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The Draugen water injection flexibles

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Extrusion resistance of High Density Polyethylene pressure sheath in a Water Injection Flexible

by

F.A.H. Janssen

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Summary

In 2005 the Northern Water Injection Template line, a smooth bore flexible, failed. The failure was the result of a leak in the High Density Polyethylene pressure sheath caused by excessive extrusion of the HDPE into a gap created by unlocked pressure armour wires. The use of produced water, that increased the operating temperature of the injection water, most likely accelerated to occurrence of the failure. This because of the temperature dependency of the material properties of the thermoplastic HDPE.

Norske Shell considered using the SWIT line for produced water re-injection but could not exclude the presence of unlocked armour wires in this line.

To asses the potential of a failure, Shell Global Solutions was contracted to predict the time to leakage of an unsupported section in the High Density Polyethylene pressure sheath as a function of temperature and gap size at a pressure of 150 bar.

Experiments showed that an increase in temperature would increase the penetration depth and rate of the HDPE liner into a gap, therefore increasing the potential of a failure. Due to the complexity of the flexible structure and the unknown actual situation a quantitative prediction is not possible.

Continuous operation at low temperatures (< 35 °C) and preventing regular pressure drops are no guarantee for preventing a failure but will delay the occurrence of the failure compared to higher temperature operation (> 60 °C) and regular pressure fluctuations.

Amsterdam, February 2007

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1. Introduction

Shell Global Solutions was contracted by Norske Shell to predict the time to leakage of an unsupported section in the High Density Polyethylene pressure sheath of a water injection flexible as a function of temperature and gap size at a pressure of 150 bar.

2. Background

The Draugen topside facilities and the injection templates i.e. Northern and Southern Water Injection Templates (NWIT and SWIT) are connected by 10” flexible flow lines. Both are smooth bore flexibles manufactured by Coflexip and installed 1993. The build-up of these 10” ID water injection flowlines are illustrated in Figure.8 and is as follows:

- Pressure sheath (High Density Polyethylene).
- Pressure armour wires (FM35 Carbon steel), also often denoted as Zeta wires.
- Anti-collapse or intermediate plastic sheath (High Density Polyethylene).
- Tensile armour wires (FM35 Carbon steel).
- Adhesive tape.
- External plastic sheath (High Density Polyethylene).

To accommodate the increasing water production, re-injecting the produced water was seen as the most favourable option. Reservoir pressure had been maintained by the injection of treated seawater into the NWIT and SWIT injection wells. Further details on the Draugen injection water system can be found in [1] and [2].

A pilot study for produced water re-injection was underway when on the 10 July 2005 the NWIT line failed. The cause of failure was identified as being due to zeta armour wires unlocking and consequent lack of support for the polyethylene liner - over a period of 12 years, the pressure in the pipe forced the small area of unsupported polymer thru' the gap in the zeta layer until it was unable to support the pressure and failed (in shear). Once the liner was holed; high pressure water passed thru' the zeta layer and the pipe failed due to the tensile armour wires being overstressed.

The temperature at the top of the riser was 37 °C before Produced Water Re-injection and 60 - 65 °C during PWRI. The estimated temperature at the failure location was 55 °C at the time of failure c.f. 27 °C for the 11+ years prior to the failure.

The SWIT line is in operation as a water injector but it is considered to use this line as a means of re-injecting produced water.

After the NWIT failure the MAOP of the SWIT line was reduced to 150 barg. This load produces a combined stress in the tensile wires just below the UTS value when the loads taken by the zeta layer are combined with tensile loads and are applied to the armour layer - the logic is that if there has been another zeta unlocking occurrence in the SWIT line similar to the NWIT line and the annulus is flooded with high pressure water, the armour wires will carry the load without failure.

When re-injection of produced water will start, the fluid temperature will increase most likely to the same extent as in the NWIT case. Since the properties of the thermoplastic polymer HDPE are temperature dependent and typically decrease with increasing temperature, Norske Shell was concerned that the expected temperature increase could initiate or accelerate a failure of the HDPE liner as a result of extrusion through the opening between the unlocked zeta armour wires and therefore initiated this study to potentially quantify this probability.

