monoclinic unit cell, with the chains linked in the *b* direction by regular hydrogen bonds, as shown in Fig. 1. The *b–c* plane dimensions have been established as $c=1{\cdot}29$ nm and $b=0{\cdot}518$ nm,[13] the phenyl units being arranged so that they lie almost in the same plane. The intractability of aramid to melt processing derives principally from the rigidity of the chain direction bonds and the chain length, which may exceed 5000 repeat units. The inter-chain hydrogen bonds contribute to this intractability



12 Creep behaviour for aramid yarn at 65°C, at stresses of 2·01, 1·98, 1·97, 1·9, 1·81 and 1·72 GPa: continuous lines are experimental data; predictions of equation (12) are shown, along with mean and LPL failure lines

and promote a crystalline phase with a two-dimensional lamellar structure, there being relatively weak bonding in the *a* direction. There is less certainty about the *a* direction dimensions, stated to range from 0·435 to 0·56 nm and about the orientation of the *b–c* layers relative to one another through the crystal thickness.[9–11,13,14,23] The weak *a* direction interactions provide the possibility of variations in the structure in this direction, due to stacking faults, etc.

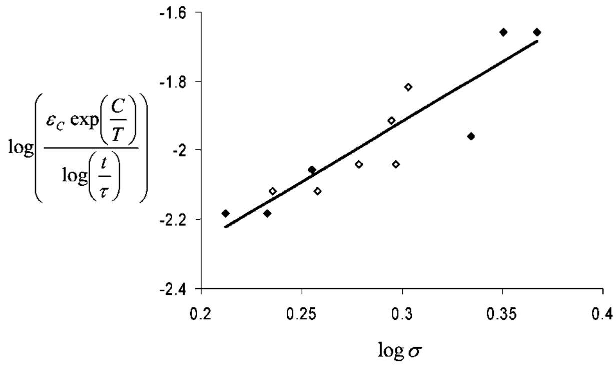
Rigid rod polymers contain various types of crystalline imperfection but there are no chain folds of the type found in semicrystalline plastics and no identifiable amorphous phase. Therefore the conventional causes of viscoelasticity are largely absent. The rigid crystalline sequences extend for virtually their full length within the crystallites – one of the factors that accounts for the high strength and stiffness of aramid fibre. The weak *a* direction bonding, in addition to the well known pleated structure of the crystalline phase, which occurs on a larger scale, accounts for the relatively low value of the compressive strength of aramid. The weak *a* direction bonding also probably accounts for the low friction coefficient and, paradoxically, the resistance to damage through fibre–fibre interactions.

Important features of the tensile creep behaviour of para-aramid are that a high tensile load produces an elastic response followed by a small, long term creep process which continues up to the point where the fibre fails. The long term creep strain is only partially recoverable, indicating that at least one mechanism of plastic deformation is present.

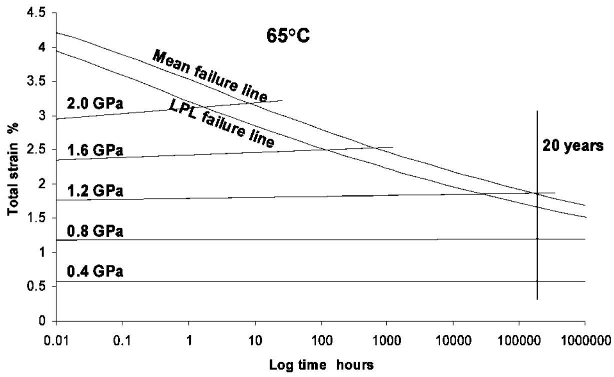
The most probable deformation mechanism in aramid fibre, bearing in mind the crystalline structure (Fig. 1), is slip on the *b–c* plane. *a–c* slip may also be possible, but this would involve breakage and possibly the reforming of the interchain hydrogen bonds. The most notable work on the tensile creep behaviour of aramid fibre was carried out by Northolt and co-workers,[14,23] who proposed that the principal plastic deformation mechanism comprises chain direction shear of the crystalline phase in regions of imperfect fibre orientation. This is the most widely accepted model for aramid. Although there are some small difficulties associated with the fact that the molecular orientation is quite high, with orientation functions close to unity, the theory otherwise accounts successfully for most of the observed phenomena, including the fact stress–strain curves in these materials showing a slight, but significant upward curvature,[5,14,23] presumably due to this improvement in orientation. Northolt *et al.*[14,23] mention that it is generally unnecessary to take account of the fact that the chain shear process will result in an improvement in orientation function as the crystalline domains rotate to an orientation nearer to the deformation axis, which, again, is a reasonable assumption.

It seems probable that the mechanisms of stress rupture and of creep are similar in that they involve slip processes of the type discussed here. However, these processes appear to take place with different stress dependence over different timescales. It seems probable that stress rupture involves the growth of flaws either from preexisting voids within the material or as a result of deformation processes near to the ends of low molecular weight crystalline sequences in the material. It is also probable that this process involves only a very small proportion of the material. This is supported by the observation that there is no evidence of a reduction in Young's modulus of the fibre during this damage growth process. Indeed there are some indications of a small increase in Young's modulus, as observed by others, due presumably to an improvement in crystalline orientation. If there were bulk changes in the distribution of stress between crystalline sequences this would undoubtedly show up as a change in modulus.

The increase in creep strain, by contrast seems to involve all of the material. It may result from widely distributed changes in the stress distribution around the ends of crystalline sequences and from small movement



13 Plot of $\log[\varepsilon_C \exp(\frac{C}{T})/\log(\frac{t}{\tau})]$ versus $\log\sigma$ for creep results at 25°C (closed symbols) and 65°C (open symbols)



14 Creep prediction for aramid yarn at 65°C, for different stress values: mean and LPL failure lines are also shown

of these sequences relative to one another. Unlike the mechanism involved in stress rupture, it does not appear to be damaging overall to the material.

Creep model

The creep data in Figs. 11 and 12, for 25 and 65°C, suggest that the creep strain at high stresses increases linearly with logarithmic time. This implies that the creep rate actually declines with increasing time, suggesting a hardening mechanism. If the creep component is governed by an Arrhenius process and is related in a power law manner to stress, it might be expected that the creep component of strain ε_C would be given by

$$\varepsilon_C = A \exp\left(\frac{-C}{T}\right)\sigma^n \log\left(\frac{t}{\tau}\right) \quad (11)$$

where A, C and n are constants. The factor τ is necessary to provide a datum for the logarithmic data. Taking τ=0·01 h effectively assumes that the decades of logarithmic time are measured from a starting point of 0·01 h. The strain at a particular time consists of both elastic and creep components, so the overall strain is

$$\varepsilon = \varepsilon_E + \varepsilon_C = \frac{\sigma}{E} + A \exp\left(\frac{-C}{T}\right)\sigma^n \log\left(\frac{t}{\tau}\right) \quad (12)$$

where ε_E is the elastic component of strain and E is the Young's modulus.

The constants governing the creep component can be found from the creep data by rearranging equation (11) and taking logs, so

$$\log\left[\frac{\varepsilon_C \exp(\frac{C}{T})}{\log(\frac{t}{\tau})}\right] = \log A + n \log \sigma \quad (13)$$

Figure 13 shows a plot of

$$\log\left[\varepsilon_C \exp\left(\frac{C}{T}\right)/\log\left(\frac{t}{\tau}\right)\right]$$

against $\log\sigma$ for the 25 and 65°C creep results. The constant C varied to minimise the mean squared scatter on this relationship, the optimum value being found to be 920 K. The constants A and n were found to be $1{\cdot}093\times10^{-3}$ and 3·48 respectively. It may be that, as was the case with the failure data, n varies somewhat with temperature. However, the variation in n from 25 and 65°C appears quite small and, given that creep data were only measured at two fairly close temperatures, n will be treated as constant in the present study. The values of Young's modulus needed for the elastic term in equation (12) were 70 and 65 GPa respectively at 25 and 65°C. The choice of these values effectively determines the elastic baseline for the creep curves so the values chosen already take account of the relaxation that appears to take place immediately after loading.

By using the parameters determined from Fig. 14, equation (12) was used to estimate the creep behaviour at the temperatures and loads studied. The dotted lines in Figs. 11 and 12 are the predictions. Given the scatter on the creep data, these predictions agree quite well with the observed results. Of course the predicted creep strain values have no meaning beyond the point at which failure takes place, so 'failure' curves were added to Figs. 11 and 12. These were obtained by eliminating σ between the creep rupture relationship (equation (1)) and the creep model (equation (12)). The LPL line was calculated in a similar manner, solving the LPL relationship simultaneously with equation (1). It is interesting to note the significant decrease in strain at failure that occurs with increasing failure time. It is also interesting that, although the governing relationships are not linear, the failure limit curves are almost linear in strain versus log time.

