Special print from “3R international 40 (2001) Special Plastics Pipes”, pages 4-12

Minimum service-life of buried polyethylene pipes without sand-embedding

Dr.-Ing. Joachim Hessel Hessel Ingenieurtechnik GmbH, Roetgen

VULKAN-VERLAG · HUYSSENALLEE 52-56 · 45128 ESSEN

Minimum service-life of buried polyethylene pipes without sand-embedding

Dr.-Ing. Joachim Hessel
Hessel Ingenieurtechnik GmbH,
Roetgen (D)

Tel. +49-2471/92022-0

E-Mail: joachim.hessel@hessel-ingtech.de

In the past 20 years polyethylene raw materials have been developed with the aim of improving the creep rupture strength. This has raised the question whether it is possible to eliminate sand-embedding of buried pipes.

Investigations were performed in order to determine the minimum quality of polyethylene pipes for this situation. The testing conditions cover the loads which are to be expected in service. Typical failure histories, the test design and the material related test conditions in order to generate a conservative result are described. The test results of pipes under internal pressure and additional external point load are reported over a range of test parameters.

A strong correlation between the long term performance of point loaded pressure pipes and the resistance of the materials against slow crack growth as determined in Full Notch Creep tests (FNCT) is confirmed. The results from the FNCT are used to predict the minimum service-life of polyethylene pipes without sand-embedding. The calculation is based on the conservative results of each test series.

Four raw material suppliers and three pipe producers were involved in these investigations.

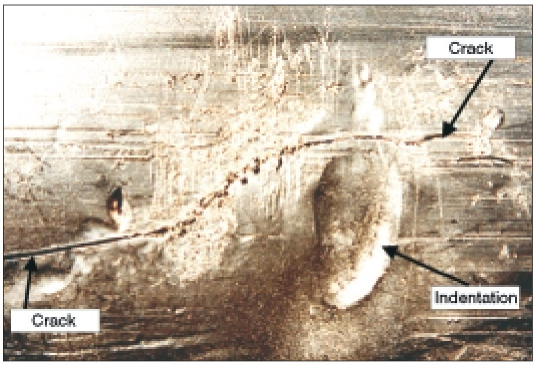

Fig. 1: Indentation and associated crack path on the outside wall of a polyethylene pipe

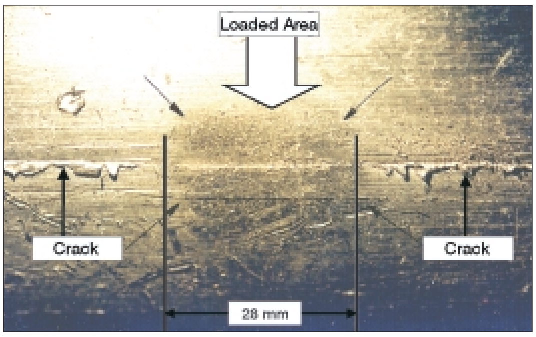

Fig. 2: Externally loaded area and associated crack path on the outside wall of a polyethylene pipe

Introduction

In the past the service-life of buried pipes has been shown to be reduced due to stress concentrations caused by external point loads. The service-life of the pipes is closely related to the material's resistance against slow crack growth. Polyethylene resins are continuously being developed with the aim of increasing creep rupture strength. This increase can be seen in the creep rupture curves of various standards between 1976 and 2000 (e.g. DIN 8075). However, in reality many of the current resins have creep rupture values significantly higher than the minimum requirements.

This raises the question, whether the creep rupture strength of current resins has reached a state of development where a failure of pressure pipes with additional external point loads should not be expected during their service-life.

The following companies took part in these investigations:

- ▷ ATOFINA, Feluy [1], [2]
- ▷ BASELL, Frankfurt [3]
- ▷ BOREALIS, Site Austria [4]
- ▷ EGEPLAST, Emsdetten [5]
- ▷ SOLVAY, Brüssel [6]
- ▷ WAVIN, Twist [7]
- ▷ WIRSBO, Maintal-Bischofheim [8]
- ▷ HESSEL Ingenieurtechnik, Roetgen

Service Experience

Buried polyethylene pipes can be damaged by point or linear loads which are acting in addition to the design loads (e.g. internal pressure, earth and traffic load). Linear loads can for example be produced by wood used as supports below the pipe during installation and not removed before the trench was backfilled [9].

Relevant standards document that a reduction of service-life can result from external point or linear loads on pipes. For this reason, DIN 4033 and DIN 19630 require that point or linear loads on the external wall of the pipe are to be avoided during installation. For the same reason, DIN 1046 requires that the trench base must be free from stones and rocks.

Typical failures of pressure pipes caused by external, locally concentrated loads are shown in **fig. 1 and 2**. The additional load shown in figure 1 was generated by a piece of rock that continuously pressed against the outside of the pipe. The point of indentation is visible near the crack in the external pipe wall. The cause for the crack shown in figure 2 was probably a small load on a limited area. The fracture surface of this crack is shown in **fig 3**.

The starting point of the crack is located at the inside of the pipe wall (bottom) and travels to the outside (top). The fracture surface shows very low deformations which is typical for creep rupture failure. The creep rupture failure is caused both by the internal pressure and the additional load generated by an object pressing against the external pipe wall.

Such failures would not occur if the creep rupture strength at the inside of the pipe wall is above the overall local stress at this point.