3. Test set-up and procedure

A purpose made test set-up, previously build to determine the extrusion resistance of PVDF pressure sheath material into a flexible Zeta Wire arrangement [3], was used for the experiments.

Variables of the test set-up are:

1. Temperature
2. Pressure
3. Fluid
4. Gap width
5. Gap length
6. Gap edge radius
7. Gap height

HDPE material of the failed Draugen NWIT with a thickness of 7 mm, undamaged sections, still on storage in Amsterdam was used as material for the tests.

For the Draugen WI injection investigation the following settings were agreed based on a discussion between Norske Shell and Shell Global Solutions.

1. Temperature 30, 40, 50, 60 & 65 °C
2. Pressure, 150 bar
3. Fluid, Water
4. Gap width, initial tests 5 mm later reduced to 4 mm.
5. Length limited by test set-up to approx. 30 mm
6. Gap edge radius based on Zeta wire radius 1.2 mm
7. Gap height, initial tests 4mm later increase to 7 mm.

Note: The Gap height was first based on the available space above the gap between two Zeta wires, see Figures 1 and 2.

Each test was run for 20 hours.

Following tests were performed:

30 °C, gap width 5 mm, gap height 4 mm.
40 °C, gap width 5 mm, gap height 4 mm.
30 °C, gap width 4 mm, gap height 7 mm.
40 °C, gap width 4 mm, gap height 7 mm.
50 °C, gap width 4 mm, gap height 7 mm.
60 °C, gap width 4 mm, gap height 7 mm.
65 °C, gap width 4 mm, gap height 7 mm.

4. Results

The first two tests i.e. at 30 °C and 40 °C using a gap width of 5 mm and a gap height of 4 mm, based on the available space above the gap between two Zeta wires, resulted in an initial deformation of the HDPE that almost immediately filled the complete free gap volume, extrusion could no occur. Therefore the gap width was reduced to 4 mm and the height increased to 7 mm.

The displacement into the gap having a width of 4 mm and a height of 7 mm versus time at 30, 40, 50, 60 and 65 °C can be found in Figure 3.

5. Discussion of the results

The extrusion of the HDPE into the gap is a two-step process, first initial deformation followed by visco elastic flow.

5.1 Initial deformation

Application of the 150 Bar test pressure results in all tests in a high initial deformation. This deformation is almost enough to fill the total gap of unlocked zeta wires. The initial deformation seems predominantly the result of the compression of the liner against the Zeta wires. For a gap with a small width the displacement of the unsupported section into the gap would than be approximately be the same as this compression. Based on this hypothesis this initial deformation (compression) can be estimated using Hook's law:

$$\varepsilon = \frac{P}{E} \qquad (1)$$

in which:
ε = strain
P = pressure [Mpa]
E = Young's modulus [Mpa]

Since the stiffness of HDPE, like most polymers, is temperature dependent i.e. decreases with increasing temperature, this explains the increased deformation at higher temperature.

Table 1 *HDPE Young's modulus (5 % secant) against temperature*

Temperature [°C]	**Modulus [Mpa]**
30	238
45	215
60	150

Source, Reference [4]

Based on the data in Table 1 the initial deformation at 60 °C should approx. be more than two times higher than that at 30 °C.

The fact that the test specimens were produced from the ex- NWIT liner, having surface irregularities, without any further surface preparation is most likely the cause that the measured initial deformations do not always comply with this expected behaviour i.e. the higher the temperature the larger the initial displacement.

5.2 Visco-elastic flow

After the initial deformation the HDPE material starts to flow in the gap, see Figure 3.

In Figure 4 the displacement between 1hour and 20 hours is plotted as a function of temperature which shows, as expected, that this displacement is temperature dependent i.e. is larger at higher temperatures.