Finally, equation (12) was used to predict the behaviour of aramid yarn at the long times typical of the design life of RTP. The results for 65°C are shown in Fig. 14. It is clear that, if the model applies at long times, creep deformation of aramid should not be a significant problem at any stress value below the level required to cause failure within 20 years.

Conclusions

Creep rupture measurements have successfully characterised the long term failure behaviour of aramid fibre yarns and provided data that can be used as the basis for future design in tensile applications, including RTP. Different yarn types showed very similar regression parameters.

Although the data scatter on individual yarn failure is larger than that for RTP spool samples the ISO 9080 4 parameter model provided a good description of stress rupture as a function of both time and temperature. The results suggest that there is unlikely to be a change in failure mechanism at long times, which lends confidence to the use of aramid fibre in highly loaded long term tensile applications.

The yarn regression lines showed an increase in slope with increasing temperature, the slopes being comparable to the slopes measured for RTP samples held under pressure at the same temperatures. Although the standard log–log form of the pressure versus time to failure relationship gave more optimistic predictions of long term behaviour than the lin–log form, based on the Eyring model, both models fitted the data equally well.

Measurements of creep strain showed that, over most of timescale investigated, the creep strain per decade is roughly constant, implying some structural change that reduces the rate of creep. The processes controlling the creep behaviour and the stress rupture behaviour appear to be independent of one another. The behaviour observed here implies that creep deformation of aramid fibre is unlikely to be an important problem at the stress levels needed to design for a lifetime of 20 years or longer.

Acknowledgements

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References

1. F. C. Frank: *Proc. Roy. Soc. Lond. A*, 1970, **319A**, 127.
2. A. Ciferri and I. M. Ward: 'Ultra-high modulus polymers'; 1979, Barking, Applied Science.
3. M. G. Dobb, D. J. Johnson and B. P. Saville: *J. Polym. Sci.*, 1977, **58**, 237–251.
4. V. I. Kostikov: 'Fibre science and technology', 1st edn; 1995, London, Chapman & Hall.
5. M. H. Lafitte and A. R. Bunsell: *J. Mater. Sci.*, 1982, **17**, 2391–2397.
6. A. K. Rogozinsky and S. L. Bazhenov: *Polymer*, 1992, **33**, (7), 1391–1398.
7. C. J. M. Van Den Heuvel: 'Time to failure of twaron 1000 yarns'; 2000, Arnhem Twaron Products Research Institute.
8. H. H. Yang: in 'Fibre reinforcements for composite materials', (ed. A. R. Bunsell); 47; 1988, Amsterdam, Elsevier.
9. M. G. Dobb, D. J. Johnson and B. P. Saville: *Polymer*, 1981, **22**, 961.
10. M. G. Dobb, D. J. Johnson and B. P. Saville: *J. Polym. Sci.*, 1977, **15**, 12, 2201–2211.
11. R. E. Wilfong and Zimmerman: *J. Appl. Polym. Sci.*, 1977, **31**, 1–21.
12. H. H. Yang: 'Kevlar aramid fibre', 19; 1992, New York, John Wiley & Sons.
13. K. H. Gardner, A. D. English and V. T. Forsyth: *Macromolecules*, 2004, **37**, 9654–9656.
14. M. G. Northolt and J. J. van Aartsen: *J. Polym. Sci.*, 1973, **11**, 333.
15. B. Dalmolen: Proc. 3rd MERL Conf. on 'Oilfield engineering with polymers', London, UK, October 2001, MERL, 249–254.
16. 'Reinforced thermoplastic pipe for the transport of gaseous fluids', ISO TS 18226, 2005.
17. 'Implementation of reinforced thermoplastic pipe (RTP) in the oil and gas industry', RTP JIP Final Report, University of Newcastle, 2006.
18. 'Guideline for the application of reinforced thermoplastic pipe (RTP) in the oil and gas industry', RTP JIP documentation, University of Newcastle upon Tyne, Newcastle Upon Tyne, UK, 2005.
19. American Petroleum Institute: 'Recommended practice for qualification of spoolable reinforced plastic line pipe', API 15S, August 2005.
20. 'Standard test method for obtaining hydrostatic design basis for thermoplastic pipe materials', ASTM-D 2837-98a.
21. 'Thermoplastic pipes for the transport of fluids – methods of extrapolation of hydrostatic stress rupture data to determine the long-term hydrostatic strength of thermoplastic pipe materials', ISO 9080, 2003.
22. H. Eyring: *J. Chem. Phys.*, 1936, **4**, 283–291.
23. M. G. Northolt: *Eur. Polym. J.*, 1974, **10**, 799.

Reference 15

Guidelines for Hydrostatic Testing of Specialty RTP pipe and tubing in accordance with DOT Pipeline Safety Regulations Part 192 for Natural Gas or Part 195 for Hazardous fluids

It is the responsibility of the pipe operator to determine the suitable hydrostatic test procedure and testing times. The procedure listed below is based upon the guidelines listed in DOT specifications Part 192 for natural gas and Part 195 for hazardous liquids.

The intent of Part 192 - Subsection J is to insure that, prior to operation, piping is tested to substantiate maximum operating pressure and identify any potential leaks. The basic requirement is to perform a hydrostatic test at 1.5 times (or greater) of the actual maximum operating pressure (at any point) for a period of 8 hours. Part 195 - Subsection E prescribes a hydrostatic test of 1.25 times (or greater) of the actual maximum operating pressure (at any point) for a period of up to 8 hours. Listed below are guidelines to aid in hydrostatic testing of Specialty RTP pipe and tubing.

Pre-Test Set-Up:

- The preferred hydrostatic testing liquid is clean water. Other non-hazardous liquids may be acceptable. Pneumatic (air) testing is not recommended.
- Testing may be conducted on the full system or in sections.
- The pipeline test section must be restrained against movement in the event of catastrophic failure. ***All Specialty RTP piping and tubing systems and must be properly buried prior to testing or in the case of an RTP-Rehab™ through an existing pipeline, the RTP system must be flanged off at each end.*** Backfill must be properly placed and compacted. Risers that are attached to buried couplings must be fully restrained against movement.
- All low pressure filling lines and other items not subject to the test pressure should be disconnected or isolated.
- The test section should be completely filled with the test liquid, taking care to bleed off any trapped air. Venting at high points and at the ends of the test section may be required to purge air pockets while the test section is filling.
- Valve openings and closings should be slow and sequenced to prevent water hammer and prevent any potential creation of a vacuum inside the pipe that could cause collapse.
- *Before applying test pressure, allow time for the test fluid and the test section to equalize to a common temperature*. A minimum wait time of 1 hour should be used.. Preferably, the test fluid temperature should be less than 80°F to expedite temperature equalization with the soil, but should never exceed the rated temperature of the Specialty RTP pipe.
- Pressure monitoring equipment and hoses should be protected from direct sunlight exposure or other potentially large temperature swings during testing, as this can provide erroneous pressure data.
- *Ideally, testing should be conducted and pressures measured at the lowest elevation in the test section*. When this is not possible, correction to the test pressure must be made for the hydrostatic head to insure that the pipe will not be over pressurized. Use the equation below or Table 1 to determine the amount to reduce the test pressure.

$$\mathbf{P_H = .4335 \times Z}$$

P_H = Hydrostatic Head Pressure (psi)
Z = Elevation difference between lowest point in test section and test location (ft)

Z (ft)	25	50	75	100	125	150	175	200
P_H (psi)	10.8	21.7	32.5	43.4	54.2	65.0	75.9	86.7

When using the table, round up to the nearest elevation difference.

Test Procedure:

The test procedure consists of an initial expansion and a test phase. All thermoplastic pipes initially expand when first pressurized. The length of time for measurable expansion is relatively short, but varies with pressure, materials, and temperature. The rate of expansion also decays logarithmically. For Specialty RTP gathering lines in a buried or pull through applications, significant expansion usually subsides after four (4) hours, but this is a function of line length, pipe size and pressure rating.