Test Materials

Polyethylene pipes 110 x 10 mm (SDR 11) classified as PE 63, PE 80, PE 100

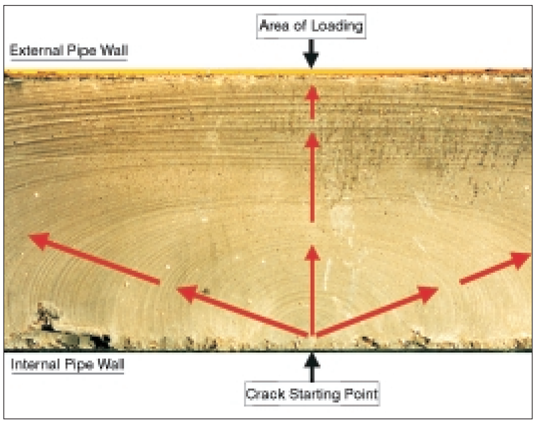

Fig. 3: Fracture surface in the wall of an externally loaded polyethylene pipe

Table 1: Pipe samples tested

Test Series [1]	Material [2]	E-Modulus (N/mm^2)	Colour
1	PE 63	950 [3]	black
2	PE 80	800 [3]	black
3	PE 80	1050 [3]	black
4	PE 80	700 [3]	yellow
5	PE 80	950 [3]	black
6	PE 100	1300 [4]	blue
7	PE 100	1400 [4]	orange
8	PE 100	1400 [4]	black
9	PE 100	900 [3]	black
10	PE 100	1100 [3]	black
11	PE 100	1130 [3]	black
12	PE 100	1130 [3]	black
13	PE 100	1100 [3]	orange
14	PE 100	1100 [3]	orange
15	PE 100	1100 [3]	blue
16	PE 100	1100 [3]	blue
17	PE 100	1100 [3]	blue
18	PE-Xa	650 [3]	black
19	PE-Xb	1200 [2]	red-orange

[1] s.a. Table 2, [2] ISO/TR 9080, [3] ISO 527 (Tensile load)
[4] ISO 178 (Bending load)

according to DIN 8075 as well as cross-linked polyethylene pipes (PE-Xa; PE-Xb) were used for the investigations (**table 1**).

Principle and Limiting Conditions of the Tests

FNCT

The resistance against slow crack growth of the samples was tested using the Full Notch Creep Test (FNCT) according to DIN EN 12814-3 Annex A. This test method is also described in supplementary sheet 2 of guideline DVS 2203 part 4 and in ISO-draft: ISO/DIS16770: Plastics – Determination of environmental stress cracking (ESC) of polyethylene (PE) – Full–notch creep test (FNCT).

The test specimens were cut from the pipes in the axial direction with parallel sides and approximately square cross-sections. Each specimen was notched perpendicular to the parallel length in the middle of the test specimen.

The specimens were loaded by a constant tensile stress of 4 N/mm^2 ± 0.03 N/mm^2 relating to the remaining unnotched cross-sections. The nominal test temperature was 80 °C ± 0.2 K.

The tensile creep tests were performed on 3 test specimens per temperature using an aqueous solutions of ®ARKOPAL N-100 in demineralised water (2/100, w/w) to accelerate the tests.

The FNCT failure times for 13 out of the 19 pipes are shown in **fig. 4**.

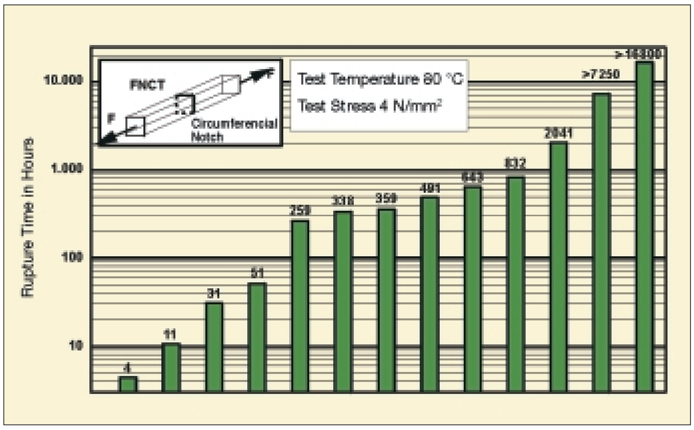

Fig. 4: Creep rupture times of specimens from pipes of different resistances against slow crack growth in FNCT

Table 2: Test program

<table>
<tr><th>Test Series</th><th>Material</th><th>Temperature (°C)</th><th>Medium</th><th>Stress (N/mm²</th><th>Displacement of Loading Tool (mm)</th><th>Loading Tool Tip Radius (mm)</th><th>Influence</th></tr>
<tr><td>1</td><td>PE 63</td><td>80; 60; 40;20</td><td>Detergent, Water</td><td>4; 2</td><td>9</td><td>5</td><td>Temperature (Arrhenius); Internal Pressure; Medium; Quality</td></tr>
<tr><td>2</td><td>PE 80</td><td>80</td><td>Detergent, Water</td><td>4</td><td>9</td><td>5</td><td>Medium; Quality</td></tr>
<tr><td>3</td><td>PE 80</td><td>95; 80; 60</td><td>Detergent, Water</td><td>4; 2; 1; 0,2</td><td>9; 4,5; 0</td><td>10; 5; 2,5</td><td>Temperature (Arrhenius); Internal Pressure; Medium; Quality; Displacement and Tip Radius; Quality</td></tr>
<tr><td>4</td><td>PE 80</td><td rowspan="16">80</td><td rowspan="16">Detergent</td><td rowspan="16">4</td><td rowspan="16">9</td><td rowspan="16">5</td><td rowspan="16">Quality (Resistance against slow crack growth; Long term performance)</td></tr>
<tr><td>5</td><td>PE 80</td></tr>
<tr><td>6</td><td>PE 100</td></tr>
<tr><td>7</td><td>PE 100</td></tr>
<tr><td>8</td><td>PE 100</td></tr>
<tr><td>9</td><td>PE 100</td></tr>
<tr><td>10</td><td>PE 100</td></tr>
<tr><td>11</td><td>PE 100</td></tr>
<tr><td>12</td><td>PE 100</td></tr>
<tr><td>13</td><td>PE 100</td></tr>
<tr><td>14</td><td>PE 100</td></tr>
<tr><td>15</td><td>PE 100</td></tr>
<tr><td>16</td><td>PE 100</td></tr>
<tr><td>17</td><td>PE 100</td></tr>
<tr><td>18</td><td>PE-Xa</td></tr>
<tr><td>19</td><td>PE-Xb</td></tr>
</table>

External Point Load

The maximum stress that the pipe material will experience from a point load is the yield stress. Therefore in this test it was ensured that the displacement of the point load into the pipe wall was sufficient to cause yielding of the material at the inside of the pipe.