The displacement versus log time curves (Figure 3) further shows that the displacement versus time function is not a typical creep curve for a thermoplastic polymer like HDPE. The difference with a typical creep curve is that the displacement per decade of time is not constant. The displacement per decade of time is decreasing. Figure 7 further shows that in the later decades the effect of temperature is more or less disappearing, displacement rates become more or less the same.

Comparing the curves, example 65 °C, Figure 5 with a typical creep curve Figure 6, as given in literature leads to the same conclusion. The most logical reason is the expected increase in wall friction in the gap with increasing displacement into the slot. As a general trend higher temperatures result in larger displacements but the larger wall friction reduces the displacement rate.

5.3 Translation to the actual situation

Since polymer flow and friction counteract, the temperature effect on the extrusion of HDPE through the unlocked Zeta wires is less straightforward than initially expected.
Figure 2 shows that the actual situation in the flexible is even more complex.

The HDPE liner material will extrude into the gap of the unlocked Zeta wire and most likely fill the available space within a short period of time. The extrusion then continues in the narrow gap between the unlocked Zetas. Whether this extrusion will lead to failure, or which extend of extrusion will lead to failure is unknown. Prediction of the failure time is therefore not feasible.

It should also be taken into account that when the pressure is reduced a lot of the HDPE liner material most likely flows back. To illustrate, samples removed from the tests hardly showed any remaining deformation despite the measured extrusion of up to 6 mm.

Fatigue effects could occur as well. The potential presence of broken zeta wires and the capability of the HDPE pushing zeta wires apart [2] complicates the issue even further. Rough edges on the broken wires could cause additional damage to the HDPE liner.

Therefore a quantitative prediction of the potential reduction in time of a liner break due to HDPE extrusion as result of an increase in operating temperature to 65 °C instead of 30 °C is on the basis of the current tests results alone not feasible. Qualitative can only be said that the potential for a breakthrough increases with increasing temperature since the HDPE will penetrate deeper and faster.

5.4 Alternative investigation

An in potential more accurate prediction can only be done in a simulated service (situation) test simulating worst case broken wires etc. However even such a test this will be highly speculative since the actual situation is not known in great detail. Revisiting the failed section of the NWIT could potentially provide further details about the actual situation.

The same applies for performing Finite Element Analysis since again the question is what exactly to simulate. Additional complication with FEA is most likely that not al required data; visco elastic behaviour of the HDPE will be readily available.

6. Conclusions

An increase in temperature will increase the penetration depth and rate of the HDPE liner into Zeta wire gaps, therefore increasing the potential of a failure. Due to the complexity of the flexible structure and the unknown actual situation a quantitative prediction is not possible.

Continuous operation at low temperatures (< 35 °C) and preventing regular pressure drops are no guarantee for preventing a failure but will delay the occurrence of the failure compared to higher temperature operation (> 60 °C) and regular pressure fluctuations.

7. References

1. Stenger, C.G. et al.: OP.00.20526 Investigation into the cause of failure of the Draugen North Water injection Template line, Shell Global Solutions, Amsterdam (November 2000).
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3. MERL Joint Industry Project, Evaluation of Polymers for high temperature flexible pipes, local analysis report, May 1999.
4. Janssen, F.A.: OP.98.20598 Liners for crude oil service The influence of crude oil, water exposure and temperature on the stiffness of polyethylene, Shell Global Solutions, Amsterdam (November 1998).