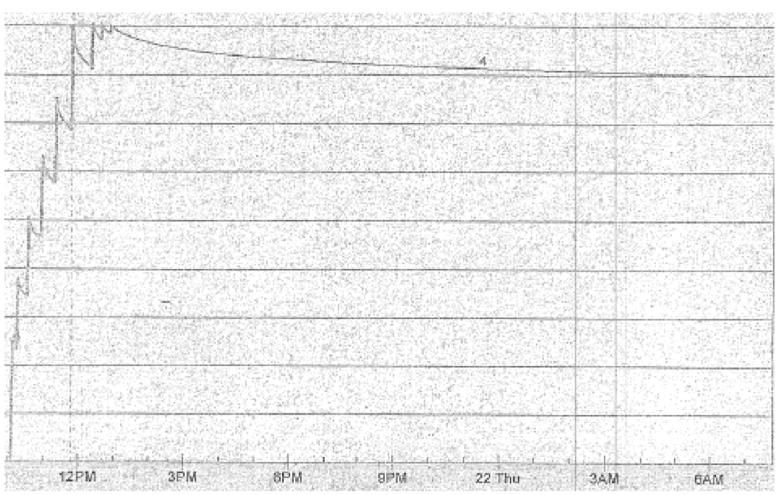
Depending upon utilizing either Part 192 or Part 195, the target test pressure is 1.5 times the max operating pressure for gas, or 1.25 times the max operating pressure for hazardous liquids. Since initial expansion will reduce pressure over time, an additional 10% is added to these values for the initial expansion phase. The following test procedure is suggested.

- For the initial expansion phase, the test pressure (P_E) should be the difference between the max operating pressure (MOP) minus any hydrostatic head pressure (P_H) times the target pressure multiplier plus 0.1.

Natural Gas: $P_E = (MOP - P_H) \times 1.6$
Hazardous Liquids: $P_E = (MOP - P_H) \times 1.35$

- This pressure is to be **maintained** within +0 psi/-10 psi for four (4) hours. Additional test liquid will be required to maintain pressure. It is not necessary to monitor the amount of liquid added during the initial expansion phase.
- Immediately following the initial four (4) hour expansion phase, the test phase can begin. If test pressure remains above the target level for an additional eight (8) hours, no leakage is indicated and strength is verified.
- Variations in pressure will occur due to changes in temperature, and there can be variations during the test, but the test pressure cannot go below the target level

Below is a picture of an actual hydrostatic test chart of pressure as a function of time. It took approximately two hours to pressure up the line and two hours of stabilization before the test was begun. There was a pressure decay of 75 PSI or an 1800PSI test over the term of the test due to the pipe moving and the water cooling in the pipe, but with each progressive hour the pressure decline was reduced. For tests in excess of eight hours there can be an increase in pressure as the test goes from cooler nights into warmer days as a result of the test fluid heating up in the hoses to the charts.



Example of Hydrostatic test Procedure

Test Conditions:
500 psi pipe
Highest elevation 1800'
Lowest elevation 1700'
Test elevation 1725'
Hazardous Liquid

Hydrostatic head due to elevation:

Z = Test Elevation - Lowest elevation = 25 ft

PH = 10.8 psi (from chart)

Expansion Pressure:

PE = (MOP –PH) x 1.35

PE = (500 psi -10.8) x 1.35

PE = 660 psi

Expanson Phase:

Maintain between 660 psi and 650 psi (660 psi – 10 psi) for 4 hours.

Test Pressure:

PT = (MOP – PH) x 1.25

PT = (500 psi -10.8) x 1.25

PT = 612 psi

Test Phase:

Charge pipe to 660 psi then wait 8 hours.

Must stay above PT or 612 psi for valid test.

Reference 16A

Case Study

Rehabilitation of a salt water disposal line in West Virginia USA

RTP-Rehab™ Case Study

Replacing a Corroded Steel line with RTP piping System

Background:

An operator in West Virginia required the replacement of a steel pipeline used to transfer salt water to a disposal well. The line had corroded and had to be replaced. Specialty RTP piping was selected for its ease of installation and elimination of corrosion issues for the future. The pipe was rated for 1,000PSI and 140F maximum operating temperature

Benefits of the Specialty RTP System:

- Polymers inert to Saltwater eliminated the need to ongoing corrosion inhibitors
- Less Friction means less Pressure drop which means smaller diameters than steel (1.25" RTPvs 2" Steel)
- Light weight Easy Installation mean lower costs vs. steel 1,000 ft per hour in steep difficult terrain
- Light weight and Flexible mean 6 ft right of way
- Light weight low cost equipment

Installation:

RTP Pipe was pulled out with an ATV and with a total crew size of three persons

7,500ft run with one length of pipe on a spool.

Trenched after pipe is laid out to minimize right of way

Pictures

No Special Equipment for Unspooling

Light Weight for Easy Transport

Reference 16B

OTC-24721-MS

A Case Study Detailing the Design, Planning, Installation and Cost and Environmental Benefit Analysis of a Reinforced Thermoplastic Pipe Pulled Through the Inside of an Existing Offshore Steel Flow Line in the East Malaysia Samarang Field

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This paper was prepared for presentation at the Offshore Technology Conference Asia held in Kuala Lumpur, Malaysia, 25–28 March 2014.

Abstract

PL-112 pipeline is located approximately 52 kilometers offshore Labuan in the Samarang field Sabah Operation. The field experiences shallow water depths between 8 to 10 meters. The 6” pipeline was installed in 1977 utilizing API-5L X-42 grade of carbon steel with a 9.52mm wall thickness and a concrete coating of 25.4mm in thickness. The length of the pipeline was 0.97 km with five times diameter radius in the riser bends (5D Bend). The original design pressure for the pipeline was 1,440 psi for flow of oil, water/brine and gas multi-phase flow.

In 2009, an anchor dragging along the seabed had hooked onto the pipeline causing it to kink and a structural integrity breach of the pipeline occurred. Sectional pipeline replacement has been performed using misalignment flanges to expedite the rectification in order to continue the production. The misalignment flanges and the area adjacent to the repair made it difficult for the operator to perform their routine operational pigging. Furthermore the pipeline also experienced some wall loss at few locations and make it more costly to perform the maintenance and repair.

The project team determined that the current infield drilling and requirements for flexibility in flow delivery options required the line to be in operation for another twenty five (25) years, hence the pipeline replacement project has been initiated. Installation options including new carbon steel pipeline replacement were evaluated together with the installation of a reinforced thermoplastic pipe (“RTP”) pulled thru the inside the existing pipeline. Based on the evaluations, the utilization of RTP was selected as the most cost effective solution to rehabilitate the line to meet a long term integrity requirements. The focus of this paper is to analyze the sizing, installation and performance of the RTP which was implemented and a technical and commercial comparison between RTP and carbon steel pipeline was compared in the conclusions. RTP pipe was selected because:

- Utilized a polymer liner inert to the present flowing fluid environments as well as withstanding any potential future effect of Sulfide Reducing Bacteria (“SRB”s) generating H_2S.
- High strength yet flexible to pull through existing carbon steel of the pipeline without effecting the RTP performance.
- Minimize the equipment requirements because of light weight flexible continuous lengths
- Rapid Installation to minimize downtime and expenses.
- Multiple size options to minimize pressure drop while maintaining critical velocities to move solids and minimize future maintenance expenses.
- Minimal environmental disturbance to the marine life and sea floor.
- Lower CAPEX & OPEX hence improved total life-cycle cost by eliminating corrosion issue and maintenance.

Pipe Sizing Analysis

When evaluating the rehabilitation of existing pipelines, it is important to analyze the right size of the pipe for current and future operating requirements. Proper pipe sizing can minimize the ongoing maintenance by creating critical velocities to move solids with the liquid flow stream, thus preventing solids build up in the pipeline which requires additional operational pigging costs. This must be accomplished without introducing extra pressure drop which may affect the back pressure applied to the formation and potentially reducing production rates. One of the benefits of thermoplastics are their smooth extruded surface compared with carbon steel pipe which reduces flowing pressure drop for comparable diameters. References have shown steel to have a relative roughness of 0.002 in/in versus thermoplastic extruded relative roughness of 0.00005 in/in. This allows for smaller diameter RTP pipes to create critical minimum velocities to move solids while not creating excessive pressure drop.

In the case of PL-112, the average fluid production was comprised of oil and water and a typical flow rate was 1,800bbls/day. The line was used as a bypass line for other flow lines and the production volume could spike to 5,000bbl/day. The maximum inlet pressure is 180 psi to minimize any backpressure against the wells and the ideal pipeline exit pressure flowing into the separator is set at 100 psi. Figure 1 and Figure 2 below shows the impact of flow rate on of a 3.5” RTP Pipe (2.95” ID) compared with a 3.0” ID steel pipe.

