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TNO report

MT-RAP-2008-01066/mso | 2

Quality of PVC sewage pipes in the Netherlands

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Project number	033.12953
Number of pages	25 (incl. appendices)

Contents

1 Introduction

The residual lifetime of existing PVC (polyvinyl chloride) tap water pipe systems in the Netherlands was studied within the project “Expected lifetime of existing PVC water distribution systems”; 007.63549. The probable degradation processes, which can occur in PVC materials, were evaluated and quantified. It was concluded that mechanical loadings leading to crack initiation and growth will dominate the premature failures. The expected residual lifetime of most of the PVC water pipes studied was calculated to be at least 100 years, provided that the pipes are properly installed and operated and that damages in the PVC pipe walls are less than 1 mm in depth.

Another application of PVC pipes in the Netherlands is in sewage systems. BureauLeiding asked TNO Science and Industry to study the quality of some excavated PVC sewage pipes. One excavated PVC sewage pipe from the Dyka location and 6 PVC sewage pipe parts from the “BIS” (pipe collecting system) for old pipes were selected. The selection of the 6 parts was performed based on visual characteristics, remainders from the sewage sediment, and the presence of a readable print on the pipe stating its origin.

The PVC parts were assessed visually and microscopically by TNO Science and Industry after cleaning by soaking and rinsing. Special attention was paid to the surface roughness, the wall thickness and the permanent deformation. Moreover, the degree of degradation of the inner surface as a result of the contact with the sewage flow was determined.

The experimental results of this study are presented in chapter 2.

A discussion on the expected lifetime of the PVC non-pressurised sewage pipes is presented in chapter 3 based on the experimental results and the crack growth resistance quantified in the former project on the existing PVC tap water pipes.

The summary and the conclusions are given in chapter 4.

2 Experiments and results

A part of a used sewage pipe of about 4 m was received from Dyka (R1/327107-TNO). It concerned a pipe which had been in use as sewage pipes at the Dyka location from 1973. The other parts of sewage pipes studied were obtained from the collecting system of old pipes. Remainders of sewage sediment were still present in those pipe parts. Herewith, it was confirmed that all pipes assessed in this studied had been applied in a sewage system. A summary of the pipes studied is given in table 2.1. Table 2.1 mentions the pipe code and the year of production.

Table 2.1 Summary of the excavated PVC sewage pipes.

TNO code	Print	Year
A	No print code Dyka: R1/327/107-TNO	1973
I	Dyka KOMO NEN 7005/7009 Kl41 125x3,2 27 5 22 3	1975
II	Dyka 110x3,2 KOMO PVC NEN 7045 kl 34 110x3,2 25-85-38-8-6-2	1985
III	Polva PVC Kl41-5-125x3,2 1051 - 85 - 25 – KOMO NEN7029 - 7045	1985
IV	Dyka 125x3,7 NEN7009/7029 Kl34 27 7 8 1	1977
V	Wavin PVC KOMO NEN 7045 7029 Kl34 125 x 3,7 1 35 86 125-44	1986
VI	Marimplast 200x4,0 1-76-11-4-2	1976

2.1 Visual assessment of the outer wall surface

The visual assessment of the outer surface of the pipe parts is summarised in table 2.2.

Table 2.2 Summary of the visual assessment of the outer wall surface of the sewage pipe parts studied.

TNO code	Remark	Figure*
A	Stains as a result of non-homogeneous discolouration; scratches	A.1
I	Slight discolouration; scratches	I.1
II	Hardly any discolouration; scratches	II.1
III	Hardly any discolouration; scratches	III.1
IV	Strong discolouration; scratches	IV.1
V	Moderate discolouration; scratches	V.1
VI	Non discolouration; scratches	VI.1

*) The figures (photographs) are found in the appendix.

The scratches present in the surface are shallow. Most of these scratches were probably introduced by incautious handling of the pipes during excavation. Notwithstanding those scratches, the functional properties of those PVC pipes are still intact.

The outer surface of the pipe (code A) shows some stains (see figure A.1). The contours of the stains are almost black. The initial gray colour of the pipes has darkened. This discolouring is ascribed to the interaction of the outer pipe surface with chemicals in the ground water flowing over the outer surface.
The part of the pipe located under the coupler hardly shows any discolouration.
The thickness of the degraded layer was less than 100 µm. The thickness of the severely discoloured layer was limited to a depth of the order of magnitude of 10 µm [1]. The properties of the discoloured layer seem to be intact. As a result of the limited thickness of the discoloured layer, the mechanical properties of the pipe will not be affected.

The discolouration of the other pipes studied was uniform and is ascribed to the surrounding soil conditions during operation. Relevant parameters of the soil conditions are acidity, humidity and composition. The thickness of the discoloured surface is limited to a depth of the order of magnitude of 10 µm. This discolouration is not affecting the mechanical integrity of the PVC. As a result, the discolouration of the outer surface has no consequences for the mechanical properties of the PVC pipe. The depth of discolouration is determined by the diffusion of chemicals into the pipe wall. Therefore, it is concluded that the thickness of the discoloured layer will increase with less than a factor of 3 within 20 and 100 years under operation.

2.2 Visual assessment of the inner wall surface

Some of the inner wall surface of the pipe parts studied showed after thorough cleaning by soaking in aqueous solution of detergent followed by an aqueous solution of sodium hydroxide and rinsing with a pressurised water jet still some remainder of sewage sediment. Especially, the part which experienced dry-wet cycles during operation showed the sewage sediment.
Some part showed visual wear from hard particles.