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Figure 1
Cross section drawing of Pressure Armour. Pressure Armour Gap size varies from 1 to 4 mm, Fillet radius varies from 0.6 – 2 mm

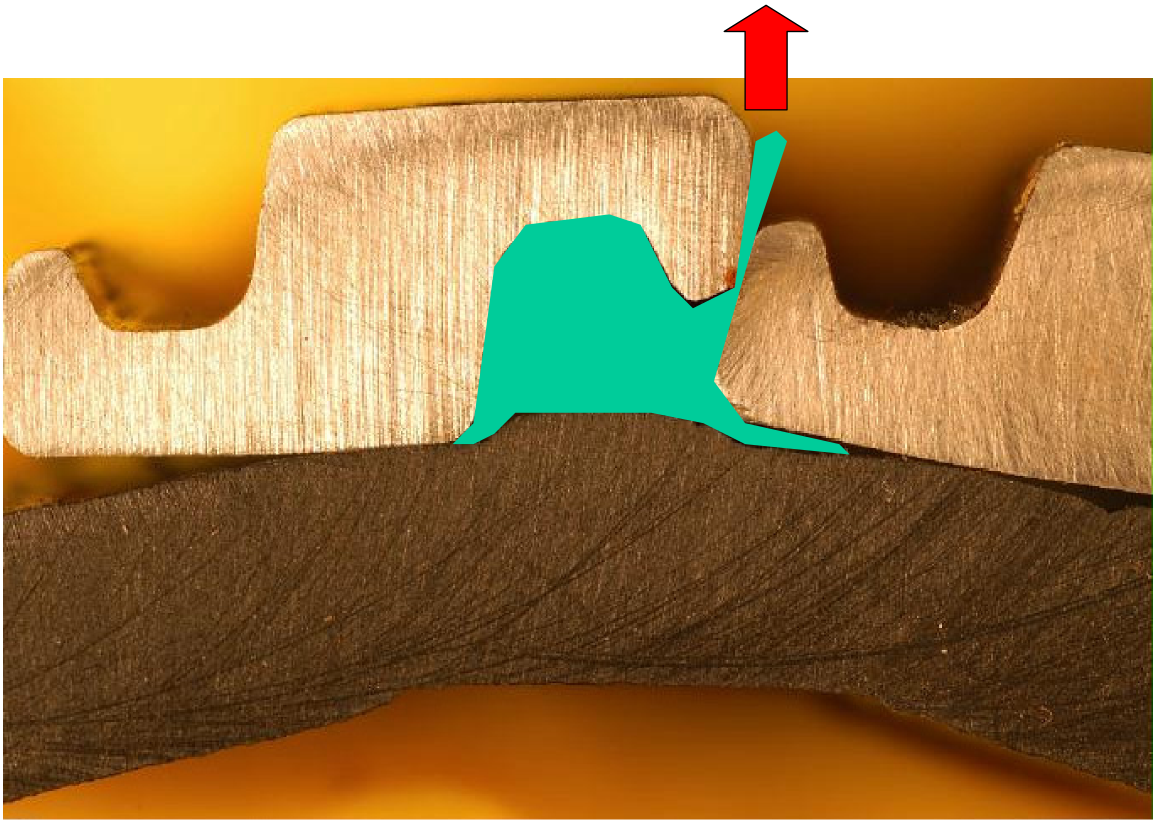

Figure 2
Photograph of unlocked section, in green anticipated direction of HDPE extrusion

