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100 Year Service Life of Polypropylene And Polyethylene Gravity Sewer Pipes

A TEPPFA Project in cooperation with Borealis and LyondellBasell

Summary Technical Report

(Based on Extracts of the Full Technical Report)

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100-years-service-lifetime prediction of Polyolefin gravity sewer systems

- A summary of the study [1] of Teppfa in cooperation with Borealis and LyondellBasell

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ABSTRACT

The prediction of the life expectancy of plastic pipe systems is well documented for pressure applications but for non-pressure application in sewage and drainage a scientific approach for prediction lifetime was not available. The study aims to provide sufficient validated data to enable an in-service life expectancy of at least 100 years to be declared for polyolefin (PE and PP) sewer pipes produced according to EN 1852-1 [2], EN 12666-1 [3] and Type B pipes of EN 13476-3 [4].

To demonstrate the long term performance of sewer pipes, solid wall and structured wall, made from PE and PP-B, the thermo-oxidative degradation, the maximum allowed stress, the long term behavior under constant strain and the effect of sewer and temperature have been investigated. Data from virgin material was used but also an intensive study on excavated pipes with lifetimes up to 38 years was included.

The study demonstrates that polyolefin sewer systems will have an in-service life of at least one hundred years when materials, products and installation practices meet the appropriate requirements (See Section 4 Conclusions for details)

The project was independently validated by prof. H. Dragaun from SV für Polymertechnologie, Austria.

1. INTRODUCTION

The prediction of the life expectancy of plastic pipe systems is well documented for pressure applications, where stresses in the pipe wall are acting continuously. Hydrostatic tests at different temperatures allow us with Arrhenius extrapolations to make a reliable estimate of the predicted lifetime at specific pressure and temperatures (Fig.1).

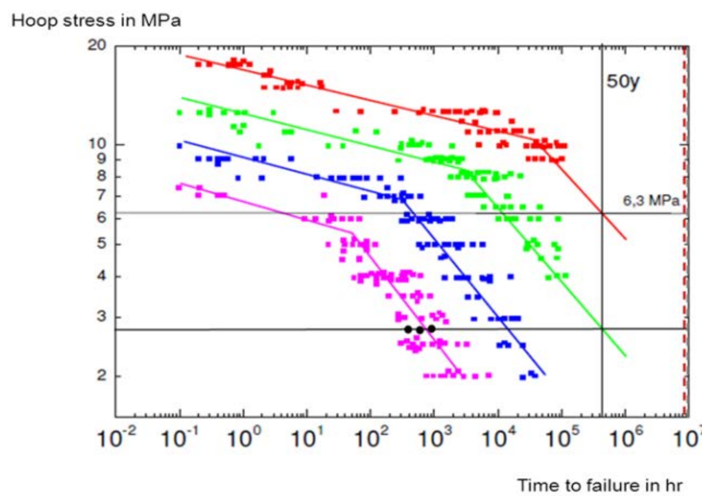

Fig 1 Life time prediction with hydrostatic tests

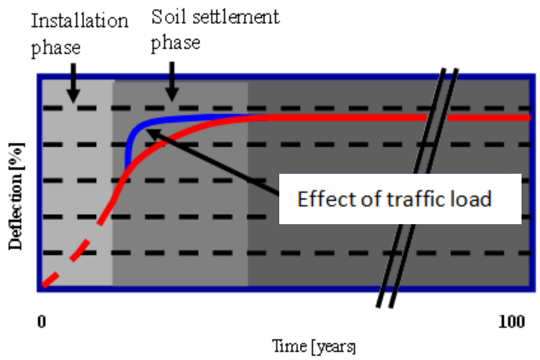

Fig 2 Deflection of installed pipes over time

For applications in sewage and drainage where pipes are installed and operate without internal pressure, a continuous deflection and subsequently a constant strain loading applies (Fig.2). Also for this application a lot of literature on the performance of polyolefin pipes [1] have been researched but a scientific approach to estimate the lifetime of these pipes and materials in non-pressure applications is not available and so far no adequate test methods are defined. Therefore, in current international product standards for non-pressure sewage pipes manufactured from PE or PP no reference has been made to the predicted lifetime of these pipes

In daily practice it becomes increasingly important to provide more accurate evidence of the predicted lifetime.

