FLEXIBLE, PRE-INSULATED POLYMER DISTRICT HEATING PIPES: A SERVICE LIFETIME STUDY

Dr. Alexander v. Bassewitz, Rehau AG + Co
Norbert Jansen, Borealis Deutschland GmbH
Volker Liebel, REHAU AG + Co

From Jan 6th 2001 until March 31st 2005 a research project, funded by the German Ministry for Economy and Research had been carried out in order to investigate technical details not yet researched. The results of the project have shown that polymer flexible pipes for district heating are fit for purpose.

The research project focused on district heating pipes with PE-X and PE-RT service pipes, semi-rigid PU foam and a PE casing.
Whilst for district heating pipes with steel service pipe, rigid PU foams and HD-PE jacket pipes all relevant material properties have been proven to be fit for purpose, this had not been done for the flexible pipe systems in question.

The questions to be answered have been:

1.) Are the PE-X and PE-RT service pipes able to withstand the temperature and pressure conditions of typical district heating systems, including the effect of oxygen in the water?
(The current standards applicable for PE-X pipes and their applications do not cover these conditions)
2.) Which heat aging properties does the semi rigid foam have, and how does the coefficient of heat transport change with time?
3.) Are the semi rigid PU foams able to withstand the thermal and mechanical actions during the lifetime, without loosing the bonding between the pipe components?

The participants of the reearch project had been: GEF Ingenieur AG (Project leader), REHAU, Borealis, Elastogran, Huntsman, Stadtwerke Lemgo, Uponor, Wärmeversorgung Südbayern, Becker Plastics, BP Solvay, DREWAG, GeorgFischer, Logstor, Fernwärme-ForschungsInstitut, IMA Dresden, Ingenieurtechnik Hessel.

1. DURABILITY OF THE SERVICE PIPE

Thermal Stability, tests carried out by Hessel Ingenieurtechnik (1)

The required lifetime of a district heating system has to be in excess of 30 years. The temperature profile for that period was assumed to be the following:

80°C / 176°F	- 29 years
90°C / 194°F	- 1 year
95°C / 203°F	- 100 hours

This temperature profile is being standardised by CEN TC 107 for Plastic service pipes (2) and is in excess of the figures in EN/ISO 10508, the standard which classifies the applications for hot and cold water systems in buildings (3).

Class	T_o		T_{max}		T_m		Application
	°C	Time (years)	°C	Time (years)	°C	Time (h)	
1	60	49	80	1	95	100	Hot water supply at 60°C
2	70	49	80	1	95	100	Hot water supply at 70°C
3	30 40	20 25	50	4,5	65	100	Underfloor heating
4	40 60	20 25	70	2,5	100	100	Underflow Heating and low temperature radiators
5	60 80	25 10	90	1	100	100	High temperature radiators

Table I: Classification of service conditions

In this standard the principles are given to calculate the life time of a pressure pipe for a given pressure and temperature profile using Miner's Rule.
Miner's Rule ISO 13760 (4) is based on the principle of adding cumulative damages to the pipe. This may be due to mechanical stress or chemical degradation. The "mechanical life time" and the "chemical life time" are calculated separately, the lower one determines the total life time.
The mechanical life time under a given pressure is calculated using hoop stress curves standardised in the relevant product standards or taken from an evaluation acc to the Extrapolation Method in ISO 9080 (5). For cross linked polyethylene these curves are well established and approved to be linear in log time / log stress without any indication of a knee, see ISO 10146 (6).
The chemical life time of a pipe, the time before degradation occurs, shown as stage III in the hoop stress diagram depends on the thermal stabilisation of the material and on the crack growth.
The temperature profiles in hot and cold water systems within buildings acc to ISO 10508 requires a pressure test at 110°C / 230°F over one year, based on an activation energy of 110kJ /mol. This test secures a chemical life time of 50 years at 70°C / 158°F.
This value was accepted by ISO TC 138 SC5 as valid for all Polyolefin's and incorporated in ISO 9080.
For a PE-X pipe as service pipe in a district heating system with the temperature profiles defined above, this test is not sufficient. Either a much longer duration of the test must be chosen or a higher test temperature. In this research project a maximum test temperature of 120°C / 248°F was chosen and a hot water circulating loop was used to take into account the influence of running water (see Fig 1).
Any leakage and failure in the coiled pipes had been observed and in certain intervals samples were taken out for measuring the tensile properties and oxygen induction time OIT.