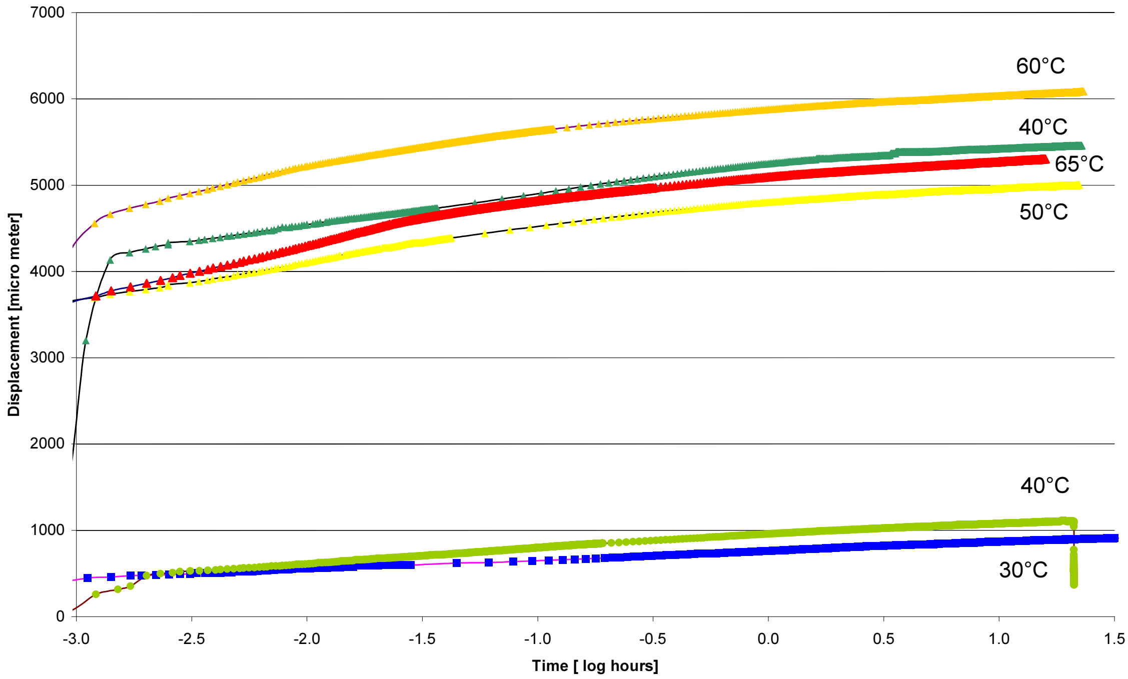

Figure 3 *Displacement into 4 mm wide gap versus time at 30, 40, 50, 60 and 65 °C*

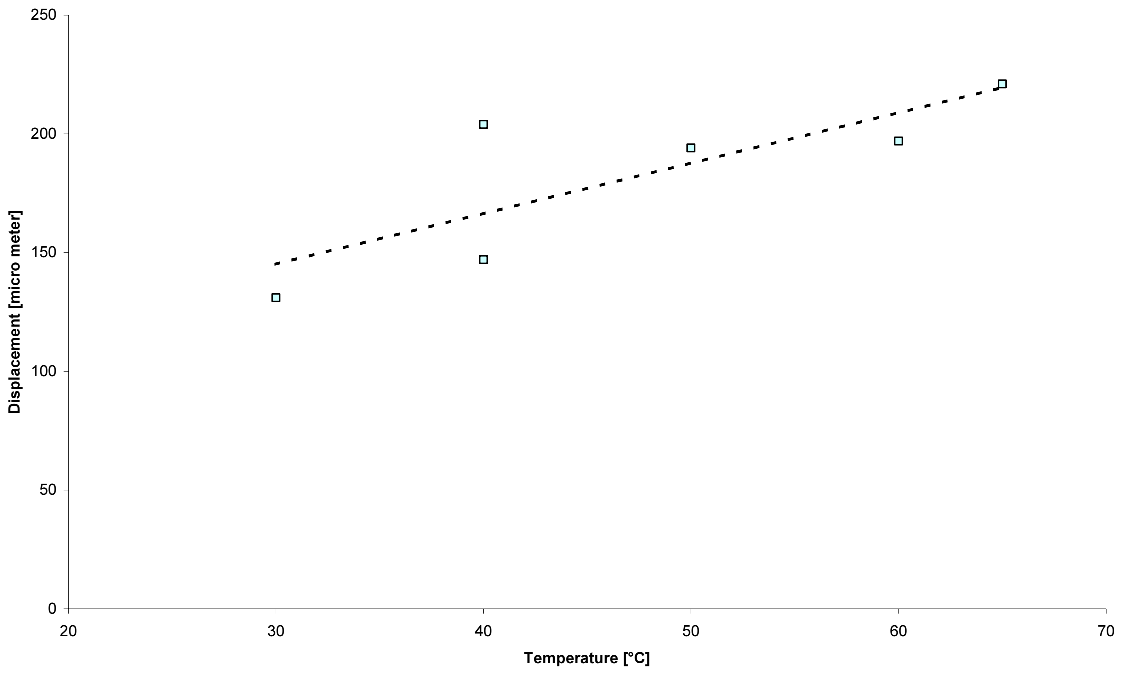

Figure 4
Displacement in 19 hours (1hour to 20 hours) as a function of temperature
Gap width 4 mm