The inner wall surface under the remainders of sewage sediment did not show any characteristics of polymer degradation.

The non-smoothness of the pipe segment code I is ascribed to the production process. It is very unlikely that this surface condition is caused by sewage.

Some of the pipe part studied showed a significant discolouration. This discolouration is associated to chemicals which were present in the sewage during operation. The discolouration can occur by absorption or by some reaction with additives in the PVC material. For example, hydrogen sulphide will react with lead stabilizer and result in black lead sulphide.

The thickness of the discoloured inner surface layer is analogous to that of the outer surface layer and the depth is limited to the order of magnitude of 10 µm. No clues have been found that the discolouring is associated to the chemical degradation of PVC. Furthermore, it is stated that a discoloured layer with a thickness of the order of magnitude of 10-100 µm is not harmful for the mechanical integrity of the PVC pipe.

[1] The thickness of discolouration could not be quantified accurately. A certain gradient of discolouration was observed. The more severe discolouration was found in a depth of 10 µm starting from the exposed surface.

The observation made are summarised in table 2.3.

Table 2.3 Summary of the visual assessment of the inner wall surface of the sewage pipe parts studied.

TNO code	Remark	Figure
A	Remainders of sediment; no discolouration	A.2
I	Clean; black-blue discolouration; non-smooth	I.2-I.3
II	Clean; yellow-brown discolouration	II.2
III	Remainders of sediment; no discolouration	III.2
IV	Remainders of sediment; partly black-blue discolouration	IV.2
V	Almost appearance of new pipe	V.2
VI	Almost appearance of new pipe	VI.2

2.3 Microscopic assessment inner wall surface

Arch segments of the soaked and rinsed pipe parts were study using light microscopy. The results are summarised in table 2.4.
Almost all inner wall surfaces studied showed characteristics of wear. The upper PVC surface layer seems to be grinded. Surface crazes, which might have been present in the inner wall surface, can be removed by this grinding process. The advantage of the removal of the crazes is that the crack resistance of the pipe increases.
The thickness reduction of this grinding process is expected to be of the order of magnitude of 10 µm (see section 2.6).

Table 2.4 Summary of visual assessment of the inner wall surface of the soaked and rinsed parts.

TNO code	Remark	Figure
A	Scratches, wear and some small crazes	A.3-A.4
I	Scratches, wear and some crazes	I.4
II	Wear	II.3
III	Moderate wear; still shiny	III.3
IV	Wear	IV.3
V	Shiny; some crazes	V.3
VI	Scratches and wear	VI.3

The surface damages indicated as craze are very small. It was not possible to be conclusive on crazes. It is stated that provided that these damages are crazes, no craze growth have occurred.

The damages found in the pipe parts studied are not expected to have any consequences for the mechanical integrity of the PVC pipes.

A wear of the inner wall surface by 10 µm, will result in a reduction of the bending stiffness of the PVC pipes studied of less than 1 %.

2.4 Dimension of PVC pipes studied; circularity

All PVC pipe parts showed some non-circularity (see table 2.5). The diameter was measured at 4 positions over the circumference. The ratio of the highest and the lowest diameter values found is defined as the non-circularity.
The non-circularity of the PVC pipe is ascribed to creep as a result of non-uniform soil loads in the period between the installation and the excavation of the corresponding pipe. The stresses associated with the non-circularity will have been decreased during service by stress relaxation.

Table 2.5 Summary of the outer diameter, the non-circularity (maximum diameter found over circumference divided by minimum diameter found) and wall thickness.

TNO code	Diameter (mm)	On-circularity	Wall thickness (mm)
A	315	1.02	10 ± 1
I	125	1.01	3.4 ± 0.1
II	110	1.03	3.3 ± 0.1
III	125	1.02	3.3 ± 0.1
IV	125	1.01	3.9 ± 0.1
V	125	1.05	3.9 ± 0.1
VI	200	1.02	4.0 ± 0.1

2.5 Internal stress in pipe wall

An internal stress gradient is realised in PVC pipes as a result of the cooling process after leaving the extruder head in the production process. The cooling is executed using water on the outer wall. A stress gradient is then introduced characterized by a compressive stress in the outer wall and a tensile stress in the inner wall. The rate of cooling and the wall thickness determines the size of the maximum compressive and tensile stresses.
The size of the maximum compressive and tensile stresses was quantified by cutting pipe rings in length direction of the pipe. The overlap of the circumference of the pipe ring is proportional to maximum compressive and tensile stresses. The PVC pipe under study with a diameter of 315 mm showed an overlap of 25 mm. The maximum tensile stress, σ, in the inner surface of this pipe wall is then calculated according:

$$\sigma \approx \frac{l_o \times d}{4 \times \pi \times R^2} E$$

where l_o is the overlap length, d the wall thickness, R the averaged radius of the pipe wall and E the modulus of elasticity.

Substitution of l_o = 25 mm; d = 10 mm; R = 152.5 mm; E = 3000 N/mm^2 results in:

$\sigma \approx 2.6$ N/mm^2

Table 2.6 Summary of the calculated internal stresses based on the overlap of the PVC ring after cutting.

TNO code	Diameter (mm)	Wall thickness (mm)	Internal stress (MPa)
A	315	10 ± 1	2.6
I	125	3.4 ± 0.1	2.2
II	110	3.3 ± 0.1	1.7
III	125	3.3 ± 0.1	1.1
IV	125	3.9 ± 0.1	1.3
V	125	3.9 ± 0.1	2.3
VI	200	4.0 ± 0.1	0.9

2.6 Surface roughness inner pipe wall

The surface roughness of the inner pipe wall of the pipes under study was determined after the sewage sediments were completely removed by soaking and rinsing. The values of the surface roughnesses are mentioned in table 2.7.