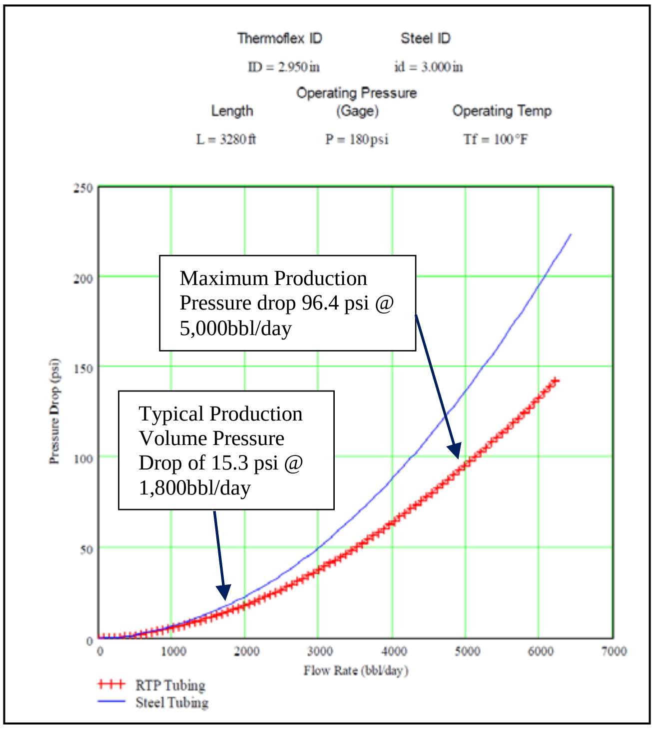

Figure 1: Impact of Flow Rate and Pressure Drop on RTP Pipe and Carbon Steel Pipeline

Refer to Figure 1, at 1,800bbl/day the pressure drop was modeled at 15.3 psi which is within the design parameters requested. However when flow is bypassed into the PL-112 line and reaches 5,000bbl/day of production the pressure drop increases to 96.4 psi which is slightly higher than the design parameters of 80 psi pressure drop. Before moving to a larger size pipe the product velocity was analyzed.

Refering to Figure 2, at 1,800 bbl/day, the flowing velocity is slightly above the minimum velocity the pipe manufacturer suggests for carrying solids in the flow stream which is 2ft/sec (0.61m/sec).

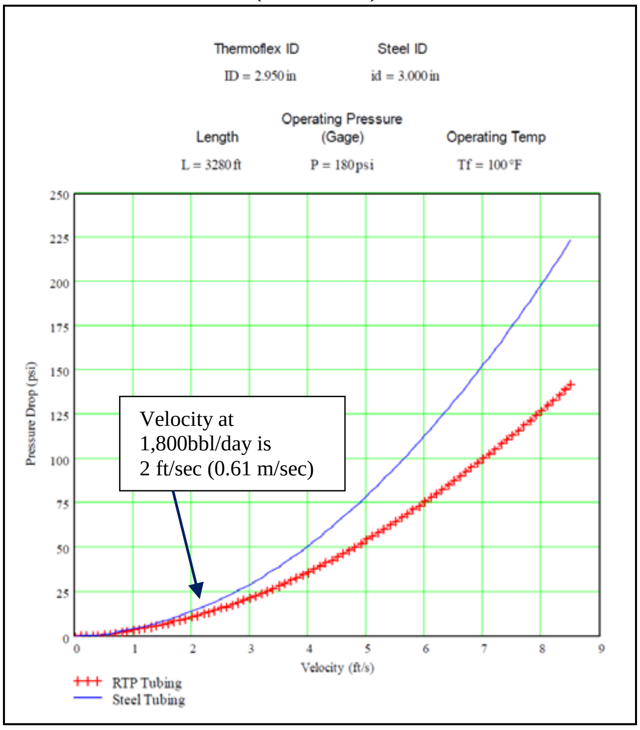

Figure 2: Flowing Velocity of Product

Sand is a potential issue with the flow line so maintaining minimum velocities to carry the sand in the flow stream will minimize future requirement for pigging the line to remove solids. Moving to a 4.5” RTP Pipe (3.83” ID) would decrease the minimum velocity at 1,800bbl/day to 1.3ft/sec (0.39m/sec). To optimise overall project expenditure, it was concluded to go with the 3.5” RTP pipe and operate with slightly higher pressure drops at maximum design flow rates which would only occur intermittently, but eliminate the need to clean solids from the pipeline on a ongoing basis.

Material Selection

The RTP pipe was constructed with internal layer of Fortron Polyphenylene Sulfide (PPS), reinforced with aramid fibers and jacketed with Nylon (refer to Figure 3)

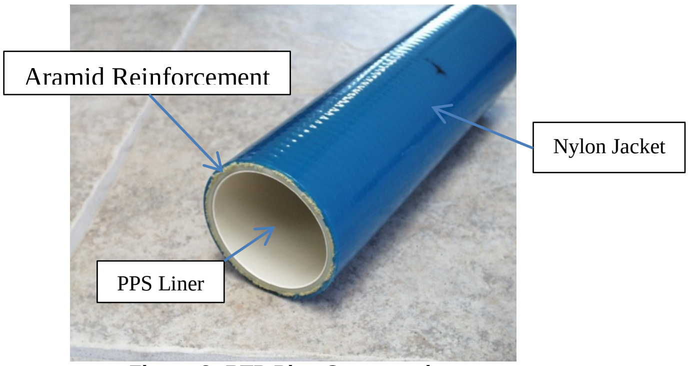

Figure 3: RTP Pipe Construction

The Fortron PPS was selected because of its resistance to hydrocarbons, Brine, CO_2 and H_2S as well as its extremely low rates of permeation of the compounds present in the flow stream. The Chemical compatibility acceptability was primarily based upon a chemical aging study contracted to an independent test lab in London, England that tested the PPS in the NORSOK M710 solution at elevated temperature to determine if there was any negative effect of the solution on the polymer. The composition of NORSOK M710 Solution is tabulated in Table 1.

Volume (%)	Composition
30	3% CO_2, 2% H_2S, 95% CH_4
10	Distilled water (conductivity < 5 µS)
60	70% heptane, 20% cyclohexane, 10% toluene

Table 1: Composition of NORSOK M710 Solution

Dog bone samples were aged in the above solution at various temperatures ranging from 140°C to 190°C to look at the change in weight, dimensions, physical strength and elongation. Results showed an immediate change in properties from dry as molded samples but then stabilization of properties occurred regardless of aging temperature. The Figure 4 below showing a sampling of the properties recorded. In this case, tensile strength as a function of aging time was recorded for various temperatures. For up to 170°C the properties stabilized after 20 days then remained relatively constant.

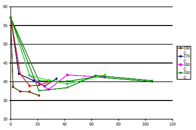

Figure 4: Tensile Strength of Fortron PPS (MPa) as a function of Ageing (Days) from 140-190C

Permeation through the liner does not necessarily damage the liner but rather can create operational issues such as build up gas pressure in the reinforcement layer creating issues with the outer jacket. In the case of the rehabilitation of a carbon steel pipeline, a build up of gas in the annulus between the RTP and the steel pipe can create non desirable issues. The Figure 5 is comparing various polymers permeation rates in CO_2 at various temperature to show a side by side comparisons. From the chart, it shows that polyethylene, a common polymer used in the oilfield has significant permeation rate compared to the other engineering plastics and Fortron (PPS) showed significantly lower levels of permeation.

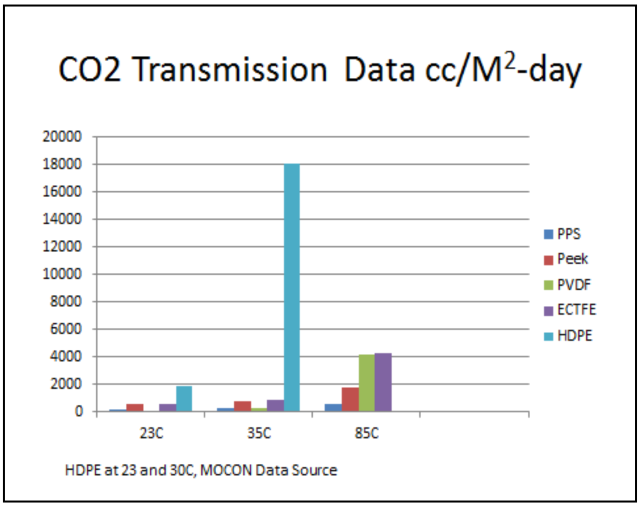

Figure 5: Comparison of CO_2 Permeation Rate for Polymer

Aramid fibers were selected as reinforcement because of its strength, cyclic/fatigue resistance and excellent fluid compatibility in hydrocarbons, brine, CO_2 and H_2S under 65°C. The jacket material selected was nylon because of its hydrocarbon resistance to potential residual oil in the existing steel pipeline and because of its excellent abrasion resistance.

Pre-planning of the Project

Some analysis were performed during the earlier stages of the project to ensure a sound project execution, which were the detail analysis of the existing pipeline, platform layout, topside piping configurations and equipment space available to perform the rehabilitation .

A sizing pig was run through the existing carbon steel pipeline to make sure the 3.5" RTP pipe can be pulled through the pipeline without any restrictions. A polyurethene (PU) coated foam pig with a 6" gauging plate was pushed through the pipeline to assure that there were no collapsed areas and the kinked area did not cause a restriction that would prevent a successful pull thru of the RTP pipe. The PL-112 showed acceptable openings to pull through the existing carbon steel pipelines.