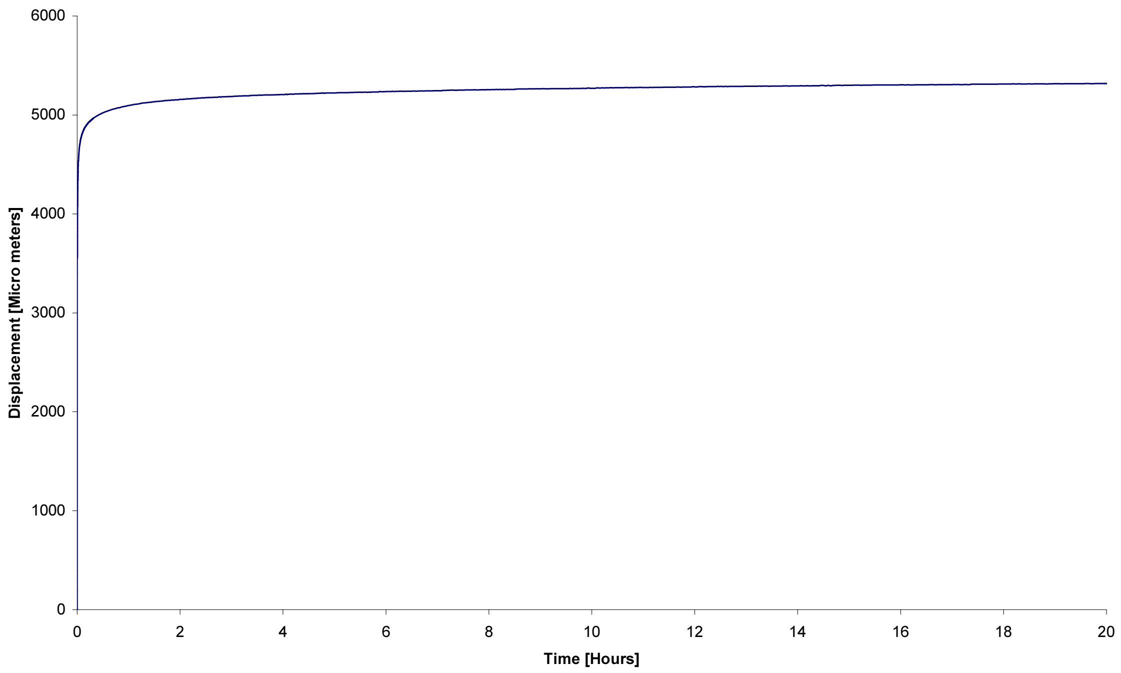

Figure 5 *Displacement of versus time 65 °C. Gap width 4 mm*

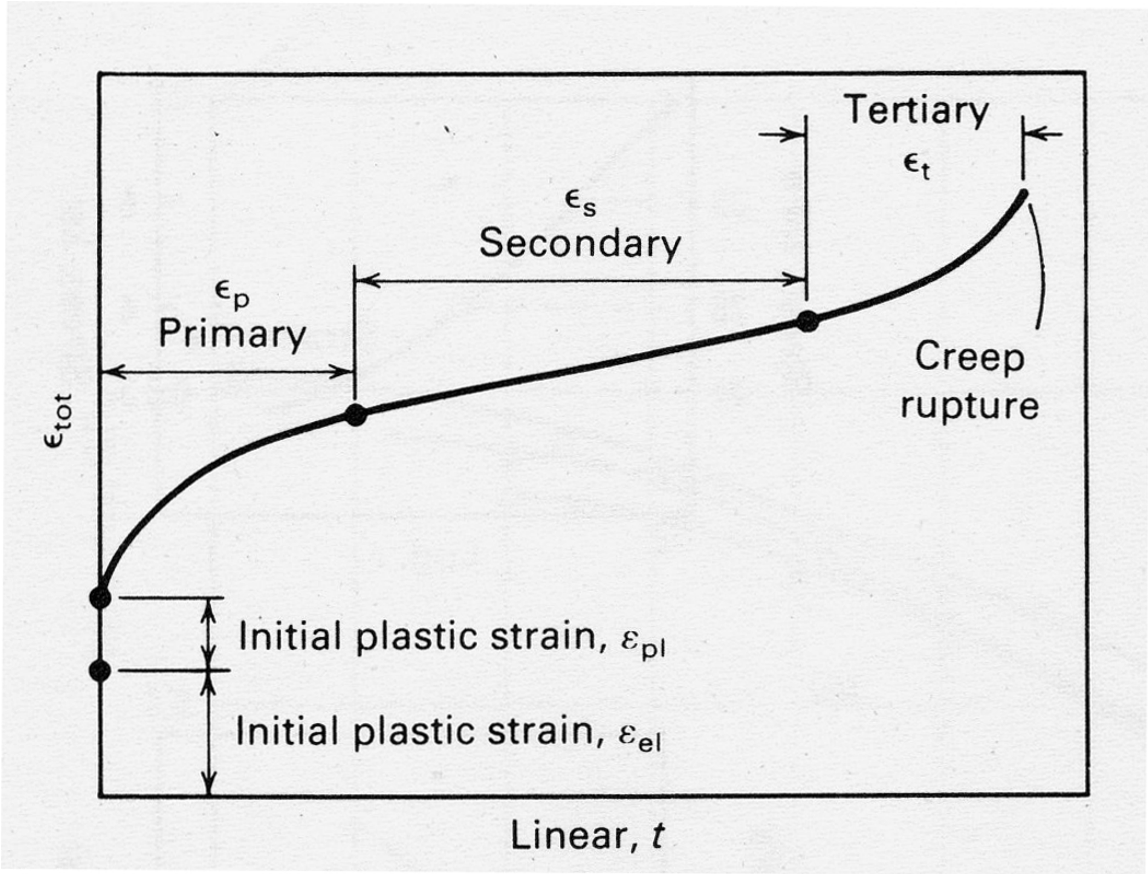

Figure 6 *Typical creep curve for Thermoplastics*