Table 2.7 Summary of the local surface roughness quantified over a distance of 0.6 mm.

TNO code	Diameter (mm)	Roughness, Ra (µm)
I	125	1.0
II	110	0.9
III	125	0.4
IV	125	0.4
V	125	0.3
VI	200	0.6

Moreover, a distance of 16 mm was scanned to quantify the intrinsic global surface roughness. This roughness is largely determined by the production process (surface condition of the extrusion head). The results of these measurements are presented in figure 2.1.

It is noted that the local surface roughness is smaller than of the global surface roughness due to the production process. The increase in local surface roughness is too small to result in a measurable change in the hydraulic properties of the PVC pipe.

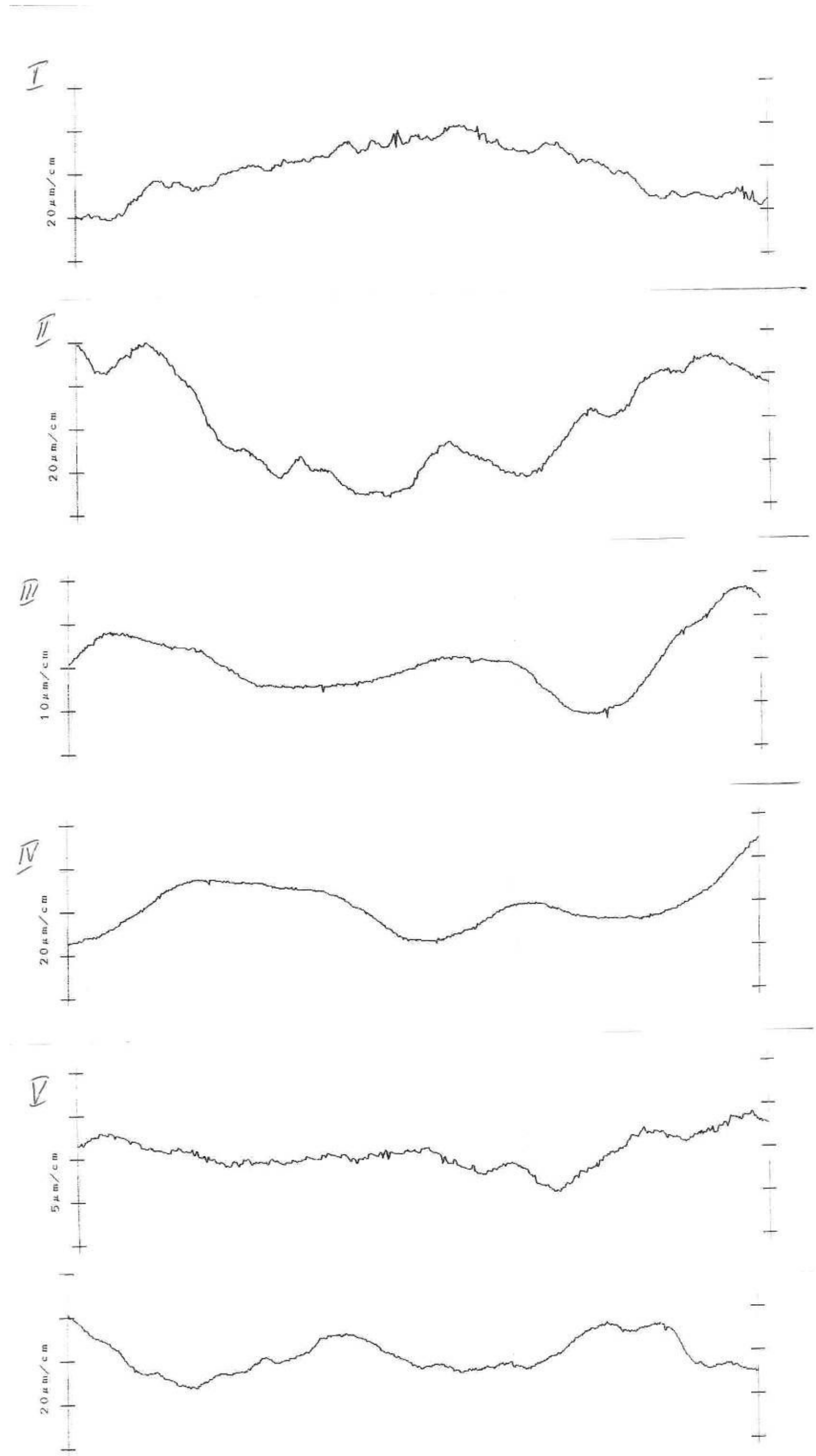

Fig. 2.1 Global surface roughness measurements on soaked and rinsed inner pipe surfaces of the pipes under study (I-VI) measured over 16 mm.

3 Discussion

A number of comprehensive studies have been performed by TNO on the long term behaviour of PVC distribution systems starting from the nineteen seventies. The “crazing and fracture” project on all kinds of PVC pipes, the “stress corrosion” projects on PVC gas pipes and the “expected residual lifetime ” project on existing PVC tap water pipes resulted in knowledge and experience about the expected long term behaviour of PVC pipe systems. The discussion in this chapter is based on knowledge and experience from earlier projects and literature searches.

The summary of the report TNO-MT-RAP-06-18693 reads:
The chemical degradation rate in buried PVC pipes can be neglected provided that the existing PVC pipe systems all contain a considerable amount of non-consumed stabilizers. Therefore, it is concluded that the residual lifetime of PVC water distribution pipes is not limited by chemical degradation.