Topside platform survey was performed to verify the riser dimensions, topside piping layouts, current equipment availability and platform deck space availability. This involved technicians traveling to both platforms at the termination of each side of the pipeline.

It was first verified that the current bends at the base of the risers were having a 6" 5D bend radius. This was not deemed acceptable for pulling through a 3.5" RTP pipe inside the existing 6" carbon steel pipeline. A 6" 12D bend radius is required to provide sufficient size of bend radius for the pull through (Refer to Figure 6). Even though a tighter radius could be implemented for the project, the generous 12D radius cost no more to fabricate and assured an easy pull through the existing pipeline.

Figure 6: Replacement of 20D Riser Bottom Bend to allow for smooth RTP Pull-thru

The existing risers had 6” ANSI 600 RTJ flanges. In order to seal off against the existing flanges and connect to the topside piping, a custom made double faced flanges were designed to allow the 3.5” RTP terminations to match with the 6” RTJ flange on the existing riser pipe and a 4” RTJ to match up to the topside piping. Dimensions were all measured to ease the preparation of drawings for fabrications and ease the development of work plan for the project (refer to Figure 15).

Lastly, the pulley layout and tie down points to locate the pulling rope over the riser opening was determined and sketched out for the work plan.

After the platform visit, all of the data was compiled into a detailed work procedure outlining the step by step procedures, a listing of equipment requirements, and fabrication drawings for all modifications for the surface equipment.

RTP Installation Process

The details discussion on the replacement of the riser bottom bends and repair of the kinked area have been excluded in this paper because they are standard conventional technologies requiring off the shelf components. The focus of the installation is from the point of conducting cleaning activities for the existing pipeline as integrity check by pushing a pig through the line with the proper bend radii in the elbows to accept the RTP piping.

The first step was to clean the existing line by running a scraping pig through the line. It was run in one direction three times and then run twice through the line in the opposite direction in order to knock out any rough or sharp areas that may have the potential to damage the pipe.

The next step was to insert the pulling rope through the line. A synthetic rope constructed from Technora aramid fiber and jacketed with a nylon cover was deployed because of its high strength, low weight and excellent creep resistance. The rated tensile load was 9,090kg to meet a minimum five (5) times safety factor over the maximum pull force required to pull the 3.5” RTP through the existing steel line. The lightweight rope required only 60 psi of pigging pressure to be pulled with a foam pig through the line, thus minimizing any potential damage to the existing carbon steel pipeline. The process of pulling the rope through the existing steel line requires a foam pig with an eyehook on the back end attached to a clevis which is attached to the eye of the rope. The pig is inserted into the pipeline. The rope is passed through a lubricator which is attached to the pig launcher to allow for a seal around the rope as water pressure moves the pig along the pipeline.

Figure 7: Retrievel of Foam Pig Attached with Pulling Rope

The largest change to the original work plan occurred because the crane on the pipe deployment platform was inoperable. The pipe was required to be pulled from a DP2 vessel over a temporary gooseneck constructed on the platform directly over the pipe. Figure 8 shows the temporary sheave scaffolding, and Figure 9 visualizes the pulling of pipe from the boat. A standard winch is used to pull the rope through the pipeline and designed to match with the tensile strength of the rope. A load cell to monitor the tensile load during pulling is set between the entry point into the riser and the winch.

Figure 8: Erecting Scaffolding and Sheave prior to Pull Thru

Figure 9: Pulling Process off the Vessel

Care must be taken during the pulling process to keep back tension against the reels of RTP pipe being unspooled and to avoid the pipe from creating an excessive loop between the riser pipe opening and the boat. This did occur once and kinked the RTP pipe creating the need to repair the kinked portion using splice coupling.

Each individual length of RTP pipe was approximately 300 meter in length requiring duplex 2205 jointless splice coupling to join pipes together. The splice couplings are comprised of a continuous length of stainless steel for an inner liner or insert with two outer ferrules that are swaged onto the pipe located between the insert and the ferrule. The result is a compression union of the two pipe ends together. When the end of a pipe on a reel is almost completed, the winch is stopped. The remaining pipe is removed from the spool and aligned into the coupling machine to swage one side of the splice coupling onto the pipe (See Figure 11). The starter end of the next length of pipe is pulled from the reel and put in line with the coupling machine and swaged onto the splice coupling already attached to the end of the previous length of pipe (See Figure 12). The winch is then activated to slowly pull the pipe into place (aligned with the gooseneck over the riser opening) and the pulling process continues. The winch pulling speed averaged 20 meters per minute.

Figure 10: Duplex Splice Coupling

Figure 11: Splice Coupling Tail of Pipe

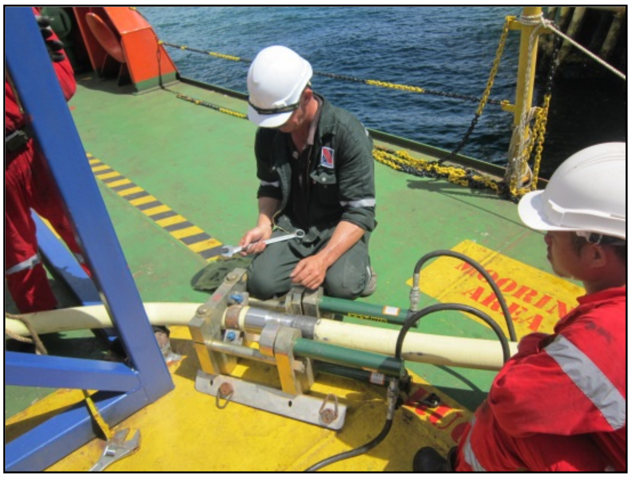

Figure 12: Splicing Lead End on Coupling

During the pulling process, the nylon jacket on the pulling rope was peeling off. It was assumed that the downhole flanges installed during the riser bottom bend modification had a sharp edge that “grabbed” the jacket and ripped it. The pulling process continued but the load cell was removed because the torn jacket was preventing the rope from passing through the load cell. The tension of the rope was then visually monitored to inspect for excess tension indicating a hang up. The exposed fiber in the synthetic rope were being damaged during the pull and eventually snapped approximately 1 meter from the end of the pull. The pulling cone was grabbed with a cable via fishing techniques and the pull was finally completed.

Figure 13: Final Pull Out of the Existing Pipeline

The RTP pipe was pulled approximately three (3) meters beyond the opening to the riser and inspected to see if there was any damage to the pipe. Since the external condition of the RTP was undamaged, it was concluded that the thinner jacket on the rope was wrinkling in the riser bend, getting caught on the sharp flange edge and tore away from the fibers..

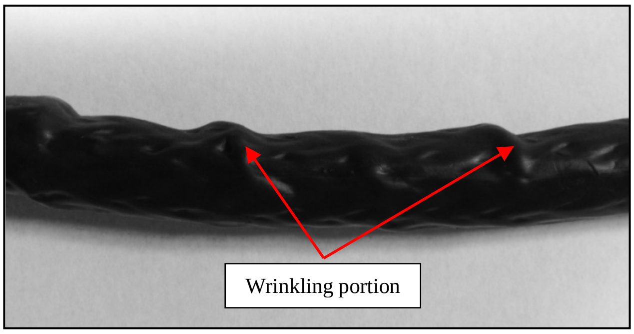

Figure 14: Wrinkling of Pulling Rope When Bent

After the post pull thru inspection, the pipe was cut back and a double faced RTJ ANSI 600# flanged termination coupling was installed to the end of the pipe. Sealing the RTP pipe inside of the steel assures that all above water RTP is encapsulated inside of the carbon steel for any fire concerns. Figure 15 details the flange connection.

Once the topside connections were installed, the new RTP line was hydro-tested for 24 hours at 360 psi. The current MAOP of the line is 180 psi. The pipe RTP needed approximately two (2) hours to stabilize before being hydro-tested for 24 hours.

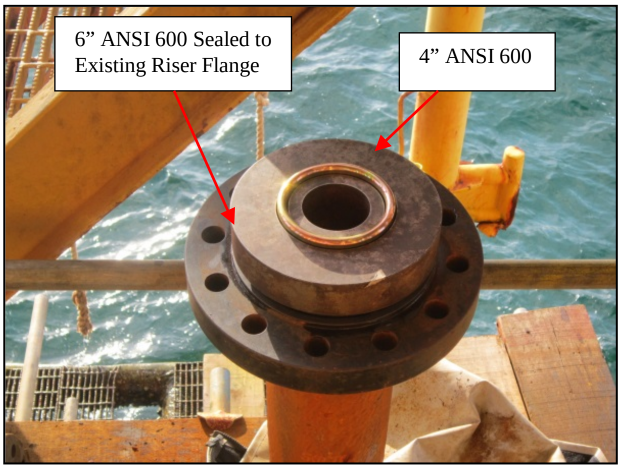

Figure 15: End Termination to Existing Riser

Figure 16: Hydrotest Pressure Chart

Results

The line has been operating for more than 13 months, flowing between 1,800bbl/day and 7,000bbl/day. It was noted by production that when operating at 7,000bbl/day, the pressure drop created back pressure against the formation choking production during these bypass flow periods.