Since the additional stress in the pipe wall far from the point of load will be zero all possible stresses that might occur in the field due to a point load are represented in this test.

There are two scenarios which are not covered: 1) the penetration of a sharp object – e.g. a nail – through the pipe wall and 2) the complete crushing of the pipe, e.g. by a large rock. In the last case the pipe is no longer functioning, but the force on the pipe is comparable to the test load in the point loading test.

The required surface elongation at the inner pipe wall (i.e. the above yield elongation) was produced by the displacement of a tool along the radius of the pipe with a tool

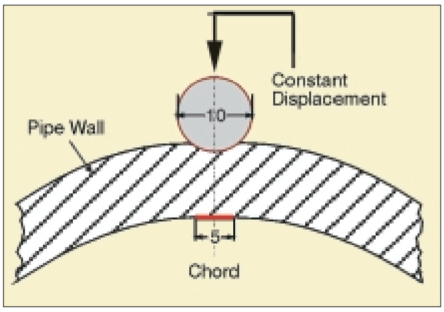

Fig. 5: Loading by an external point load before starting the internal pressure test

tip radius of 5 mm. The tool loading was carried out at room temperature with no internal pressure in the pipe. The tool was loaded until a chord with a length of 5 mm was measured at the inside surface of the pipe (**fig. 5**). This occured at a tool displacement of 9 mm from the outer surface of the pipe.

The elongation at the inside surface can be calculated using the following equation:

$$\varepsilon = [0.318 \cdot F \cdot R] / [b' \cdot s \cdot E(t)]$$

where:

- ε Elongation at the inner surface of the pipe wall
- F Radial acting force (single load)
- R Mean pipe radius
- s Wall thickness
- E(t) E-modulus
- b‘ Supporting width

The supporting width of the load (b') can be determined experimentally by measuring the force on the tool with the pipe under internal pressure.

Finite element calculations (**fig. 6**) confirm that with the tool loading a pipe under internal pressure of 8 bar the elongation of the inner surface of the pipe due to the tool displacement was in excess of twice the yield elongation of the material, which is 9 % for all the materials given in table 1.

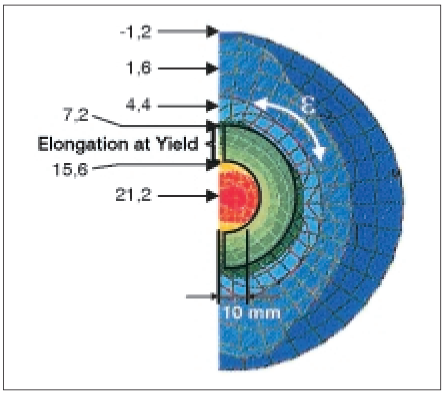

Fig. 6: Surface elongation in % at the inside wall of the pipe due to an external point load and an internal pressure of 8 bar

The internal pressure of the pipes was chosen to produce a hoop stress of 4 N/mm2 during the test (ISO 1167).

To accelerate the tests they were performed using an aqueous solution of 2 % Arkopal N-100 and demineralised water.

The test fluid was continuously mixed in the pipes to prevent separation.

Test materials 1 and 3 were also tested using water with no detergent.

In order to determine the influence of internal pressure 4 pressure levels were applied for test series no. 3. The magnitude of the additional external point load was kept constant.

Test Temperatures

The tests were performed at 80 °C. In addition the activation energy was calculated for test series 1 and 3 by performing tests at temperatures between 20 and 95 °C.

A summary of the test program is given in **table 2**.

Theoretical Basis for Determining the Maximum Service-Life

Generally the maximum service-life of plastics is determined by thermal ageing, which causes embrittlement of the material. The relevant parameters other than temperature and time are the environment and the available oxygen.

Water saturated with oxygen has proved to have the greatest effect on the reduction of the maximum service-life because it causes accelerated thermal ageing.

Equivalent thermal ageing times are found for either the mixture of a detergent and water or just water without a detergent. The time to the beginning of the effect of thermal ageing is independent of the elongation of the material.

The onset of thermal ageing was investigated by Gaube et al. in the temperature range between 80 °C and 40 °C. The criteria for evaluation was that the elongation to rupture of the aged sample was 50 % of the elongation to rupture of the unaged sample. Later investigations on pipes under internal pressure showed that the onset of thermal ageing found by Gaube testing sheets was identical with the starting point of the sharp decent of the creep rupture curves of pipes. This

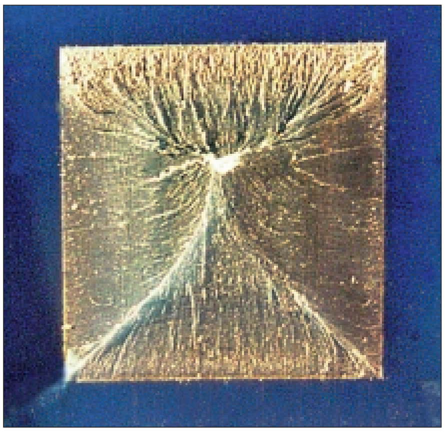

Fig. 7: Fracture surface of a FNCT specimen taken from a PE 100 pipe

point is the beginning of thermal degradation of the pipe [12].