The physical ageing rate in the PVC pipe wall is a self retarding process, which will slowly evolved at soil temperatures in the range of 5-15 °C.
The influence of physical ageing is moderate for well-gelled PVC pipes. The resistance for slow crack growth will decrease very slowly in time.
The influence of physical ageing can become significant for poorly-gelled PVC pipes. The resistance to slow crack growth, which is already low for poorly-gelled PVC pipes, was shown to decrease significantly upon physical ageing.

The loading history can have resulted in some micro-cracks in the PVC pipe wall. The presence of micro-cracks in some of the excavated PVC pipes studied resulted in a reduction of the resistance to impact and fatigue loads.

In summary, it is concluded that the existing PVC tap water pipe systems in the Netherlands will operate for at least 100 years provided that the internal and external loads do not result in hoop stresses which will exceed 12.5 MPa and that no micro-cracks and mechanical damages are present in the PVC pipes.
The residual lifetime of existing PVC water pipe systems, in particular when the PVC pipe is of marginal quality, can be reduced by among others fatigue loads, the presence of micro-cracks and non-uniform ground settlements. Some of the excavated PVC water pipes from the nineteen seventies and nineteen eighties showed some marginal quality.

The current study on the excavated PVC sewage pipes showed that:
- surface discolouration was found in a limited number of pipes studied and often only locally;
- moderate surface wear (erosion) occurred on the inner wall;
- moderate non-circularity was found.

The conclusions stated in TNO-MT-RAP-06-18693 on the PVC tap water pipes also hold for the sewage pipes studied here, because the surface discolouration and the surface wear in the PVC sewage pipes studied is limited to a depth of the order of magnitude of 10 μm.

The expected external stresses in the wall of a PVC sewage pipe are low. The initial strain in the PVC pipe wall will have been of the order of magnitude of 0.1 % based on the non-circularity found experimentally. The non-circularity is related to creep under the non-uniform soil pressure. The maximum non-circularity is found for the PVC pipe coded V. This pipe showed a permanent maximum strain level of 0.3 %.
The increase in creep deformation between 30 and 100 years under soil loads will be only a fraction of the creep deformation found after 30 years provided that the soil load is not disturbed. It is thus highly improbable that the PVC sewage pipes will show a significant increase in non-circularity by an extended use after 30 years of operation.

The stress levels, which are expected in the PVC pipe walls studied during operation, are mentioned in tabel 3.1. It is assumed that it concerns non-pressurised PVC sewage pipes.

Table 3.1 Expected stress levels in the PVC sewage pipes studied.

Origin	Stress (MPa)
Internal stress (production process)	< 3
Soil loads	< 3*
Total loads	< 6

*: provided that no peak stresses occurs due to the presence of hard substances in the soil surrounding the pipe.

Conservative stress values are shown in table 3.2 for the craze initiation and the craze growth resulting in cracks.

Table 3.2 Summary of required stress levels for PVC to cause damage initiation and growth within 100 year.

Damage	Stress
Craze initiation (aged PVC)	>10 (MPa)
Slow crack growth (aged PVC)	>12 (MPa)

A well-installed PVC sewage pipe will show a wall stress lower than 3 MPa as a result of soil loads. Combined with the non-relaxed internal stress due to the production process, it is expected that the maximum tensile stress in the PVC sewage pipes will not exceed 6 MPa.

The conservative criteria for craze initiation and crack growth, starting from a crack depth of 1 mm, obtained from previous PVC projects are thus not fulfilled by PVC sewage pipes. The initiation of crazes during operation is therefore unlikely. This conclusion is in agreement with the observation that only some small crazes were found in the inner wall surface and no craze growth.

4 Summary and conclusions

The investigation was performed on behalf of BureauLeiding. Seven part of sewage pipes were studied. One sewage pipe in operation during 1973 was excavated at the Dyka facilities. The other six parts were selected from the “BIS” collecting system. The criteria for the selection were:

- applied as sewage pipe;
- readable print on the pipe.

The selected parts were assessed at TNO by:

- visual inspection;
- microscopic inspection;
- geometrical analysis and deformation;
- surface roughness and inner surface degradation assessment;

Although some PVC sewage pipes showed signs of operation, the integrity of the PVC pipes is still intact. Some mechanical damage (scratches) and some abrasion were observed, which can be attributed to the transport of abrasive compounds, for example sand particles.

No chemical degradation of attack by aggressive solvent was observed in the parts studied.

Based on the TNO knowledge of PVC pipe systems and the lifetime investigations of PVC materials starting about 40 years ago, no craze initiation, craze growth and crack growth are expected given the expected maximum wall stress in those pipes.

The expected lifetime of studied PVC sewage pipes is expected to be exceeding 100 years. In general the lifetime of PVC sewage pipes will be exceeding 100 years, provided that no aggressive chemicals are transported in the sewage system and the transport of abrasive particles is limited.

The investigations on the PVC sewage pipes studied here confirm the common knowledge that the lifetime of PVC pipe systems will exceed 100 years under most service conditions.

5 Signature

Eindhoven, April 2008

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APPENDIX – Photographs
The codes A, I, II, III, IV, V and VI corresponds to the pipe codes mentioned in table 2.1.


Fig. A.1 Stained pattern on outer pipe wall.