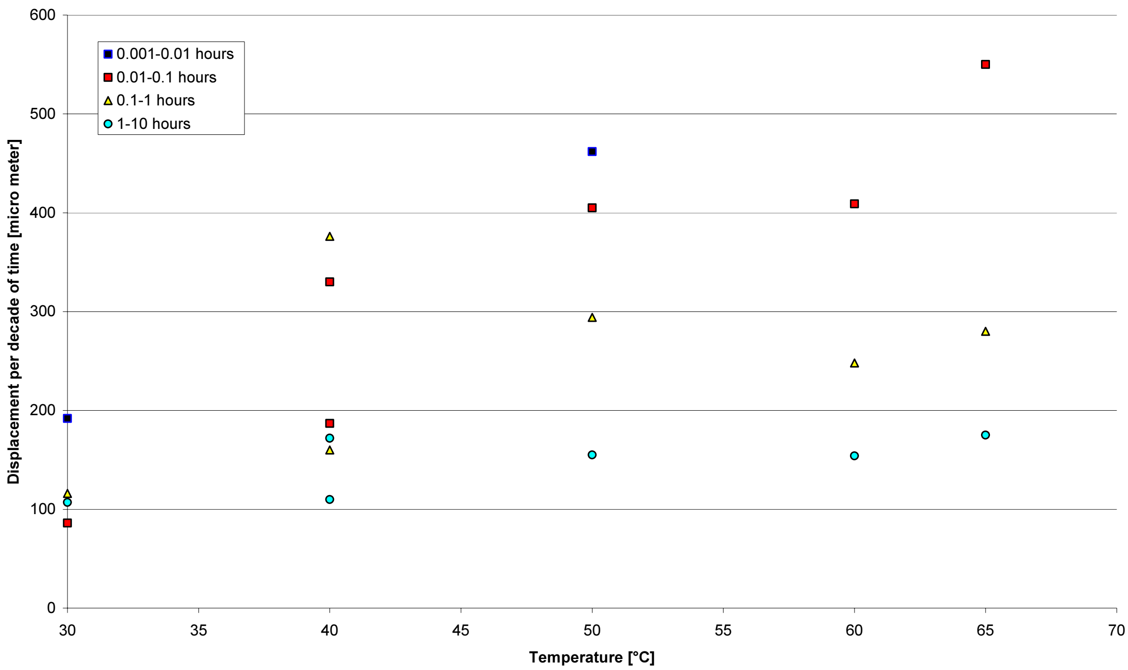

Figure 7
Displacement per decade of time hours as a function of temperature.
Gap width 4 mm