Another method to describe the thermal ageing of polyolefines is the measurement of the viscosity number according to ISO 1628-3. This number is related to the molecular weight. [13].

With all three methods a correlation is obtained which can be described by the equation of Arrhenius. This means that the thermal degradation takes place after a short period of time at high temperatures (e. g. 80 °C) and after a long period of time at low temperatures (e. g. 20 °C) according to the activation energy.

It is accepted that if polyethylene with conventional stabilisation is tested for one year at 80 °C without thermal ageing this is equivalent at 20 °C to 100 years service [14].

Results of the Investigations

Although 6 of the 19 test series are not yet completed it is possible to evaluate the results with regard to the required minimum quality of polyethylene pipes for their installation without sand-embedding.

Taking into account the evaluation procedure [15] the results are conservative, that means they are on the safe side.

Failure Mechanism

Assuming that the process of slow crack growth (stress cracking) is the relevant long term failure mode for pipes under additional external point load these re-

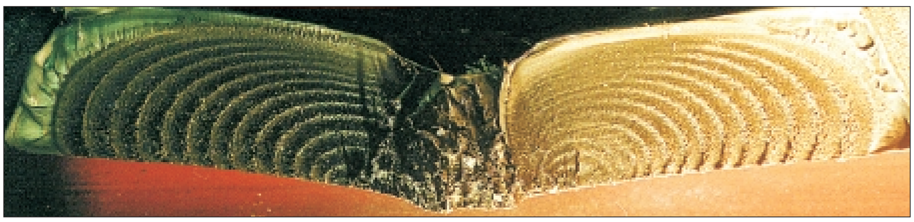

Fig. 8: Fracture surface in a PE-pipe subjected to an external point load and internal pressure

Fig. 9: Fracture surface in a PE-Pipe subjected to internal pressure only

sults should correlate with the resistance against stress cracking as tested by the FNCT.

The fracture surface both in FNCT (**fig. 7**) and in the pipe under external point load (**fig. 8**) shows low deformations without evidence of macroscopic ductility. This has been confirmed by investigations of Laurent using a scanning electron microscope [16].

The same appearance is also visible at fracture surfaces of pipes under internal pressure only (**fig. 9**).

For pipes under external point load the crack always starts at the inside of the pipe wall but not at the point of the largest material strain, directly below the loading tool (**fig. 10 to 13**). From fig. 6 it can be assumed that the crack starts in the region where the material is at the yield point, i.e. before it becomes oriented.

A similar phenomenon is found in the Cone-test where the crack initiation is not at the point of maximum elongation but a certain distance away [17].

Influencing Parameters

Pipe Quality

The results of the investigations on point loaded pipes and in the FNCT, which are complete at the time of reporting are shown in **fig. 14**, where the figures at the data points correspond to the number of the test series in table 2.

This shows that the pipe quality with regard to the long term performance under internal pressure and additional external point load correlates with the rupture times of notched specimens in FNCT. This relationship is supported by the correlation between pipes under internal pressure and FNCT published by Fleißner [18].

As expected the samples made from PE 63 show the shortest rupture times both for point loaded pipes and in the FNCT. The rupture times in both tests increase from PE 80 to PE 100 to PE-X.

Test series no. 4 (PE 80) is exceptional because the rupture times are in the region of some PE 100 materials (no. 6 to 10).

Fig. 10: Cracks in the inside wall of a PE 80 pipe subjected to an external point load and internal pressure (Test series 4)

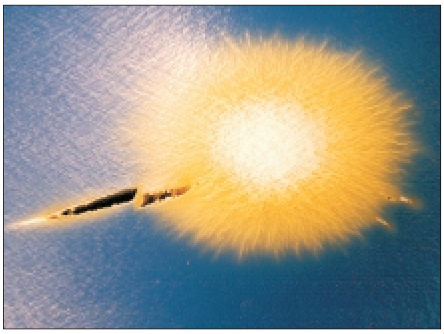

Fig. 12: Cracks at the inside wall of a PE 100 pipe subjected to an external point load and internal pressure (Test series 6)

Fig. 11: Cracks at the inside wall of a PE 100 pipe subjected to an external point load and internal pressure (Test series 8)

Fig. 13: Cracks at the inside wall of a PE 100 subjected to an external point load and internal pressure (Test series 7)

As can be seen in fig. 14 the relationship between the rupture times of the two tests is linear on a double logarithmic scale. The correlation coefficient is greater than 0.98 which is acceptable for technical applications. The mathematical description of the correlation leads to the formula:

$$t_{1,\,FNCT} = 10 \uparrow (m_1 \cdot \log t_{1,\,Pipe} + a_1) \qquad (1)$$

where

$t_{1,\,FNCT}$: Rupture time in FNCT (80 °C, 4 N/mm², 2 % Arkopal N-100)

$t_{1,\,Pipe}$: Rupture time of point loaded pipe and internal pressure (80 °C, 4 N/mm², 2 % Arkopal N-100)

$m_1 = 0.874$

$a_1 = -0.151$

The shaded area in fig. 14 shows the regions where thermal ageing will occur for conventionally stabilised polyethylene pipe resins.

From these results it can be concluded that pipes with rupture times in the FNCT above 2000 hours (80 °C, 2 % Arkopal N-100, 4 N/mm²) could be installed without sand- embedding for service pressure 4 bar (safety factor 2). This is because the pipes under external point load exceed the limit of thermal ageing at 80 °C, which relates to a service-life of at least 100 years at 20 °C [19].