Test conditions:

Test Temperatures:	120°C - 110°C - 95°C / 248°F - 230°F - 203°F
Test Pressure:	1.5 bar
Velocity:	1m/s
Fluid:	District heating water (DHW) and Drinking water (DW)
Water change	1/week

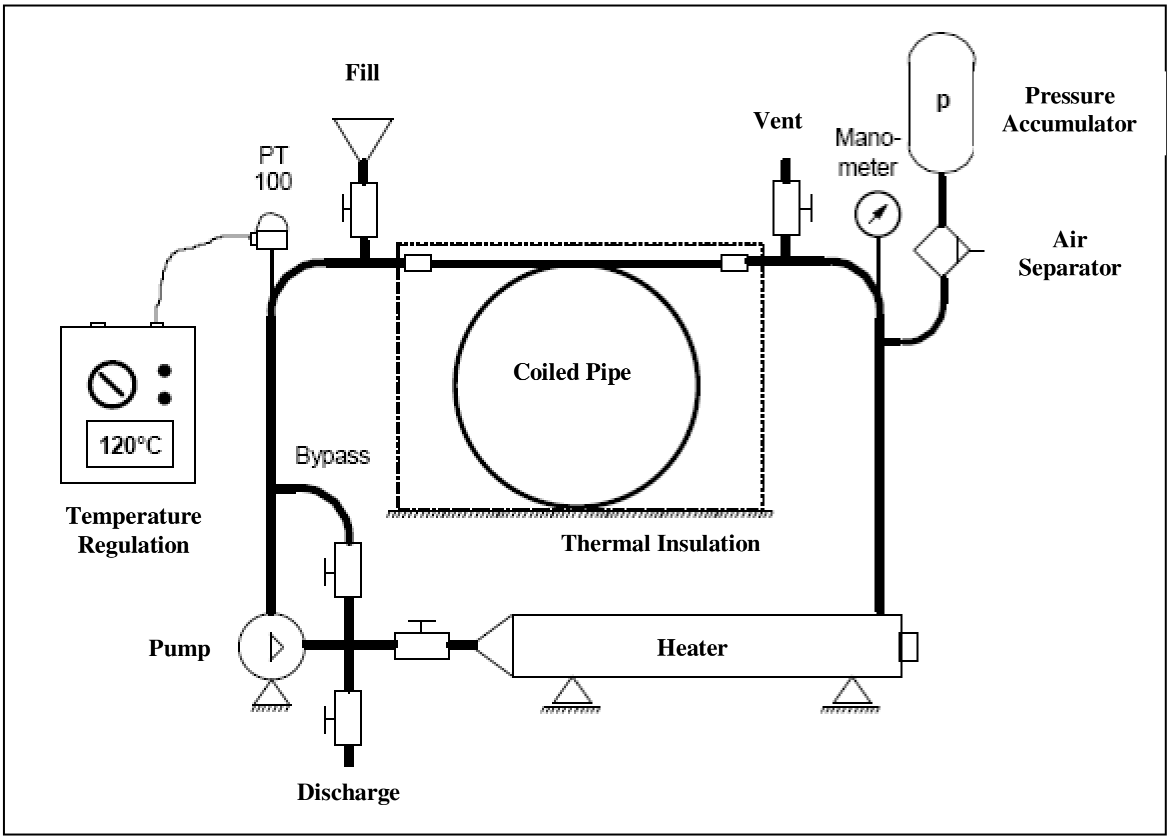

Fig. 1: Schematic plot of the test equipment

Pipe samples: 5 PE-X pipes and 1 PE-RT pipe 20x2

#2 PE-RT
#3 Peroxide cross linked PE-Xa
#6: Electron beam cross linked PE-Xc
#7: Peroxide cross linked PE-Xa
#8: Silan cross linked PE-Xb
#9: Silan cross linked PE-Xb

Test duration:	District heating water, -	120°C / 248°F	up to 15200h
		110°C / 230°F	up to 13000h
		95°C / 203°F	up to 13000h
	Drinking water	120°C / 248°F	up to 11000h

TEST RESULTS

Pipe Failure

For PE-X pipes, failures were observed only in the 120°C / 248°F test, they were of brittle nature. PE-RT pipes failed at 110°C/230°F as well. The failure times at 120°C / 248°F are given in table II.