There was no operational pigging and chemical treatment carried out on the line line since the line was put back in operation with the RTP pipe.

The total cost of installation, including riser modifications, vessel costs and installation, was 67% lower than the projected costs for a conventional installation of a carbon steel pipeline. The Figure 17 shows the percentage of installation and materials, the rework of the steel pipeline and vessel costs incurred, and the cost savings versus a new steel line.

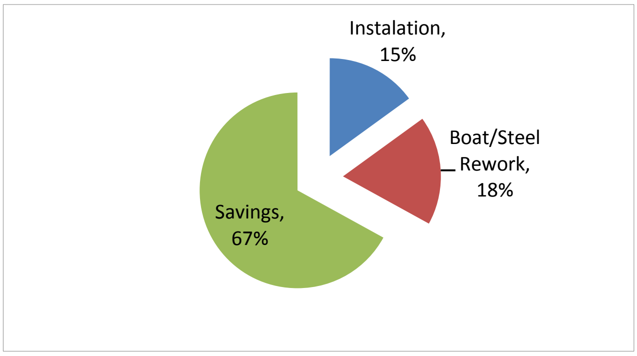

Figure 17: Distribution of Cost Savings (%)

If rework to the damaged pipeline from the anchor were not necessary, the risers had a suitable bend radius not requiring replacement, and both the pulling winch and pipe can be staged and installed from the platforms, then installation would be 15% of the cost of laying a new conventional steel line.

The total installation campaign for this project was 18 days which includes the removal and replacement of riser bottom bends and subsea kinked portion and Waiting on Weather (WOW) downtime. The installation of the RTP was three days.

Lessons Learned

It is extremely important to spend the time to analyze the pipeline, platforms and equipment prior to the project execution. During the project execution, it is being observed that improper lifting method of RTP spools during transportation had damaged the RTP since RTP prone to buckle/kink when it is not handled properly. Besides that, operational issues on the crane's malfunction at platform and unavailability of dedicated work boat for project team to assist equipment and personnel transfer also cause significant delays to the project. It is essential to inspect the existing lines using gauging pig for internal inspection and ROV for external inspection to know the current condition and configuration of the pipeline. A detail audit of the platforms ahead of time is essential to assure space to perform the work, equipment availability and capability and the location of the risers with piping details to develop a detailed work plan.

The existing rope protective jacket was too thin resulting in a stripping of the rope jacket during the pulling operation. For an improvement, after the completion of the project testing was performed on three (3) alternative jackets to protect the internal synthetic fibers. The first was a heavier polymer jacket that resists wrinkling at the minimum bend radius the rope will experience. The second option was an exterior fiber braid woven over the inner synthetic rope to provide abrasion resistance. The last option was a combination of a thicker polymer jacket with a braided fiber over the polymer jacket. (See Figures 18, 19 & 20)

Figure 18: Thicker Polymer Jacket Pulling Rope

Figure 19: Braided Jacket Pulling Rope

Figure 20: Polymer & Braided Jacket Pulling Rope

In all cases the rope was spooled on an 8" diameter spool with no wrinkling. Drag tests are still being conducted but initial results show excellent resistance to abrasion.

Conclusion

Overall, the pipeline rehabilitation using RTP installation was a success and incurred 67% less capital cost compared to an installation using conventional carbon steel pipeline. Proper planning and analysis of the pipeline to be rehabilitated shall be executed at earlier stage to ensure smoother installation process and better achievement to the project in term of schedule and expenditure. Spending a small amount of capital to inspect the condition of the existing pipeline prior to the project execution saves significant time and money during the execution. Besides that, detailed platform evaluation including piping configurations, deck space availability and equipment capability assures more reliable project plan and adherence to timelines.

BEFORE THE
RAILROAD COMMISSION OF TEXAS

APPLICATION OF JEFFERSON BLOCK 24 OIL AND GAS, LLC FOR WAIVER PURSUANT TO 49 CFR 192 AND RULE 8 OF THE TAC, TITLE 16, PART 1 FOR INSTALLATION OF REINFORCED THERMOPLASTIC PIPE FOR DELIVERING GAS NEEDED TO ACHIEVE A GAS LIFT PROCESS FOR PROLONGING THE LIFE OF A CERTAIN WELL WITHIN THEIR HIGH ISLAND BLOCK 24-L PRODUCING FIELD, LOCATED IN STATE WATERS, JEFFERSON COUNTY, TEXAS	§ § § § § § § § § § § § § §	**GAS UTILITIES DOCKET No. 9995**

FINAL ORDER

Notice of Open Meeting to consider this Order was duly posted with the Secretary of State within the time period provided by law pursuant to Tex. Gov't Code Ann. Chap 551, et seq. (Vernon 2004 & Supp. 2010). The Railroad Commission adopts the following findings of fact and conclusions of law and orders as follows:

FINDINGS OF FACT

1. On July 6, 2010, Jefferson Block 24 Oil & Gas, LLC (JB24) filed this application for a waiver of CFR 192.59 and 192.123 to allow JB24 to operate a single gas-lift/oil gathering line constructed using a concentric pipe configuration. The line will be constructed using an outer 4" pipe made of carbon steel and an inner 1 ¼" reinforced thermoplastic pipe (RTP).

2. Notice of the application was provided by certified mail, return receipt requested to all affected persons entitled to notice pursuant to Pipeline Safety Rule 8.125(e)(1).

3. Notice of the application was published in compliance with Pipeline Safety Rule 8.125(e)(2) in the *Beaumont Enterprise*.

4. No protests were filed in response to the notice of application.

5. On December 3, 2010, the Commission's Pipeline Safety Division, filed a memorandum recommending approval of JB24's waiver application.

6. High Island Block 24-L (HI-24) is a producing oil and gas field that was originally developed by Arco in the late 1960's and early 70's. Jefferson Block 24 Oil & Gas, LLC (JB24) acquired the field in 2007 and continues to develop the field.

7. The HI- 24 field is located in Jefferson County, in the Gulf of Mexico and in Texas State Waters. It is located approximately 16 miles southeast from the town of High Island, Texas. The field is comprised of 16 wellbores occupying five State Leases.

8. There are two primary production facilities, Platform A and Platform B. The wells are satellite "caisson" structures that flow to either platform through buried gathering, or flow lines. The "A" wells flow to Platform A and the "B" and "C" wells all flow to Platform B. Platform A is a manned, fully operational facility where all the produced fluids are treated and separated. Platform B serves as a collection and transfer point where the produced fluids are sent to Platform A. Once treated and separated, the liquids are transported back to Platform B through a 12" pipeline with high pressure gas where it is again separated, metered, and recombined for export sales. The combined fluid and gas stream is transported through an 8" Gas Pipeline to a subsea tie-in in High Island Block 33L with Transco Operations System No. 4.5.

9. Within the 720 acre State lease M-103389 the High Island 24 C-10s/t well was drilled and completed in July, 2008. It is a single-well caisson structure that flows to HI-24 Platform B facility via a 4" buried flow-line 5,915' in length.

10. A June 4, 2010, well test for High Island 24 C-10s/t well measured the latest production rates at 93.3 BOPD, 135 Mcfd, and 384 BWPD at 290 psi FTP. Estimated total production from the HD Sand, to date, is 71,400 Mcf gas, 100,700 barrels oil, and 75,400 barrels water. The well ceased flowing on June 30, 2010, and now needs artificial lift to continue producing.

11. JB24 proposes to install a concentric 1-1/4" Reinforced Thermoplastic Pipe (RTP) inside the existing carbon steel 4" flow-line that connects "C-10" well to Platform B, rather than install another pipeline to accommodate the gas needed for the gas lift process of well "C-10". This particular RTP is a three-component pipe comprising a thermoplastic liner, reinforcing layers, and a thermoplastic outer cover.

12. The RTP product that is to be used for the interior gas piping was chosen primarily because of the following:

- Its superior permeation resistance and corrosion resistance in the most severe of environments.
- The reinforcement is an interwoven polyaramid fiber, also known as Kevlar.

- It has extremely good fatigue properties and resistance to chemical attack and hydrolysis.
- The aramid fibers offer resistance to hydrocarbon degradation.
- The outer jacket is nylon which has better abrasion resistance than steel to remove the risk of damage to pipe during pull through installation.