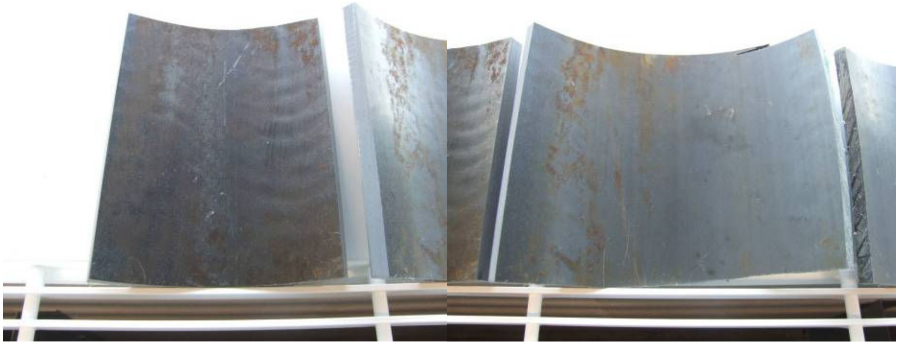
Fig. A.2 Inner surface pipe wall of some parts.


Fig. A.3 Inner wall surface; wear tracks in the length direction of the pipe (shown surface: ca. 10x10 mm).

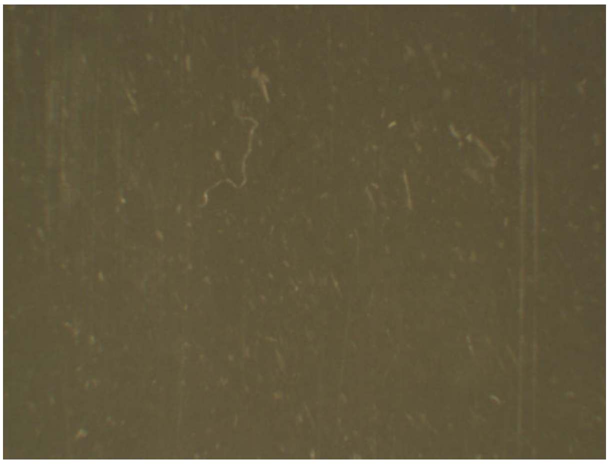

Fig. A.4 Inner wall surface; small damages and craze (shown surface: ca. 10x10 mm).

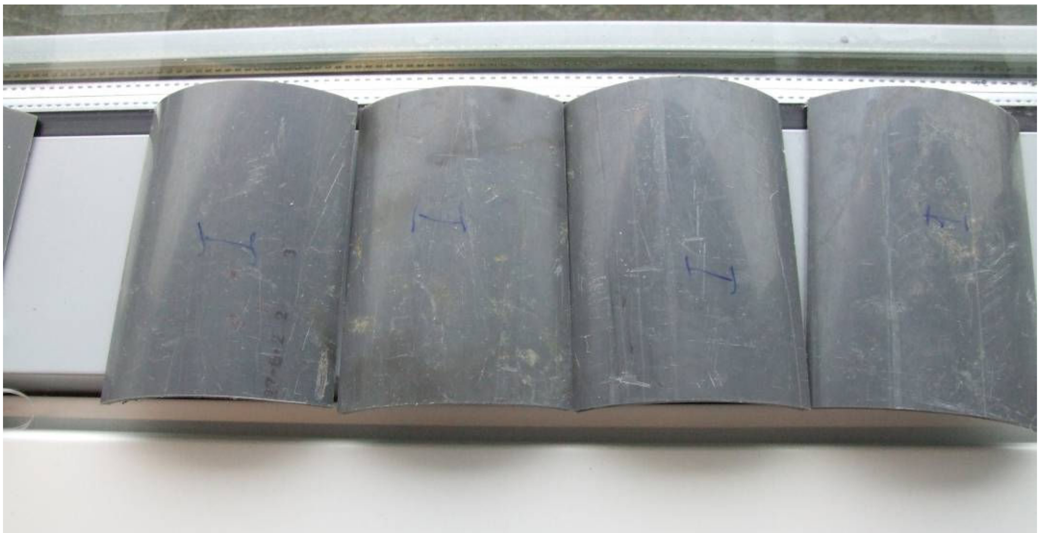

Fig. I.1 Outer pipe wall.

Fig. I.2 Inner pipe wall.

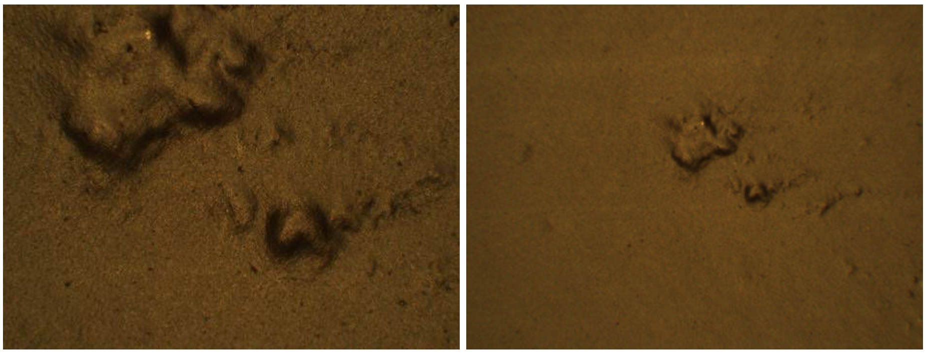

Fig. I.3 Surface inner pipe wall; non-smoothness ascribed to production process (shown surface right: ca. 10x10 mm; left: magnification 6x right photograph).