The study prepared aims to provide sufficient validated data to enable an in-service life expectancy of at least 100 years to be declared for polyolefin (PE and PP) sewer pipes. The study covers PE and PP pipes produced according to EN 1852-1 [2], EN 12666-1 [3] and Type B pipes of EN 13476-3 [4].

Border conditions

The investigation and conclusions are drawn based on the following assumptions:

- The pipes should be made according to an accepted high level of production practices and should fulfill the requirements of European product and system standards (EN1852 for PP, EN12666 for PE and EN13476 for Structured Wall Pipes of PE and PP). The 30 % Ring flexibility test together with the impact test as defined in the standards are adequate and selective tests to avoid excessive high stress concentrations and bad welding lines between the 2 layers of type B structured-wall pipe.
- The analysis and predictions are based on the use of virgin materials only.
- Modified materials and mineral filled materials are not covered in this report

2. APPROACH

To demonstrate the long term performance of sewer pipes, solid wall and structured wall, made from PE and PP-B, the following items have been investigated:

a. Thermo-oxidative degradation and allowable stresses

<u>Thermo-oxidative degradation</u>

To achieve a 100 year service lifetime it has to be proven that non-pressure pipes resist premature (brittle) failures caused by thermo-oxidative degradation. To prove this a test method and results of the materials used for pipes under study has to be proposed.

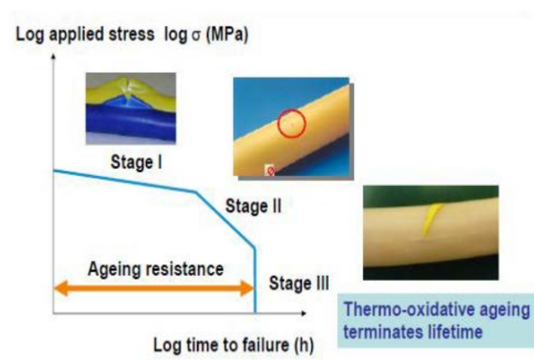

Fig 3 Hydrostatic pressure behaviour of PE pipes

Maximum allowable stresses

The resins from which the pipes are made should fulfill the basic requirements as defined in the products standards to demonstrate the resistance to slow crack growth. By those checks it is proven that the material fulfills the reference lines given by ISO15494 [5].

The maximum allowable stresses in non-pressure pipes to assure a 100-year service lifetime, especially for structured-wall constructions are collected from the reference lines at 23 °C, 30 °C and 45 °C extrapolated to 100 years.

b. Long term behavior under constant strain

The long term behavior under constant strain loading of non-pressure sewer pipes been analyzed by the use of relaxation tests, measuring the relaxation modulus as a function of loading time. The relaxation tests have been assessed based on 3 possible basic shapes for relaxation (compliance) curves (see figure 4) as defined by Janson [6]. The data is used to calculate the long term expected stresses by means of extrapolation to 100 years. The values found should be lower than the allowed stresses as determined under paragraph 2.a. to prevent the risk of pipe failure under constant long term deflection.
This has been completed on pipes made of virgin material and excavated pipes (see paragraph d.).