The results of test series no. 12 (pipe under external point load) and no. 15 (FNCT and pipe under external point load) can be found in the area of thermal ageing.

Those test series which are not yet completed at the time of this report are summarised in **table 3**.

Internal Pressure of Pipe

All point loaded pipes were tested with an internal pressure of approximately 8 bar following the relevant test standards for polyolefin pipes (hoop stress 4 N/mm²). For test series no. 3 additional tests were carried out at lower internal pressures with a notch at the inside pipe surface in line with the point load (**fig. 15**).

A linear relation in a double logarithmic scale results from these tests in a similar manner to conventional creep rupture curves without additional loads. This shows that an important influence on the failure times is the internal pressure in the pipe.

The mathematical description of this relation is given in formula 2:

$$t_{2,\,Pipe} = 10 \uparrow (m_2 \cdot \log pi_{\,Pipe} + a_2) \qquad (2)$$

where:

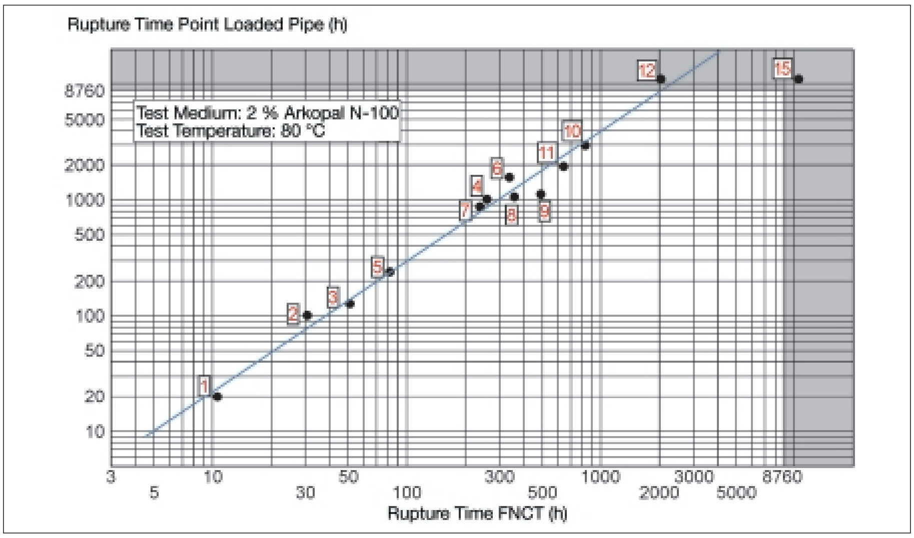

Fig. 14: Correlation between test results for external point loaded pipes and from the FNCT on specimens taken from polyethylene pipes (Number at data points refer to the test series number)

Table 3: Pipe samples still under test

Test Series	Material	Test Duration in FNCT (h) [1]	Test Duration in Point Loaded Pipe Test (h) [2]	Evaluation according to Table 11 (S = 2)
13	PE 100	>4000	>4000	No sand up to 8 bars
14	PE 100	>4000	>3200	
16	PE 100	>4000	>4000	
17	PE 100	>4000	>4000	
18	PE-Xa	>16000	>12000	
19	PE-Xb	>2650	>2500	No sand up to 6 bars

[1] 80 °C, Tensile Stress 4 N/mm², 2 % Arkopal N-100
[2] 80 °C, Hoop Stress 4 N /mm², 2 % Arkopal N-100

$t_{2,\ Pipe}$: Rupture time of point loaded pipe with notch at the inside surface and internal pressure (80 °C, 4 N/mm², 2 % Arkopal N-100)

$pi_{\ Pipe}$: Internal pressure of pipe in bar

m_2 = -0.823

a_2 = 2.365

Temperature

From experience, creep rupture times increase according the formula for the activation energy found by Arrhenius.

Table 4 shows the calculated activation energies [21] for test series 1 and 3 for point loaded pipes in comparision with the values for the activation energies for the "brittle regions" of the creep curves of PE 63, PE 80 and PE 100 according to DIN 8075.

The values for the activation energies for point loaded pipes in table 3 are considerably lower than those for the creep curves given in DIN 8075. This means that the time-temperature correlation given in DIN 8075 is not applicable to point loaded pipes and would result in overoptimistic values when extrapolated to 20 °C.

Fig. 16 shows the linear relation between the inverse of absolute temperature and the logarithm of the creep rupture times for the test series 1 and 3. The calculated correlation coefficients are above 0.98. Thus a constant activation energy is confirmed both for test series 1 between 80 °C and 40 °C and for test series 3 between 95 °C and 60 °C. The following formula is derived from the test results of test series 1:

$$t_{3,\ Pipe} = 10 \uparrow ((1/T - a_3) : m_3) \quad (3)$$

where

$t_{3,\ Pipe}$: Rupture time of the point loaded pipe (4 N/mm², 2 % Arkopal N-100)

T: Absolute temperature [K]

m_3: $2.87 \cdot 10^{-4}$

a_3: $2.43 \cdot 10^{-3}$

To date there has been no indication that the activation energy is changing for lower temperatures. Thus the extrapolation of the values measured at higher temperatures in a short period of time to lower temperatures and long period of times is confirmed.

Investigations in the past have shown that the activation energy determined from tests in an aqueous solutions with detergents provides a conservative estimate of the activation energy determined from tests in water without detergent [22].

Medium

In order to get results in reasonable times for all pipe qualities, the investigations usually were performed under the influence of an aqueous solution with Arkopal N-100 (2 % w/w).

Both in the FNCT and for point loading tests it was important to ensure a homogeneous mixture of the test fluid, because incomplete mixing produces undefined concentration conditions and longer, not comparable rupture times.