Pipe	Material	Standard	DHW	DW
#2	PE-RT	DIN 16833	3429 h	3088 h
#3	PE-Xa	DIN 16892	12610 h	9411 h
#6	PE-Xc	DIN 16892	> 15200 h	> 11100 h
#7	PE-Xa	DIN 16892	> 15200 h	> 11100 h
#8	PE-Xb	DIN 16892	10031 h	10872 h
#9	PE-Xb	DIN 16892	15081 h	> 11100 h

Table II: Failure times of the pipes at 120°C / 248°F

The pressure strength at 120°C / 248 °F calculated from the extrapolated hoop stress curves gives a value above the test pressure of 1.5 bar, so it has to be concluded that the failures result from local degradation.

Tensile Test

Tensile tests were carried out in form of a ring tensile test; tensile stress and elongation were measured in circumferential direction. These tests did not show any degradation over the complete duration of the pressure testing. The elongation at break stayed the same as that of the virgin pipe, even in the vicinity of the brittle failure point.
The tensile stress increased up to 25% due to recrystallisation.

OIT Test

OIT samples were taken from the inner surface of the pipe and measured at 200°C / 392°F. Examples of the decrease of the OIT value with the test duration is given in Fig 3-5 for pipe #3 and #9. A linear relation between the OIT and log time is found down to 5min. A distinction into a regime A and a regime B with a different slope could not be detected. Such a distinction was several times reported in the literature (7) and explained by precipitation of the stabiliser in the material during regime A and the migration and consumption in regime B.
An OIT measurement with values below 5 min and a trial to extrapolate these values to OIT=0 does not seem to be advisable.
On the other hand there is a large difference between the OIT = 5min and the first failure in the pressure test with the exception of PE-RT, see Table III and IV.