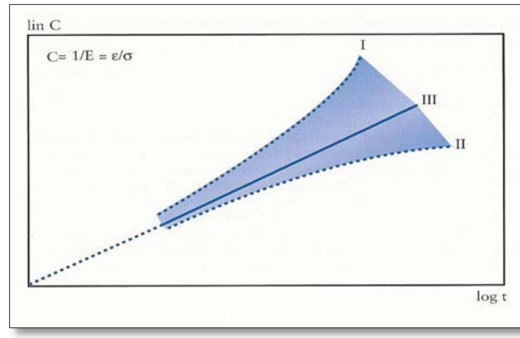

Fig 4 Janson compliance curves

The constant load applied during the test was 15 % which is far above the maximum allowed load of 8 % deflection as indicated by installation requirements [7].

c. Effect of sewer water and temperature

EN476 [8] allows a continuous discharge temperature of 45˚C for diameters ≤ 200mm and 35˚C for diameters > 200mm.
In this report, the behaviour at a continuous maximum temperature of 45˚C has been evaluated. However a study was done to find out how realistic these values are.

Note: diameters ≤ 200mm are mostly used in house connections where diameters > 200mm are used as sewer mains where the temperature in practice is even lower.

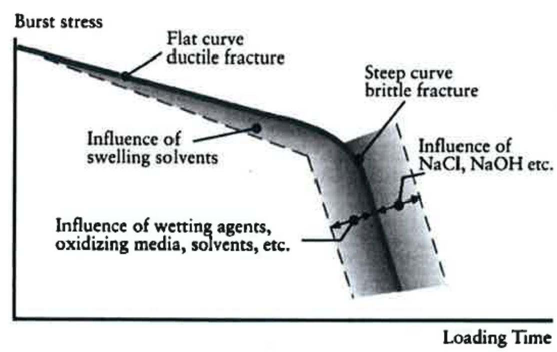

Fig 5 Effect of chemicals

In addition the life prediction could also be effected by the composition of chemicals in the sewer water. An intensive investigation done in Austria was used as input [9] to analyze how critical the sewer water is and judge if possible reduction of life time due to sewer water could be expected.

d. Excavation projects

Excavation projects have been included to analyze the remaining quality of the sewer pipes after a period of operation and the prediction of remaining lifetime of these pipes.

At 5 sites, pipes which have been in service for long periods have been excavated and analyzed.

- PE solid wall pipes 200mm SN8 excavated in Finland, 38 years old (figure 6.1);
- PE solid wall pipes 280mm and 355mm SN8 excavated in Germany, 16-18 years old (figure 6.2);
- PP solid wall pipes 110mm SN8 excavated in Norway 23 years old (figure 6.3);
- PP structured wall pipes 160mm SN8 (double wall pipe) excavated in Norway 20 years old (figure 6.4);
- PP structured wall pipes 200mm SN6 (ribbed pipe) excavated in Denmark, 12 years old (figure 6.5).

Fig 6.1

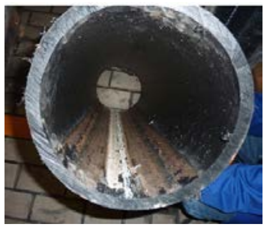

Fig 6.2

Fig 6.3

Fig 6.4

Fig 6.5

Analysis has been completed on physical characteristics, polymer degradation, pressure tests according to current standards, deflection after excavation as a measure of internal stresses, residual ageing resistance (PE), ring flexibility and impact testing.

3. RESULTS

a. Thermo-oxidative degradation and allowable stresses

By using Arrhenius extrapolation and activation energy values for PE and PP it was concluded in the report that the PE and PP grades for non-pressure pipe application shall demonstrate their resistance to thermo-oxidative degradation by fulfilling the requirements of Table 1.

Table 1 Thermo-oxidative requirement and test conditions

Material	Test condition	Requirements	Test method
PE	95 °C, σ = 1.0 MPa, water in water	> 8760 h	ISO 1167
PP	110 °C, σ = 1.0 MPa, water in air	> 8760 h	ISO 1167

Experimental data has proven that virgin materials for non-pressure pipes can fulfill this level.

The allowable stresses at 100 years are calculated from the reference lines given in ISO 15494 [5] and presented in Table 2.