In order to transform the test conditions to the service conditions for gas or water pipelines the difference between the in-

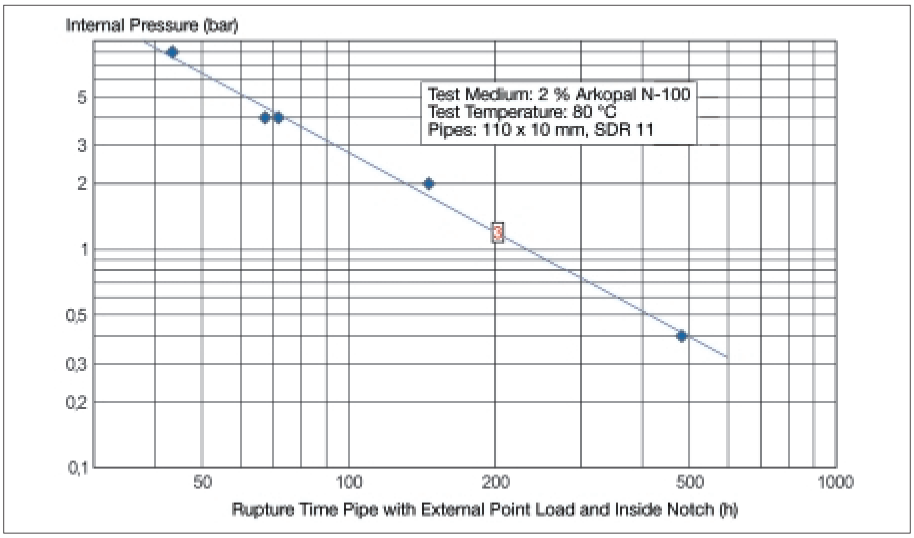

Fig. 15: Effect of internal pressure on the long term performance of external point loaded pipes (Test series 3)

Table 4: Activation energy for creep rupture of pipes under pressure with and without additional external point load (brittle failure)

Test Series	Material	Activation Energy (kJ/mol)	Remark
1	PE 63	66.8	With Point Load
3	PE 80	81.6	
	PE 63	165.1	Without Point Load (DIN 8075)
	PE 80	168.6	
	PE 100	178.9	

fluences of detergent or water on the creep rupture behaviour needs to be quantified.

The test data available at the time of this report are summarised in **table 5**. The values agree well with the results from a round robin test on the FNCT [23].

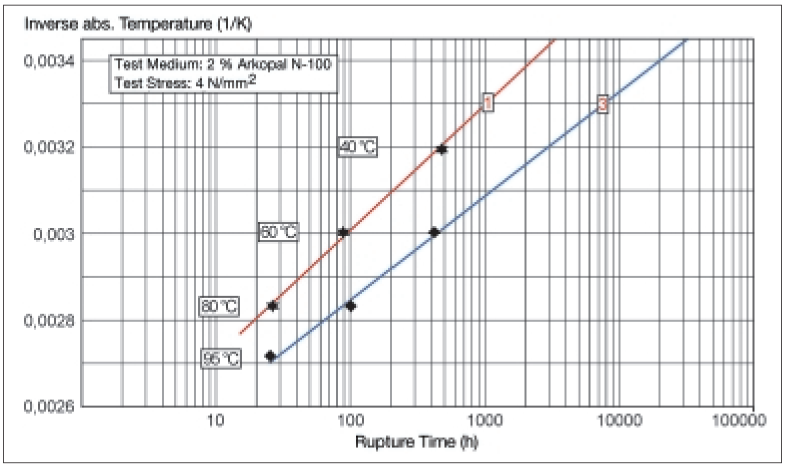

Fig. 16: Effect of temperature on the long term performance of external point loaded pipes (Test series 1 and 3)

Table 5: Influence of water and detergent on polyethylene in the FNCT

Test Series	Material	Testing Time in Arkopal N-100 (h) [1]	Testing Time in Water (h) [1]	Time Factor $t_{Water}/t_{Detergent}$
1	PE 63	10.6	44.3	4.2
2	PE 80	30.8	171.9	5.6
3	PE 80	51	289.0	5.7
7	PE 100	238.8	2320.1	9.7

[1] 80 °C, Tensile Stres 4 N/mm², Geometric Mean Value from 3 Single Specimens Each

Table 6: Influence of Loading Tool Tip Radius for test series 3

Tip Radius of Loading Tool (mm)	Rupture Time for Point Loaded Pipes (h) [1]	Displacement of Loading Tool (mm)
2.5	117.7	9.0
5.0	127.3	
10.0	113.1	

[1] 80 °C, Hoop Stress 4 N/mm², 2 % Arkopal N-100

Radius of the Loading Tool

The outside of the pipes were usually loaded using a tool with a tip radius of 5 mm. Additional tests were performed on test series 3 with tool tip radius of 2.5 mm and 10 mm.

The test results show that a tool tip radius between 2.5 mm and 10 mm there is no difference in the rupture times of the pipes (**table 6**).

Displacement of the Loading Tool

A displacement of the loading tool of 9 mm caused an elongation at the inner surface of the pipe wall which exceeded the yield strain of the materials.

The displacement of the loading tool was varied between 9 mm and 0 mm (contact of the loading tool at the outer pipe surface) in test series 3.

In this connection it is important to note that the pipes were loaded at room temperature without internal pressure but the tests are carried out at elevated temperature with internal pressure.

The results are given in **table 7** and indicate there is no significant difference in rupture times for displacements between 0 and 9 mm.

Thus it seems that small displacements of an external point load introduce a reduction of the creep rupture time.