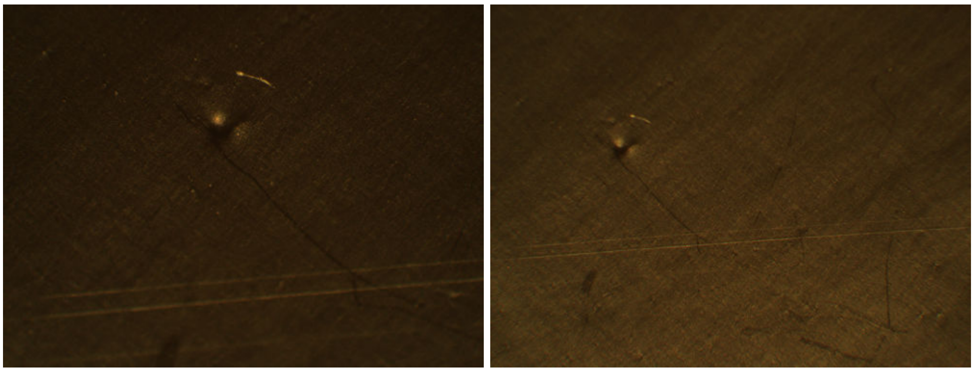

Fig. I.4 Surface inner pipe wall; non-smoothness ascribed to production process (shown surface right: ca. 10x10 mm; left: magnification 6x right photograph).

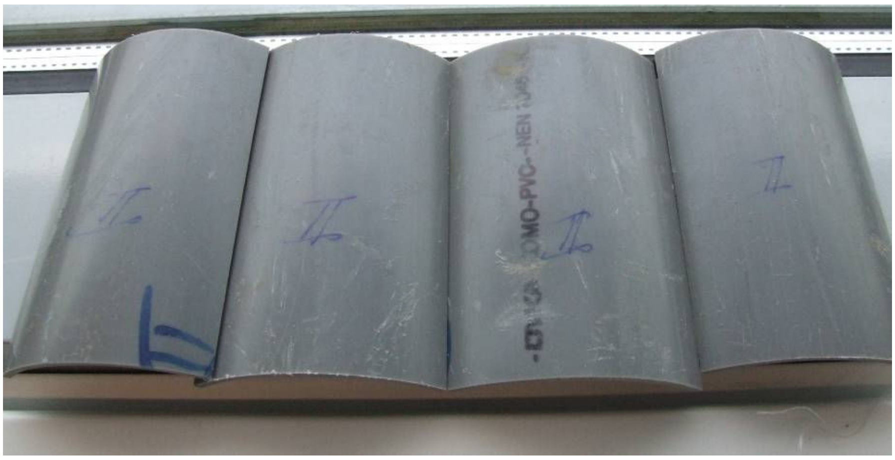

Fig. II.1 Outer pipe wall.

Fig. II.2 Inner pipe wall.

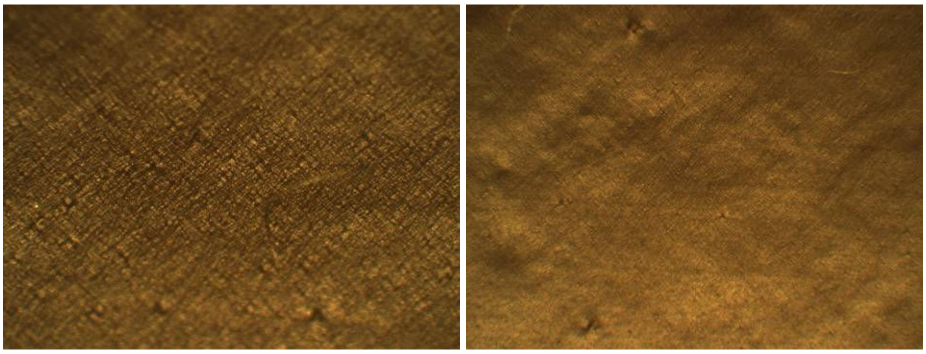

Fig. II.3 Surface inner pipe wall; non-smoothness ascribed to production process (shown surface right: ca. 10x10 mm; left: magnification 6x right photograph).

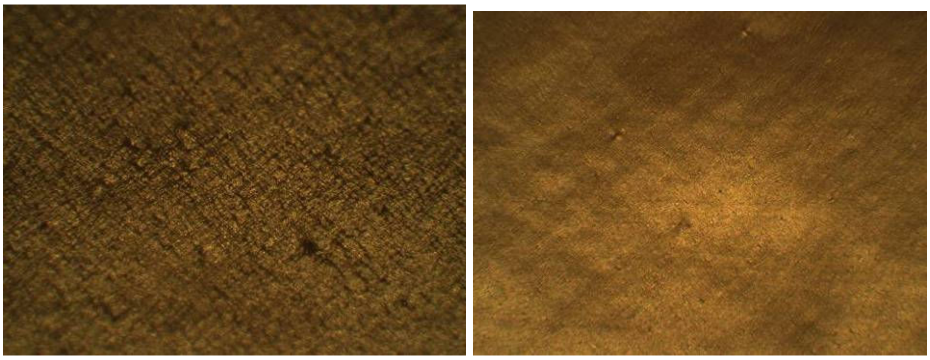

Fig. II.4 Surface inner pipe wall; non-smoothness ascribed to production process (shown surface right: ca. 10x10 mm; left: magnification 6x right photograph).