Table 2 Maximum allowable stresses at 100 years lifetime, calculated from [5]

Material	Stress in MPa (45 °C / 100 years)	Stress in MPa (30 °C / 100 years)	Stress in MPa (23 °C / 100 years)
PE	5,2	6,6	7,4
PP	3,9	6,9	7,9

The resins from which the pipes are made have been tested and fulfill the basic requirements of hydrostatic testing at elevated temperatures during 1000h, as defined in the products standards to demonstrate the resistance to slow crack growth.
Also solid excavated pipes have been tested, see d.

b. Long term behaviour under constant strain

In the investigation it is found that in all cases, virgin and excavated pipes, follow a straight line in the compliance versus log time curves, up to 13270 h test duration which demonstrates a stable pipe material and pipe wall. This also means that a straight relaxation behaviour may be expected allowing extrapolation of this data to 100 years.

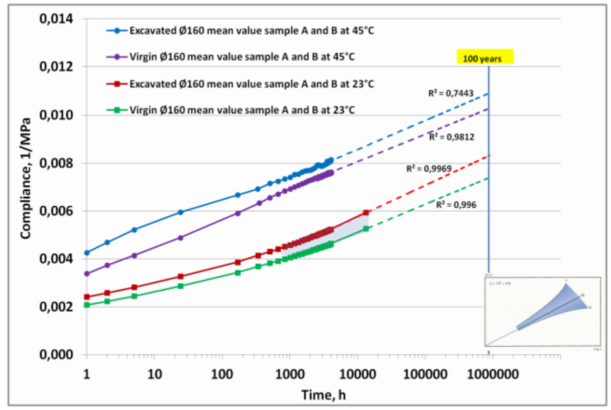

Fig 7. Creep data following Janson compliance curve III (see fig 4)

In table 3 calculated stresses of SN8 pipes after relaxation at long term (100 years), by 8% and 15% deflection at 23˚C, are shown.

Table 3 Calculated stresses of SN8 pipes by 8 % and 15 % deflection

	T (°C)	Stress after 4000 h		Stress after 13270 h		Stress after 100 years	
At deflection of		8 %	15 %	8 %	15 %	8 %	15 %
PP 110mm solid wall	20	3.37	4.87	2.88	4.15	2.05	2.95
PP 160mm structured-wall	20	4.79	6.91	4.21	6.06	3.17	4.57
PE 200mm solid wall	20	3.74	5.40	3.47	5.01	3.01	4.34
PP 160 mm structured-wall at 45 °C	45		4,74				3,29

At maximum deflection of 8% the long term stresses are well below the critical values (see table 2).

A maximum deflection of 15% of structured wall pipes becomes more critical. However, relaxation tests conducted at 15% deflection over 13270 h have demonstrated that the pipes relax in a regular way without unstable deviations, indicating that no failure would be expected. It has been found and reported [1] that at 15 % deflection, the (relaxed) stress is already lower than the long term allowable stress within 24 h relaxation time for solid wall pipes and within 1000 h relaxation time for structured-wall. At 8 % deflection the stresses of the structured-wall after 24h relaxation time are also below the allowable stress.

<u>In summary</u>

- Considering the remaining stresses it is recommended that deflections of more than 8% should be avoided. The pipes have to be installed according to the relevant standard (CEN/TR1046) [21] and the recommendations of the Teppfa study "Buried Pipes"- [15] referenced in this report.
- As stated, it should be remarked that the allowable long term stresses are not continuously exceeding the defined levels at the operating temperatures. Thus there is some safety already in this approach

c. Effect of sewer water and temperature

Study of sewer temperatures has shown that in practice under various situations the temperature does not exceed 30˚C. This means that a significantly higher margin of safety has been included in our approach concidering the actual temperatures occurring, the stresses in the pipes are far below critical values

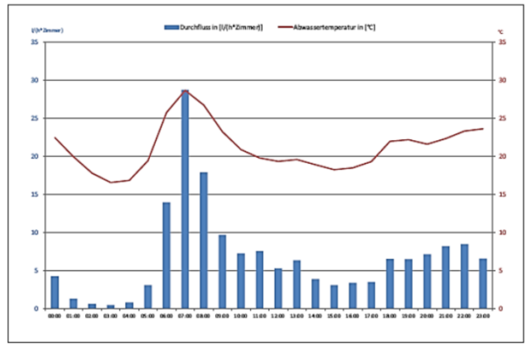

Fig 8 Temperatures in sewer system.