13. JB24 intends to use ThermoflexR™ pipe manufactured by Polyflow, Inc.™ for the concentric line installation. The 1 ¼" ThermoflexR™ line pipe that will be used in this installation will have a high pressure rating of a minimum 1500 psi. This rating will be certified by the Bureau Veritas and be derived using the methods prescribed in Test Method D1598 and D1599. This is a 1000 hour hold test and short bursts. The Bureau Veritas certification representing the specific pipe used in this project will be provided prior to installation

14. The existing 4-inch flow-line from well C-10 was hydro-tested on August 17, 2008 to 2160 psi for eight hours. The gas injection line will operate at +/- 800 psi, with the pressure not to exceed 1000 psi. The proposed gas injection line will have a maximum inside diameter of 1.08" and will be compression-sealed into the existing flow-line pipe at either end with an integrated double-face "RTJ" bolted flange resulting in a designed installation with one piece construction to create a joint-less system between each terminus within the 4-inch flow-line.

15. The produced fluids (oil, water, and gas) of "C-10" would continue to return to Platform B through the annular space between the outside surface of the proposed 1-1/4" RTP line and the internal wall of the existing 4" flow-line, while the gas used in the gas lift process will utilize the newly installed RTP line pipe.

16. Periodic Integrity Management Program pressure testing will be done separately on both the steel and the interior RTP line at prescribed time intervals between tests. In the case of the RTP line, the RTP line will be pressured up to test pressure and held for the appropriate amount of time while monitoring the steel/RTP annulus for 0 pressure increase. The steel line will be tested by applying pressure and monitoring the RTP line for 0 pressure increase provided that test pressure of the steel line does not exceed the collapse pressure of the RTP line. If a test of the steel line is needed that exceeds the collapse of the RTP, adequate pressure to prevent collapse must be applied to the RTP and monitored during the testing of the steel pipe. In no case will the pressure applied to the steel line and RTP line be equal.

17. Additional continuous integrity assurance monitoring will be accomplished by adding a strainer in the concentric ThermoflexR™ pipe as it leaves the altered flow-line and before well C-10, and another strainer downstream of the altered flow-line at Platform B. These strainers will be examined at prescribed intervals as a means of monitoring the integrity of the concentric RTP pipe. If an excessive amount of thermoplastic pipe, nylon or aramid fiber is caught in either strainer, remedial action will then be taken.

18. A segment of exposed ThermoflexR™ as the line leaves the head of the newly modified flow line in route to the well will be installed in such a manner that it can be periodically blocked in and removed for physical examination to ensure that the line's integrity has not degraded during operation.

19. JB24 will provide certifications, or other documented proof all construction personnel involved during all phases of installation and inspection of the ThermoflexR™ pipe were trained in accordance with all necessary JB24 project and installation processes and procedures.

20. JB24 will provide documented records that a minimum of 50 feet of the ThermoflexR™ pipe pulled beyond its final destination for visual inspection. The records should indicate an examination was performed by a certified Polyflow™ technician for any possible damage that may have occurred during the pulling and pushing of the ThermoflexR™ through the 4" flow-line. If any compromising damage had occurred during the pulling process, the records should indicate the cause of damage, and how it was addressed to the satisfaction of all onsite personnel including representatives of ThermoflexR™/Polyflow™ ensuring that its future operation is not in any way compromised.

21. JB24 will pressure test the final installation in accordance with CFR 49 Part 192 Subpart "J" (more specifically §§192.505 and 192.619(a)(2)(ii)),while monitoring and periodically documenting pressures and temperatures during the pressure test.

22. Before this gas lift system installation is put into operation written operations and maintenance process and procedure pertinent to the operation and maintenance of the concentric ThermoflexR™ pipe installation will be provided for approval by Railroad Commission personnel.

23. At a minimum, the above mentioned written process and procedure will be added to JB24's existing operation and maintenance manual that will specify all necessary time intervals mentioned in these findings of fact

24. Before any modifications or work toward this request can begin TRRC personnel will need to provide approval, and this approval will not come before Pipeline Hazardous Materials Safety Administration (PHMSA) has had ample time to review and declare no objections.

CONCLUSIONS OF LAW

1. The Commission has original jurisdiction to consider Applicant's application pursuant to TEX. UTIL. CODE ANN. §121.201 and 49 U.S.C. §60105.

2. Proper legal notice was timely given to all persons and entities entitled to notice under applicable statutes and rules.

3. All things have occurred and have been accomplished to give the Commission jurisdiction in this case. The Commission has jurisdiction under statutes and rules, including 49 CFR 192.53, 55, 105, 107, 109, 111, 113, 221, 455, 503(b) and 619, to authorize the requested special permit and use of pipe not manufactured in accordance with a listed specification in those rules.

4. Applicant is required to comply with all other minimum safety standards set forth in 49 C.F.R. Part 192 as they apply to normal operation and maintenance.

5. The application for this special permit was not filed to avoid the expense of safety compliance, or to correct an existing violation.

6. Granting the requested special permit is not inconsistent with pipeline safety.

Therefore, **IT IS ORDERED** by the Railroad Commission of Texas that the application of Jefferson Block 24 Oil and Gas, LLC, for a waiver pursuant to 49 CFR 192 for installation of " ThermoflexR " pipe for use in their Gas Lift Process, located in Texas Waters, Jefferson County, Texas be **GRANTED ONLY** as to the insertion of the 1-1/4-inch ThermoflexR liner into the existing 4-inch flow-line at the location specified subject to the special provisions outlined below. No further waivers for installation within any system or pipeline are granted.

IT IS FURTHER ORDERED that JB24 is required to submit annual reports to the Commission regarding any leaks or problems associated with the operation of this pipeline. Should any unforeseen problems occur, the Commission may request the removal and/or replacement of the approved Reinforced Thermoplastic Pipe.

IT IS FURTHER ORDERED that JB24 is required to prepare a process and procedure for operation, maintenance and integrity management assurance of the concentric ThermoflexR™ pipe installed for this gas lift process.

All requested findings of fact and conclusions of law which are not expressly adopted herein are denied. All pending motions and requests for relief not previously granted or granted herein are denied.

UPON THE PASSAGE of sixty (60) days from the date this order is signed and no objection from the Secretary of Transportation having been received as provided for in 49

U.S.C. §60118(c)(1), this order shall become final and effective. However, no work is to be preformed towards this waiver without approval from the Railroad Commission's Pipeline Safety Division.

SIGNED this 8th day of February, 2011.

RAILROAD COMMISSION OF TEXAS

CHAIRMAN ELIZABETH A. JONES

COMMISSIONER MICHAEL L. WILLIAMS

COMMISSIONER DAVID PORTER

ATTEST:

SECRETARY

INSTALLATION PROCEDURE

Upon your approval of this proposal, a detailed prognosis containing technical information and step-by-step installation procedure will be provided for your review. See Appendix 4 for sketches of our proposed operation. Briefly, the process is as follows:

1) Mobilize equipment to location via liftboat. Perform site surveys @ "B" and "C-10" structures. Hold safety meetings, including a review of the entire operation and specific JSA's.
2) Thermoflex spool and fluid tanks will be placed on "B". Fluid pump, pulling unit (winch), and pigging equipment will remain on the liftboat, which will travel to C-10.
3) Flush the 4" line with seawater, displacing the fluid in the line to "A" for treatment.
4) Hydro-Test 4" line to 2000 psi. (Note: Line was last tested to 2160 psi in August 2008).
5) Pig the 4" line from C-10 to "B". The last pig will be attached to a rope, connected to the pulling cable.
6) Modify the ends of each riser to accept the flanges for termination of the Thermoflex line.
7) Connect the Thermoflex (spooled @ "B") to the pulling cable. Begin pulling the line from "B" to C-10.
8) Install termination connections and flanges on each end of the line(s).
9) Flange up and test the lines. Prepare for production.