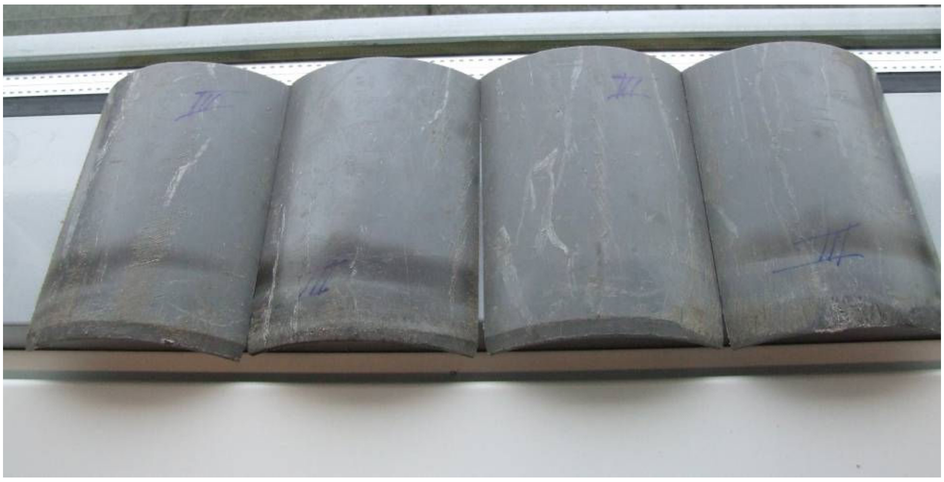

Fig. III.1 Outer pipe wall.

Fig. III.2 inner pipe wall.

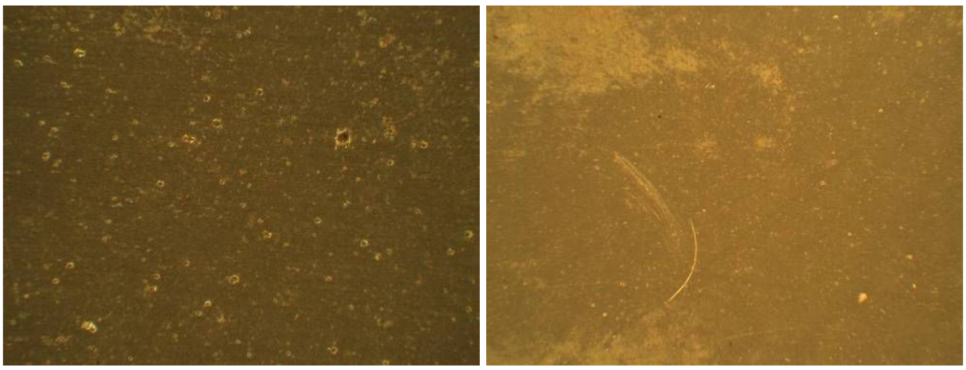

Fig. III.3 Surface inner pipe wall (shown surface right: ca. 10x10 mm; left: magnification 6x right photograph).

Fig. IV.1 Outer pipe wall.

Fig. IV.2 Inner pipe wall.

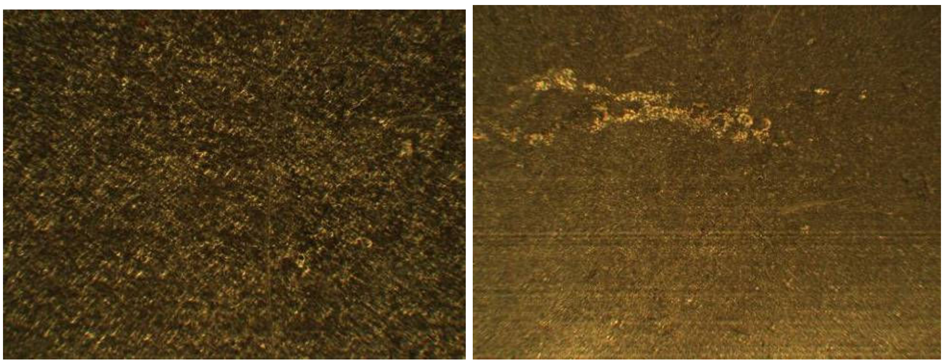

Fig. IV.3 Surface inner pipe wall; remainder of sewage sediment (shown surface right: ca. 10x10 mm; left: magnification 6x right photograph).

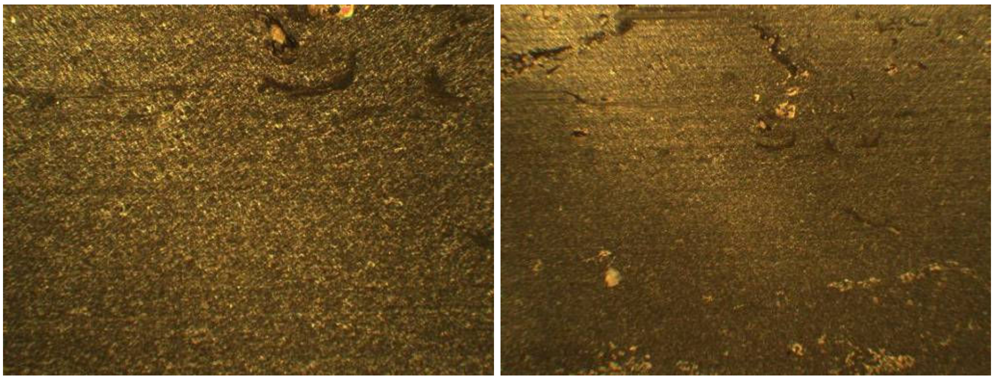

Fig. IV.4 Surface inner pipe wall; remainder of sewage sediment (shown surface right: ca. 10x10 mm; left: magnification 6x right photograph).

Fig. V.1 Outer pipe wall.

Fig. V.2 Inner pipe wall.