Table 7: Influence of Loading Tool Displacement for test series 3

Displacement of Loading Tool (mm)	Rupture Time for Point Loaded Pipes (h) [1]
0.0	101.6
4.5	106.1
9.0	127.3

[1] 80 °C, Hoop Stress 4 N/mm², 2 % Arkopal N-100

Notches at the Inner Pipe Wall Surface

In order to investigate the influence of notches with a small depth at the inside pipe wall surface, tests were carried out for test series 1, 2, 3, 6 and 8. The notches were 0.85 mm deep and were located at the inside pipe surface in line with the external point load.

Fig. 17 shows the creep rupture times of the test series with and without a notch. A linear relation is found between the two kinds of specimen according to the following formula:

$$t_{4,\,Notch} = 10 \uparrow (m_4 \cdot \log t_{4,\,Pipe} + a_4) \qquad (4)$$

where

$t_{4,\,Pipe}$: Rupture time of the point loaded pipe (80 °C, 4 N/mm², 2 % Arkopal N-100)

$t_{4,\,Notch}$: Rupture time of the point loaded pipe with an inside notch (80 °C, 4 N/mm², 2 % Arkopal N-100)

$m_4 = 0.818$

$a_4 = -0.05$

These results show that the internal notches reduce the rupture times of a pipe which reaches the thermal ageing under the influence of water by a factor of 4.1 compared to unnotched pipes.

The depth of the notches were varied between 0.25 and 0.85 mm using specimens from test series 3. However, no significant difference was found in the creep rupture times.

Scattering of the Test Results

The scattering of the results of test series 2, 6 and 9 are given in **table 8** and were used to calculate the cumulative frequency at which 2.5 % of the specimens tested would be expected to fail, in a similar manner to that used for creep rupture tests (ISO/TR 9080).

Calculation of Minimum Test Requirements

In order to calculate the minimum test requirements equivalent to a specified service-life of point loaded polyethylene pipes at 20 °C applied for water or gas conveyance the following formula is used:

Table 8: Scattering of the test results for point loaded pipes

Test Series	Material	Standard Deviation (of the Logarithm)	2*Scattering Factor
2	PE 80	0.0195	1.09
6	PE 100	0.0717	1.39
9	PE 100	0.0849	1.48

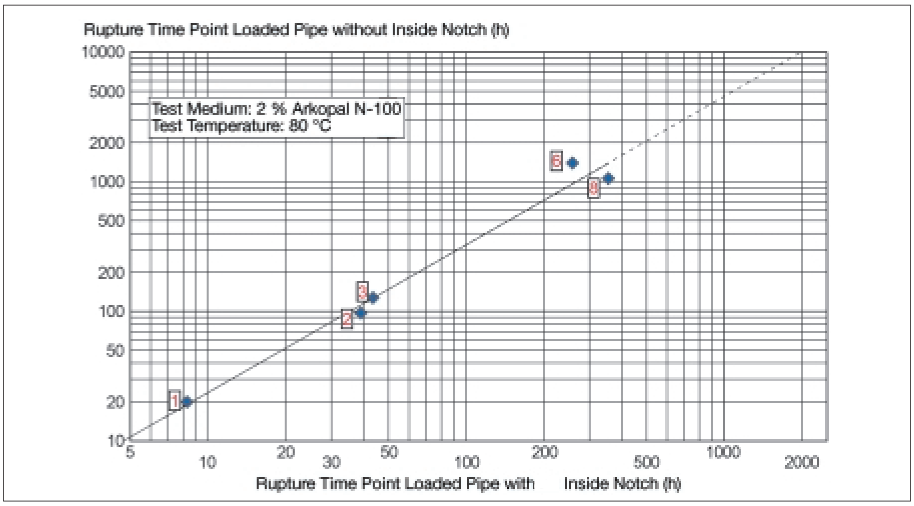

Fig. 17: Effect of 0.85 mm deep notch at the inside wall on the long term performance of external point loaded pipes (Test series 1, 2, 3, 6 and 8)

$t_{Pipe,\ Test} = (t_{Pipe,\ Service} \cdot F_{Notch} \cdot F_{Scattering}) : (F_{Temperature} \cdot F_{Medium} \cdot F_{Internal\ Pressure,\ Safety})$ (5)

The minimum required time in the FNCT at test conditions is obtained when formula (5) is inserted in formula (1):

$FNCT_{min} = 10 \uparrow (m_1 \cdot \log t_{Pipe,\ Test} + a_1)$ (6)

where

$t_{Pipe,\ Test}$: Failure time of the pipe under test conditions

$t_{Pipe,\ Service}$: Service time of the pipe at 20 °C; σ_V = 4 N/mm²; Water; Point Load > ε_s

F_{Notch}: Time factor, representing a notch at the inside wall surface (4)

$F_{Scattering}$: Time factor, representing a probability of failure of 2.5 %

$F_{Temperature}$: Time factor, representing the activation energy between test- and service temperature

F_{Medium}: Time factor, representing the influence of the test fluid compared to water

$F_{Internal\ Pressure,\ Safety}$:

Time factor representing a hoop stress other than σ_V = 4 N/mm² and the safety factor

$FNCT_{min}$: Minimum rupture time in FNCT at 80 °C; 4 N/mm²; 2 % Arkopal N-100

A summary of all the data used in the calculation of the minimum service-life is given in **table 9**.

The calculation of the creep rupture times of point loaded pipes using the activation energy in table 4 (test series 1) predicts a service-life of 106 years at 20 °C when a rupture time of 8760 hours is exceeded at 80 °C. Thus the material of test series 1 appears to correspond with the material for which extrapolation time limits are described in ISO/TR 9080.

The minimum rupture times in the FNCT at 80 °C, 4 N/mm²; 2 % Arkopal N-100 which are shown in **tables 10 and 11** were calculated using formula (5) and (6) and the data given in table 9.