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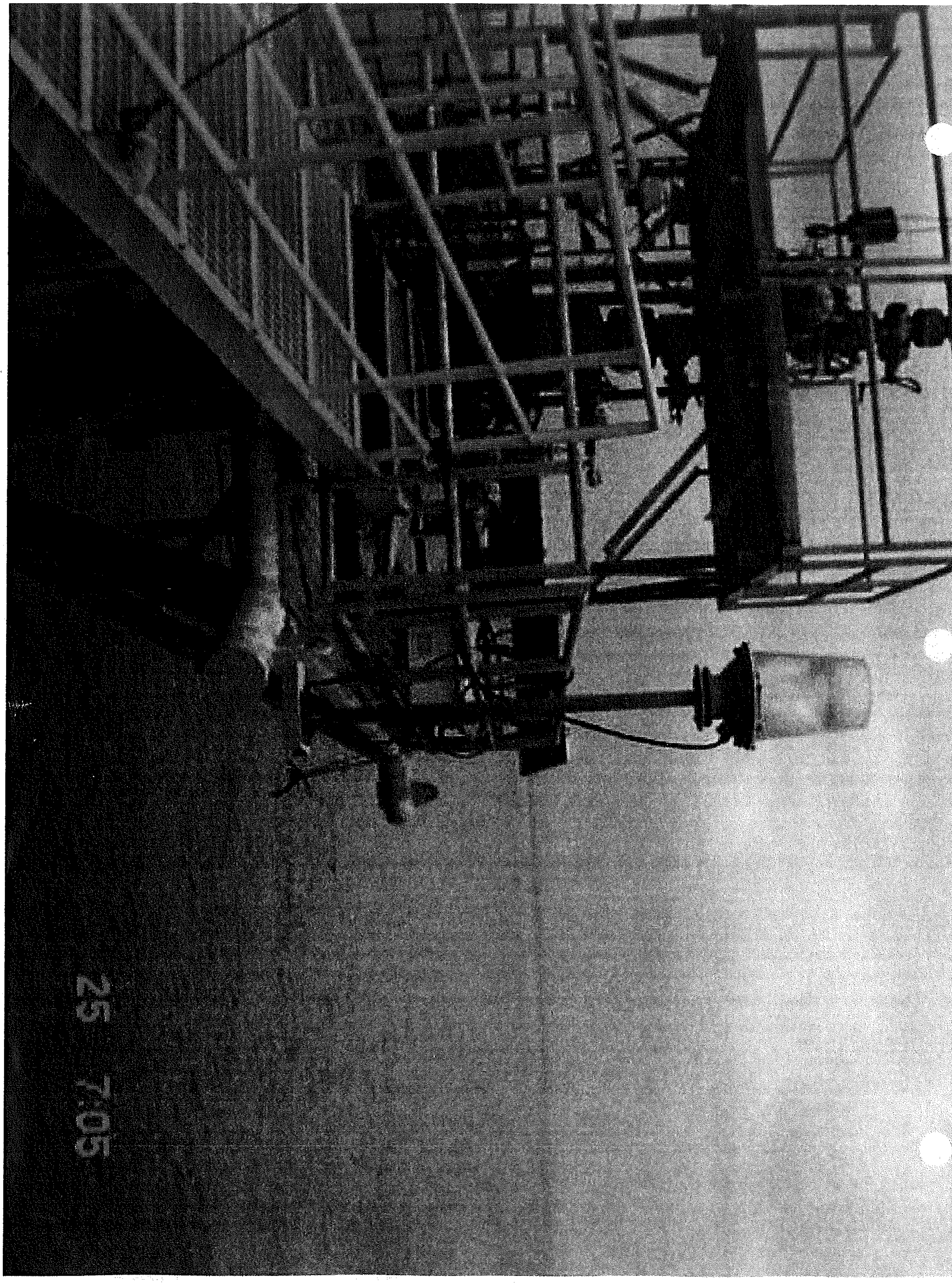
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Reference 18

U.S. Department
of Transportation

**Pipeline and Hazardous
Materials Safety
Administration**

1200 New Jersey Avenue, SE
Washington, D.C. 20590

AUG 2 1 2015

The Honorable Twinkle Andress Cavanaugh
President, Alabama Public Service Commission
P. O. Box 304260
Montgomery, Alabama 36130-4260

PHMSA-2015-0153

Dear President Cavanaugh:

On June 22, 2015, the Pipeline and Hazardous Materials Safety Administration (PHMSA), received your letter dated June 9, 2015, notifying us that the Alabama Public Service Commission (Commission) is granting a waiver to ExxonMobil US Production Company ("ExxonMobil"), to allow for the use of 3-inch Specialty RTP, LLC Reinforced Thermoplastic Pipe (RTP) to rehabilitate two abandoned 6-inch carbon steel pipelines. This RTP will be used to transport both natural gas and "produced liquids" between two platforms (77B and 76 Aux) in Mobile Bay, Alabama. The natural gas segment is under the jurisdiction of the Commission while the "produced liquids" is not jurisdictional to the Commission. The distance between the two platforms is 9,187 feet (1.74 miles) and traverses the Mobile Bay Entrance Channel. This waiver has been requested from 49 CFR §§192.53, 192.59 and 192.123, since the RTP is not currently recognized in 49 CFR Part 192.

ExxonMobil submitted an application to the Commission to repair the existing pipelines which were in service until 2014 when leaks were identified on each. At that time, ExxonMobil "shut-in" both lines. Prior to that time, in an attempt to mitigate corrosion, both pipelines had cathodic protection. The proposal requests the use of the RTP by means of a "pull-back" of the RTP through the existing 6-inch pipelines. Following installation of the fuel gas pipelines the RTP will operate between 300-400 psi. The RTP is designed to allow for a Maximum Allowable Operating Pressure of 1,600 psi if needed.

The Commission's grant of the waiver is conditioned on ExxonMobil's compliance with seventeen specific requirements listed in your letter. Based on these conditions, PHMSA does not object to the waiver for the specified line. However, PHMSA recommend modifications to language in Conditions 10 and 16 as described below.

Condition 10 currently reads:

> "ExxonMobil must follow its existing **Integrity Management Program Practices**, modifying as needed, for the special permit section, to detect and manage leaks. **The Integrity Management Program (IMP)** must also include **a plan that allows for** inspection of the pipe at appropriate intervals to insure there have been no adverse effects

to the pipe's integrity (and its composite layers) that may have occurred through operation of the pipe."

There are some that may confuse the term "Integrity Management Program" with Gas Transmission Integrity Management in Subpart O, or even Distribution Integrity Management in Subpart P. Neither of these subparts applies to the system subject to the State waiver and considered to be onshore gas gathering. PHMSA proposes this condition be revised to read:

(New) Condition 10:

"ExxonMobil must follow its existing ***plans and procedures applicable to gathering lines****, modifying as needed, for the waiver, to detect and manage leaks. The* ***plans and procedure****s must also include* ***provisions that address*** *inspection of the pipe at appropriate intervals to ensure there have been no adverse effects to the pipe's integrity (and its composite layers) that may have occurred through operation of the pipe."*

Condition 16 currently reads:

"These two pipelines will traverse the entire width of the Mobile Bay Entrance Channel. This will require frequent monitoring by ExxonMobil to eliminate any potential problems that might arise. This will include daily patrolling, and a leakage survey for the first week after installation is complete, followed by quarterly patrols thereafter. If any discharge is found relating to either of the two RTP-inserted pipelines, flow will be terminated immediately and the RTP **will no longer be authorized by this Commission for use in either pipeline**."

Through additional discussion with the Commission staff, there were concerns that the wording at the end of the last sentence might be too harsh and did not include options for additional testing and return to service with similar RTP pipe, particularly in cases where the discharge (i.e. product release) is relatively minor. At the same time, if the product release is significant additional remedial measures may be needed up to and including replacement with pipe currently approved by 49 CFR Part 192 (as mentioned in Condition 15). Below is suggested wording for Condition 16. PHMSA agrees that the pipe should be sent out for testing, but also leaves it up to the operator and State to discuss and agree on the appropriate measures for return to service of the pipe, depending on the nature of the failure and impact of the release. PHMSA proposes that this condition be revised to read:

(New) Condition 16:

"These two pipelines will traverse the entire width of the Mobile Bay Entrance Channel. This will require frequent monitoring by ExxonMobil to eliminate any potential problems that might arise. This will include daily patrolling and a leakage survey for the first week after installation is complete, followed by quarterly patrols thereafter. If any discharge (i.e. product release) is found relating to either of the two RTP-inserted pipelines, flow will be terminated immediately and the RTP **will be removed or abandoned in place if damaged beyond reasonable repair. If removed, the section of RTP that contains**

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the failure will be sent to an independent laboratory for testing/inspection to determine the exact cause of failure and the results will be reported back to the Commission. The operator and State will discuss options for return to service based on the nature of the failure and results from the independent laboratory testing. Options may include replacement of the affected section of RTP."

If the Commission includes all of the above measures to ExxonMobil, then there is no need for the Commission to resubmit the waiver request for PHMSA's review, but is requested to send a copy of the revised ExxonMobil waiver to PHMSA after the final decision.

If you wish to discuss this special permit or any other pipeline safety matter, my staff would be pleased to assist you. Please call Mr. John Gale, Director of Regulations, at 202-366-0434, for regulatory matters or Mr. Kenneth Lee, Director of Engineering and Research at 202-366-2694, for technical matters.

Sincerely,

for: Jeffrey D. Wiese
Associate Administrator for Pipeline Safety