Analysis of the composition of sewer water result in a conclusion that no effect on the lifetime of pipes is expected. The concentrations of possible harmful chemicals are far too low to create an effect.

d. Excavation projects

All excavated pipes, PE and PP-B, have shown no reduction in quality.

- The physical characteristics (OIT, Intrinsic viscosity, MFR, density, melting point, tensile properties, elongation at break) are all in the range of the old PE63 data sheets.
- With GPC, no accelerated polymer degradation was found due to sewer water attack
- In pressure tests, σ2,8MPa at 80˚C on 200mm PE pipe, found failure times, (resp. 584h, 417h, 1034h) these are similar results as published for original PE63 pipes of the first generation.
- In pressure tests, σ2,5MPa at 95˚C on 110mm PP-B pipes, found failure times (resp. 1260h and 2x >2800h),these were much longer than the original requirements (>1000h).
- The deflection after excavation was , ~1,5% for PE pipes 200, 280 and 355mm and 1,6 - 2,0% for PP-B solid wall and structured wall pipes.
- With heat aging tests, a residual lifetime of more than 50 years has been calculated
- Ring flexibility and impact test at -10˚C for PP-B pipes, solid wall and structured wall, meet today's requirements

		Unit	Structured wall DN160mm Norway		Solid wall DN110mm Norway		Ultrarib DN200 Denmark	
			Outer layer	Inner layer	Outer layer	Inner layer	Outer layer	Inner layer
DSC	Melting temperature	°C	159,2	159,8	161,5	160,6	167,7	165,7
	Crystallisation temperature		113,5	112,9	111,3	112,2	128,1	122,5
OIT	210°C/O²	Min	6	5	7	3	17	25
MFR	230°C/2,16kg	g/10min	0,39	0,47	0,64	0,61	0,51	0,34
HPLC	Irganox 1010	ppm	1300	1258	1135	850	1708	3183
	Irgafos 168	ppm	106	X	X	X	1249	1004
	Irgafos 168OX	ppm	X	X	X	X	309	574
GC	DSTDP	ppm	2450	2449	2392	2429	1938	X
Spectroscopy	IR		PP-B (8,85w%) Fe2O3	PP-B (9,22w%) Fe2O3	PP-B (6,81w%) Carbon black		PP-B (4,48w%)	PP-B 12,65 %
Mechanic	Ringstiffness	kN/m²	7,86		5,67		10,14	
	Ringflexibility	%	43,82		36,37		45,07	
	Falling weight -10°C / H50	mm	984 (8kg)		2820 (8kg)		3325 (10kg)	

Fig 9. Example test data collected on pipe

<u>In summary</u>

Using qualified polyolefin materials and pipes that are well extruded and installed according to good workmanship-practice, the test results of the 5 excavated PE and PP pipes have shown that polyolefin pipes are well qualified to reach a 100 years lifetime.

Even for PE of the first generation it has been demonstrated that after 38 years of operational use, a total lifetime approaching 100 years can be expected. PP materials up to 23 years operation time did not show any significant reduction of mechanical properties and stabilization.

4. CONCLUSIONS

In this study, it has been demonstrated that a 100 years lifetime for non-pressure sewage pipes of PE and PP-B can be expected, provided that the following conditions are met:

a. The pipes shall meet the requirements of European product and system standards, resp. EN1852 for PP, EN12666 for PE and EN13476 for Structured Wall Pipes of PE and PP, and
b. The material, pipes and installation shall meet the requirements specified in table 4.