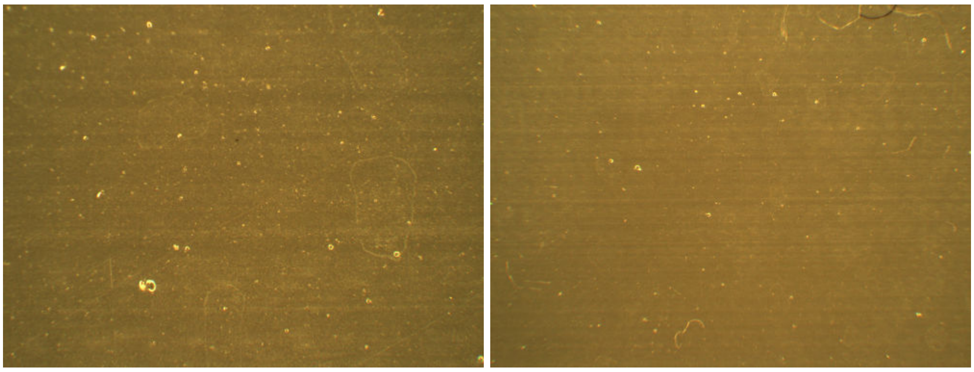

Fig. V.3 Surface inner pipe wall (shown surface right: ca. 10x10 mm; left: magnification 6x right photograph).

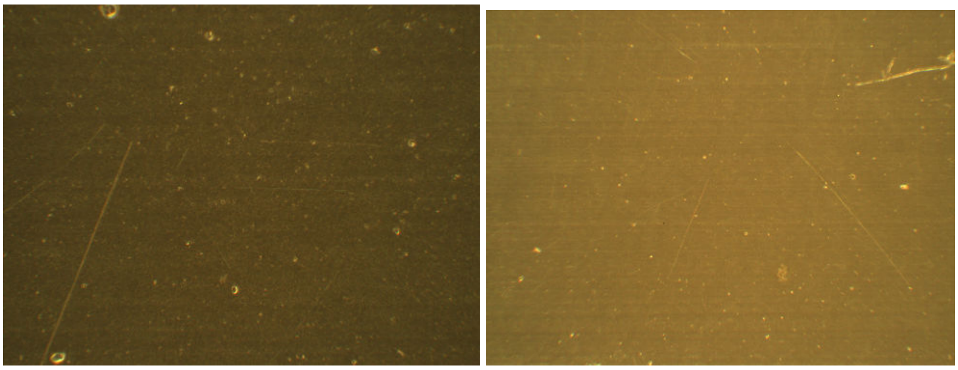

Fig. V.4 Surface inner pipe wall (shown surface right: ca. 10x10 mm; left: magnification 6x right photograph).

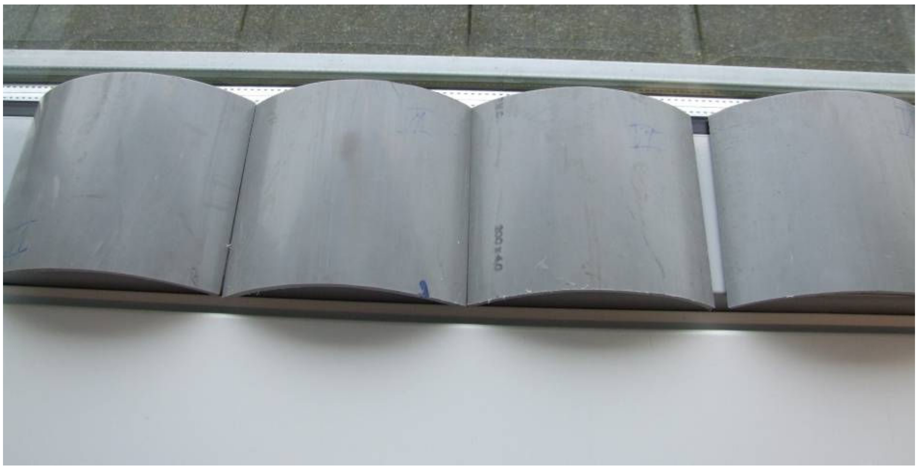

Fig. VI.1 Outer pipe wall.

Fig. VI.2 Inner pipe wall.

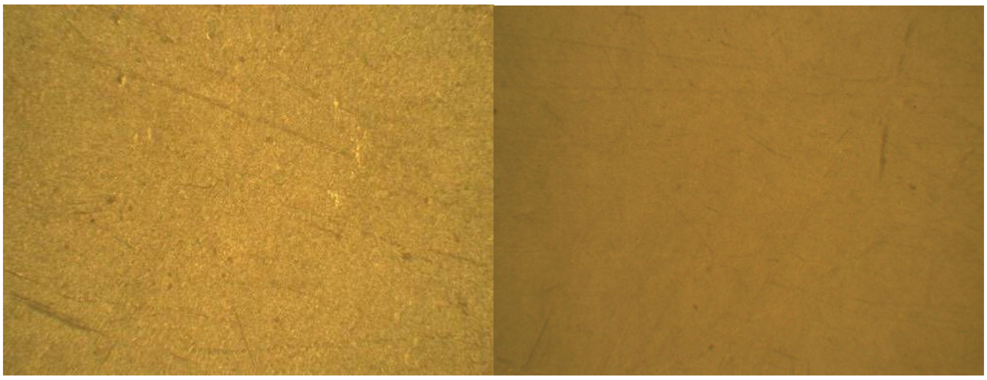

Fig. VI.3 Surface inner pipe wall (shown surface right: ca. 10x10 mm; left: magnification 6x right photograph).