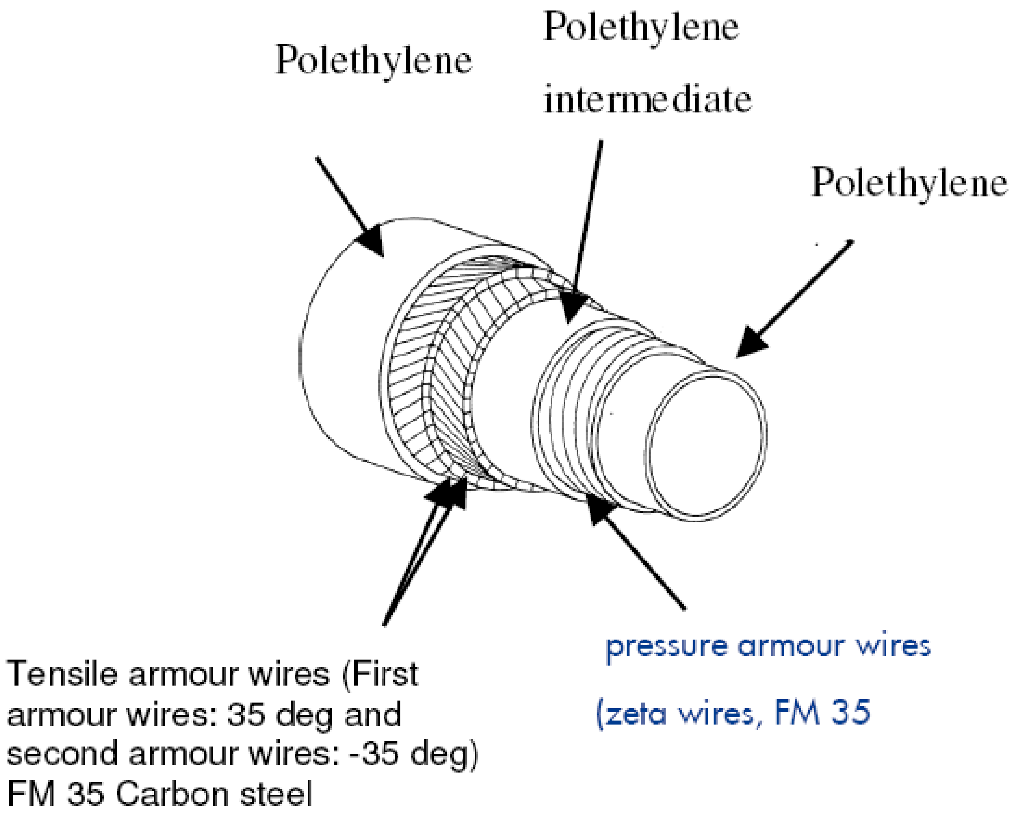

Figure 8 *Different layers of the 10" Draugen water injection flexibles*

Bibliographic Information

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