Table 4. Requirements for sewer pipes and materials to prove the 100 years lifetime

Category	Performance Characteristic	Condition	Requirements
Material requirements	Thermo-oxidative degradation 1)	PE: 95 °C, σ = 1.0 MPa PP: 110 °C, σ = 1.0 MPa	> 8760 h > 8760 h
	Max. allowable stresses derived from the available reference curves [5] 2)	45 ˚C: PE, σ = 5.3 MPa 3) PP, σ = 3.9 MPa 5) 23 ˚C: PE, σ = 7.4 MPa 3) PP, σ = 7.9 MPa 4)	100 years 100 years 100 years 100 years
Pipe requirements	Hydrostatic tests EN 12666 and EN 1852	PE: 80 °C, σ = 2.8 MPa PP: 95 ˚C, σ = 2.5 MPa	1000 h 1000 h
	Product requirement acc. to EN 13476	Ring flexibility	30 %
	Relaxation tests	PE & PP: Acc. to Janson [6]	≥ 4000 h at 15 % deflection
	Microscopic analysis of the strained pipe samples	PE & PP: At the end of ≥ 4000 h Janson test	No crack initiation, no cracks or other damages
Installation requirements	Pipe installation	Acc. to CEN/TR 1046 [7] Acc. to Teppfa study [10]	Moderate or Well compaction Standard proctor >87 %
	Maximum pipe deflection at commissioning	Acc. to CEN/TR 1046 [7]	Max. 8 %

1) Using test conditions based on these experimental data, the prediction of 100 years service-lifetime with regard to the resistance to thermo-oxidative degradation can be assured.
2) The calculated stresses for 45 °C at 100 years lifetime assumes for
- PE, that no second branch after 50 years appears.
- PP-B, that no third branch (thermo-oxidative degradation) after 50 years appears.
3) Hoop-stress calculated acc. To ISO 15494 [5], Annex B, paragraph B.1.2, Equation B.2 for PE 80
4) Hoop-stress calculated acc. To ISO 15494 [5], Annex E, paragraph E.1.2, Equation E.6 for PP-B (first branch)
5) Hoop-stress calculated acc. To ISO 15494 [5], Annex E, paragraph E.1.2, Equation E.6 for PP-B (second branch)

This outcome is supported by other recent investigations, indicating that non-pressure sewage pipes do not behave differently from the pressure pipes of the same period [11], where it has been concluded that after a service time of 30 years a remaining lifetime of at least 50 years is predicted.

5. WAY FORWARD

The additional requirements of this study, listed in table 4 shall be added to future versions of the relevant product standards to prove the long term stability of the material and the wall construction as well as the long term resistance to stress cracking.

6. THIRD PARTY VALIDATION

The whole test program and the results has been validated by an independent third party authority which was Prof. Dr. Heinz Dragaun, SV fur Polymertechnologie, Brunnengasse 10 3424 Wolfpassing, Austria.

“100-years-service-lifetime prediction of Polyolefin gravity sewer systems”

I consider this project to be very relevant to improving knowledge of the in-service performance of polyolefin sewer systems all over the world.

As an experienced person in the field of testing plastics pipes at the “TGM-Versuchsanstalt - Federal Institute of Technology, Department Plastics Technology and Environmental Engineering”, Vienna since 1975, I was invited as an independent expert to review and comment on the work which was carried out for this project over the last 3 years.

Summarizing it is to say a lot of investigations were conducted - both on material data and also in the area of functional performance in the field - on pipe samples not only from new production but also older materials which were excavated after long term practical application from different European countries (some which have been in service for almost 40 years)

All test methods used were executed in accordance with valid International Standards (ISO) and the actual knowledge of science in polymer materials.

The investigations were carried out on classical solid wall pipes (monolayer and multilayer) and also on so called geometrical structured wall pipes, which is a more recent innovation In my opinion the project has been conducted in a proper and scientifically reliable way with close cooperation between material producers and pipe and fitting producers with the target of demonstrating how long time service quality can be achieved in the field of Polyethylen(PE) and Polypropylene (PP) pressure less sewer systems.

Prof. Dr. Heinz Dragaun

7. LITERATURE

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