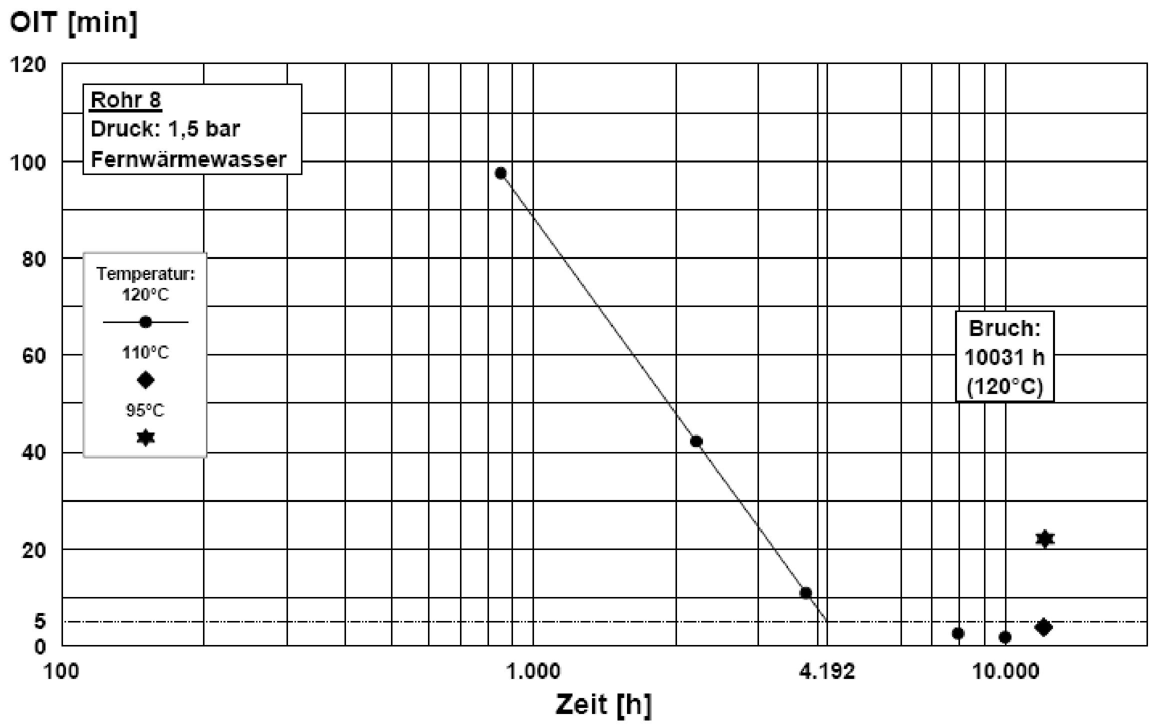

Fig. 3: OIT from pipe # 8 in district heating water

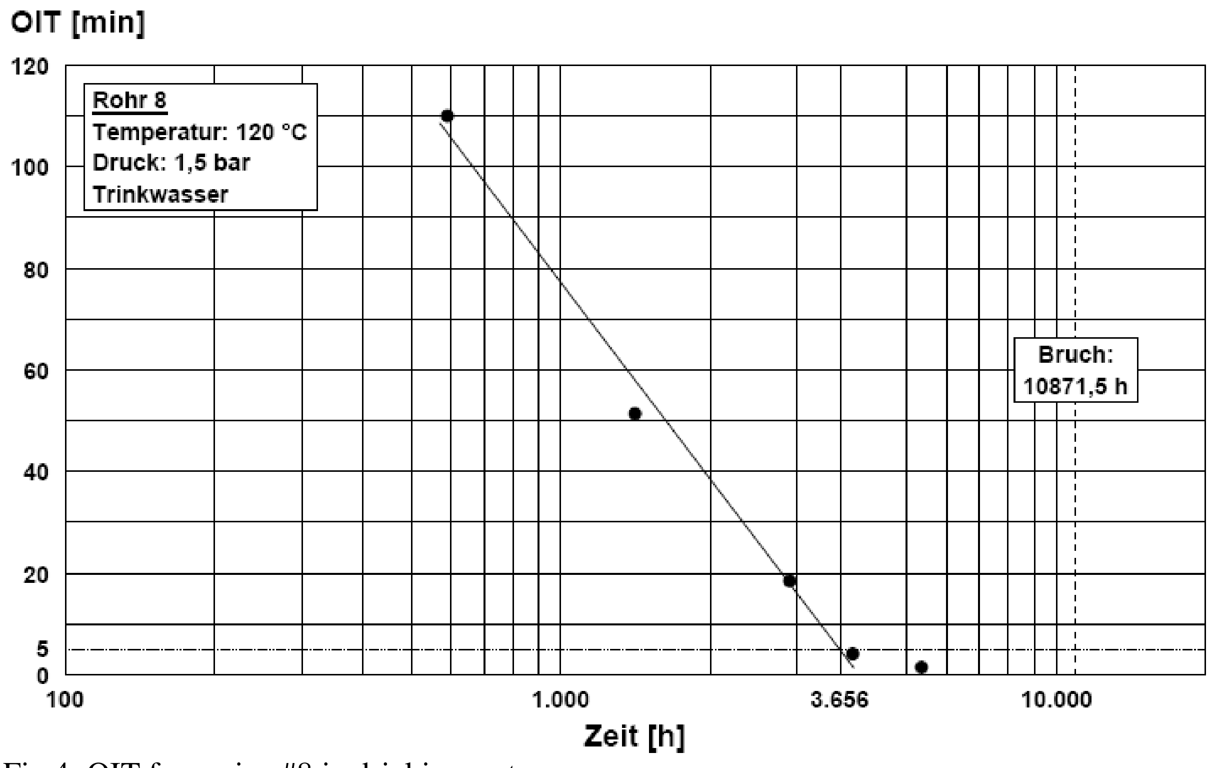

Fig 4: OIT from pipe #8 in drinking water

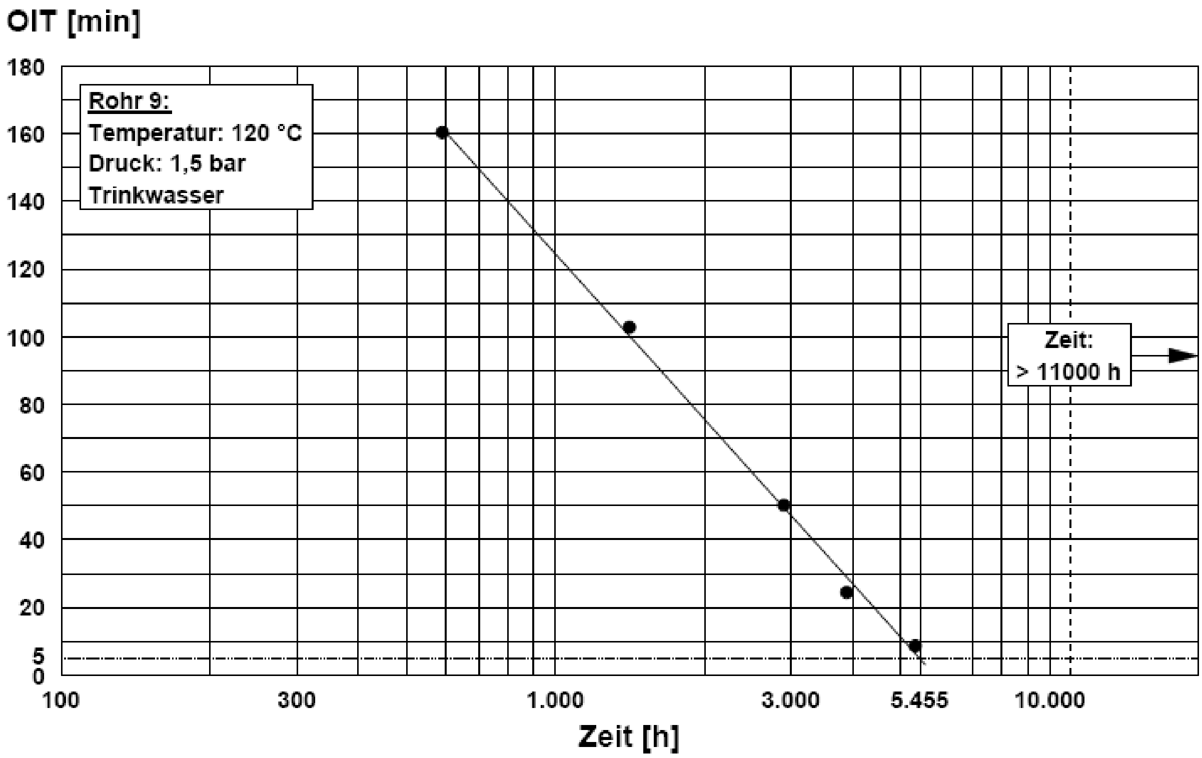

Fig 5: OIT from pipe #9 in drinking water

Pipe	Material	$T_{(OIT=5min)}$ [h]	Failure time [h]
#2	PE-RT	3803	3429
#3	PE-Xa	8398	12610
#6	PE-Xc	3026	> 15200
#7	PE-Xa	7754	> 15200
#8	PE-Xb	4192	10031
#9	PE-Xb	2595	15081

Table III: OIT = 5 min times and failure times in DHW

Pipe	Material	$T_{(OIT=5min)}$ [h]	Failure time [h]
#2	PE-RT	2792	3088
#3	PE-Xa	3754	9411
#6	PE-Xc	3439	> 11000
#7	PE-Xa	5538	> 11000
#8	PE-Xb	3656	10872
#9	PE-Xb	5455	> 11000

Table IV: OIT = 5 min times and failure times in DW

CALCULATION OF LIFETIMES

In order to calculate the life times of the investigated pipes the pressure test results were chosen and not the OIT values. As activation energy for degradation a value of 104kJ/mol was taken to be on the safe side and which was also calculated by M. Ifwarson and P. Ericson (8) from pressure test with PE-X pipes. The calculated life times of the investigated PE-X pipes for the standardised temperature profile are given in Table V.

Pipe	Material	Lifetime [years] in DHW	Lifetime [years] in DW
#2	PE-RT	13.6	12.2
#3	PE-Xa	50	37.3
#6	PE-Xc	> 60.3	> 43.6
#7	PE-Xa	> 60.3	> 43.6
#8	PE-Xb	39.8	43.1
#9	PE-Xb	59.8	> 43.6

Table V: Life time in DHW and DW based on an activation energy of 104 kJ/mol

Conclusions:

- **All PE-X pipes have a life time over the required 30 years for District Heating Water and Drinking Water.**
- **There are however significant differences subject to the recipes and process technologies, even within the PE-X types (see #3 and #7, #8 and #9).**
- **PE-Xc pipe currently are not widely used in district heating pipes. They obviously have the potential of being fit for purpose, but prove has still to be provided for larger diameters / wall sicknesses.**
- **PE-RT cannot be expected to achieve a lifetime of 30 years under the conditions to be expected in district heating networks.**

The tests were carried out without the oxygen barrier which is used for the service pipes in district heating system to prevent the permeation of oxygen into the heating systems. Pipes with an oxygen barrier have longer degradation times. This gives an extra safety in the life time.

2. AGING OF SEMI-FLEXIBLE PU-FOAM

Tests carried out by Fernwärme-ForschungsInstitut (10)

The durability of the thermal isolation of district heating pipes with metal service pipes and stiff polyurethane foam is well established up to temperatures of 140°C/ 284°F. For flexible piping systems containing a plastic service pipe the situation was different: The PUR foam is semi-flexible and the water diffusion from the service pipe into the foam has to be taken into account.