The qualifying of polyethylene pipes against the minimum requirements is therefore possible by determining the individual properties and parameters for the calculation.

Many thanks are given to Dr. Mike Troughton; TWI (The Welding Institute, Cambridge) for fruitful technical discussions and assistance in translation.

Table 9: Data used to calculate the minimum service life

Symbol	Value	Remark
$t_{Pipe.\ Service}$	876000 hours	Time to Thermal Ageing at 20 °C
F_{Notch}	4.1	from Formula (4) at Time to Thermal Ageing
$F_{Scattering}$	1.48	Table 8, Test Series 9
$F_{Temperature}$	106.4	Table 4, Test Series 1
F_{Medium}	5.6	Table 5, Test Series 3
$F_{Internal\ Pressure.\ Safety}$	variable	from formula (2)

Table 10: Minimum rupture times in the FNCT which is equivalent to a minimum service-life of 100 years at 20 °C for external point loaded pipes without an internal notch

$FNCT_{min}$ (h)	Hoop Stress from Internal Pressure (N/mm²)		Safety Factor
575	4.0		1.0
676			1.25
948			2.0
483	3.0		1.0
567			1.25
770			2.0
360	2.0		1.0
423			1.25
575			2.0
219	1.0		1.0
257			1.25
360			2.0
133	0.5		1.0
156			1.25
219			2.0

Table 11: Minimum rupture times in the FNCT which is equivalent to a minimum service-life of 100 years at 20 °C for external point loaded pipes with an internal notch

$FNCT_{min}$ (h)	Hoop Stress from Internal Pressure (N/mm²)	Safety Factor
1976	4.0	1.0
2645		1.25
3254		2.0
1606	3.0	1.0
1886		1.25
2645		2.0
1199	2.0	1.0
1408		1.25
1976		2.0
728	1.0	1.0
855		1.25
1199		2.0
442	0.5	1.0
519		1.25
728		2.0

Literature

[1] to [8]: Reports of HESSEL Ingenieurtechnik GmbH, Roetgen

[1] Client ATOFINA, Report R00 04 261-1
[2] Client ATOFINA, Report R01 04 508-1
[3] Client BASELL, Report R01 04 447
[4] Client BOREALIS, Report R01 04 500
[5] Client EGEPLAST, Report R01 04 460-1
[6] Client SOLVAY, Report R01 04 459-1
[7] Client WAVIN, Report R01 04 457-1
[8] Client WIRSBO, Report R98 04 262-1
[9] Hessel, J.: Zeitstandverhalten von Polyethylen unter dem Einfluß lokal konzentrierter Spannungen 3R international 34 (1995) 10/11, S.573/579
[10] Hessel, J., Mauer, E.: Zeitstandzugprüfung in wäßriger Netzmittellösung. Materialprüfung 36 (1994) 6, S. 240/243
[11] Nonhoff, G.: Personal Information (4/2000)
[12] Gaube, E. et al.: Zeitstandfestigkeit und Alterung von Rohren aus HDPE; Erfahrungen aus 30 Jahren Rohrprüfung. Kunststoffe 7 (1985), S. 412/ 415
[13] Gebler, H.: Langzeitverhalten und Alterung von PE-HD-Rohren. Kunststoffe 9 (1989), S. 823/ 826
[14] Wernicke, K.: „100 Jahre Nutzungsdauer für Druckrohre aus PE” Wiesbadener Kunststoffrohrtage 2000
[15] Hessel, J., Mauer, E., Schleyer A., Schröder-Wrede, V.: Ein neues Konzept zur Lebensdauerabschätzung von Schweißverbindungen an Kunststoffmantelrohren aus Polyethylen. 3R international 34 (1995) 3, S. 94/101
[16] Laurent, E.: Comprehensive Evaluation of the Long-Term Mechanical Properties of PE 100 Resins Meeting the Requirements of Modern Installation Techniques. Plastics Pipes XI – 4th September 2001, Munich
[17] Köstring, V.: Von den Rohreigenschaften zum fertigen Produkt: PE 100-Rohre mit integrierten Schutzschichten. Vortrag 9, Wiesbadener Kunststoffrohrtage 2001, 26. und 27.04.2001
[18] Fleißner, M.: Langsames Rißwachstum und Zeitstandfestigkeit von Rohren aus Polyethylen. (Slow crack growth and creep rupture strength of polyethylene pipe). Kunststoffe 77 (1987) 1, p. 45/50
[19] Hessel, J., Koch, R., Gaube, E., Gondro, C., Heil, H.: Langzeitfestigkeit von Deponiedichtungsbahnen aus Polyethylen Kunststoffe 2 (1988) S. 155/160
[20] Hessel, J.: Zur Mindestqualität von Rohren aus PE für die Erdverlegung ohne Sandeinbettung. Report No. 4, Wiesbadener Kunststoffrohrtage 2000, 04. und 05.05.2000
[21] Westphal, W. H.: Physikalisches Wörterbuch. Springer-Verlag, Berlin/ Göttingen/ Heidelberg. 1952
[22] Larsen, Chr. T., Hessel, J.: Neue Erkenntnisse zum Langzeitverhalten von Schweißverbindungen an Kunststoff-Mantelrohren. 3R international 36, Heft 6 Juni 1997, S. 283/ 287
[23] Round Robin Test on FNCT 1998. Participants: BASF, DSM, FINA, HESSEL, MAINOVA, REINERT-RITZ, SIMONA, SOLVAY, TARCO, TGM, TWI, TÜV Süddeutschland. Symposium on 0312.1998, Main Office of Deutscher Verbandes für Schweißen und verwandte Verfahren (DVS), Düsseldorf