The project carried out by FFI investigates 2 district heating pipes comprising a PE-X service pipe and an isolation of PUR foamed with CO_2 and Cyclopentane and an outer casing layer of PE.

The geometric properties of the service pipes were 40 x 3.7 mm, the outer diameter 90 mm. The properties of the foams have been determined as:

Density: 75 kg/m^3
Cell Size: 0.2 mm
Compression resistance: 0.2 MPa

Different diffusion processes have to be taken into account:
- Cell gas diffusion. The cell gas will diffuse out and air will diffuse into the cells of the foam.
- Water vapour diffuses from the service pipe into the foam.
- Water diffuses from the outside through the casing layer into the foam in a wet surrounding.

All these processes might influence the properties of the foam. They were measured after storing or operating the pipe for 2 years in different conditions:

St RT:	Storing at room temperature	
St 70	Storing at 70°C / 158°F	
OP dry	Operating at 95°C / 203°F	service water in dry soil
OP wet	Operating at 95°C / 203°F	service water in wet soil
OP wtr	Operating at 95°C / 203°F	service water in cold water

Thermal conductivity
The results are given in Table VI.

Pipe	Coefficient of heat conductivity λ_{50} at 50°C / 122°F [W/mK]							
	Before Aging	After 1 year					After 2 years	
		St RT	St70	OP dry	OP wet	OP water	St RT	OP water
#A	0.022	0.024	0.027	0.028	0.028	0.029	0.028	0.031
#B	0.022	0.024	0.027	0.028	0.028	0.029	0.028	0.031

Table VI: Coefficient of heat conductivity λ_{50} at 50°C / 122°F [W/mK]

An increase of the thermal conductivity has been detected; the increase during the 2^{nd} year was significantly smaller than in the first year. Conclusions to be drawn:

a.) Operating in dry or wet soil has only very little effect on the aging compared with the aging effects of just storing at 70°C / 158°F.

b.) Even the results when operating under water are not significantly different from other operating modes.

c.) The limit set in EN 253 for Plastic Jacket Pipes (with steel service pipes within) of 0.033 W/mK for the whole lifetime can be regarded as being met for all operating conditions with the exception of operating under water.

Other properties
An investigation on the density, cell size and compression resistance did not show any significant change.

3. MECHANICAL PROPERTIES OF SEMI-FLEXIBLE PU-FOAM

Tests carried out by IMA Dresden (9)

The performance of polymer district heating pipes depends on these mechanical properties of the PU foam to be maintained during the lifetime: dimensional stability and shear strength.
For rigid PU foams, the respective properties have been proven, but no research had been taken out with regard to semi-flexible PU foams as used in polymer district heating systems.
Calculations carried out by GEF Ingenieur AG showed that the demands on dimensional stability and shear strength (0.2 MPa) are identical for systems with steel service pipes or polymer service pipes, as the shear.
The extrapolations of the tests carried out at IMA Dresden proved, that the PU foams used for flexible district heating pipes comply with these demands up to a temperature of 120°C / 248°F during a lifetime of 30 years.
Therefore, these foams are perfectly suitable for the flexible district heating pipes with a maximum operating temperature of 95°C / 203°F, but not for district heating pipes with operating temperatures above 120°C / 248°F.

4. SUMMARY

The tested district heating pipes with PE-X service pipes and semi flexible PU foam are fit for purpose for a lifetime of more than 30 years.

Literature:

1. Final Report *Zeitstandsverhalten und Wärmealterung von Mediumrohren aus Kunststoff und deren Schweißverbindungen*, Hessel Ingenieurtechnik, 2005
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4. ISO 13760: *Plastics pipes for the conveyance of fluids under pressure - Miners rule - Calculation method for cumulative damage*
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6. ISO 10146: *Crosslinked polyethylene (PE-X) pipes - Effect of time and temperature on the expected strength*
7. J. Viebke and U.W.Gedde, *Polymer Eng and Science*, 37(1997), p. 896
8. M. Ifwarson and P. Ericson, *Kunststoffe*, Bd 76(1986), p. 245
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10. Final Report *Experimentelle Untersuchungen zum Einfluss der Diffusion*, Fernwärme-Forschungsinstitut, 2005
11. EN 253: *District heating pipes - Preinsulated bonded pipe systems for directly buried hot water networks - Pipe assembly of steel service pipe, polyurethane thermal insulation and outer casing of polyethylene*