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OLD PVC-U WATER PRESSURE PIPES: AN INVESTIGATION INTO THE DESIGN AND DURABILITY.

Frans Alferink — Wavin M&T, Dedemsvaart, NL
Lars-Eric Janson — SWECO, Stockholm, Sweden
Les Holloway — Wavin Industrial Products, Durham, UK

SUMMARY

Wavin Marketing & Technology in close cooperation with the Overijssels Water company (WMO) have investigated the performance of old PVC water pipes. Pipes were dug up and evaluated to characterize the pipe material and to determine the functional properties.
Most of the pipes still fulfil the current criteria for PVC water pressure pipes after being in service for periods up to 35 years. Lifetime expectancies of these pipes will easily be exceeded. From this it is clear that new pipes will continue to perform for far in excess of the 50 years lifetime as laid down in standards.

INTRODUCTION

Wavin Marketing & Technology have been studying the performance of old operational PVC water pipes in close cooperation with the water company of Overijssel, the WMO.
The objective of this study was to estimate the functionality of these old pipes after many years of service, and to confirm that PVC pipes will be able to fulfil their task for at least 50 years which was the original service life.
The most important functional properties are the resistance to internal pressure and the strainability of the material. Therefore amongst others, internal pressure tests, tensile tests and impact tests have been performed.

A similar study was carried out on PVC sewer pipes. This work was published at the Plastics Pipes Conference in Edinburgh in 1995.(Reference 1)

EXPERIMENTAL APPROACH

In 1990 about 15 pipe samples as selected by the water company of Overijssel (WMO), were dug up and sent to the Sterlab certified laboratory of Wavin Marketing & Technology. In 1993 another 4 samples were dug up to extend the measurements.
Where possible, depending on sample size, each pipe was tested in order to characterize the raw material, the quality of processing and some functional properties. Sample lengths varied between 2 and 20 metres. Therefore not all the samples were tested to the same extent.

Characterisation tests.

The following tests were carried out to characterize the raw material and processing:

* K-value of the polymer used
* Carbonyl content
* Vicat softening point
* Gelation level by means of DSC.

The K-value was determined because it is one of the most important parameters characterizing the PVC type.
The gelation level was determined because this is considered to be one of the most important conditions in relation to long term strength of the pipe. The gelation level is a measure of the consistency of a material structure and is related to the melting and shear behaviour during processing. Processing should allow sufficient time to build up a good network structure. On the other hand when the material remains too long in the extruder, the network will break down by thermal degradation and overgelation
Differential Scanning Calometry (DSC) measurements were carried out. This gives a local gelation level which is determined by heating up a sample of about 20 mg at a rate of 10 °C/min from 35 °C to 240 °C in a nitrogen atmosphere. The above-mentioned method is extensively described in Reference 2.

The above-mentioned characterisation is important because PVC has evolved considerably over the last 40 years. Differences in performance found between pipes from different age should not only be related to ageing but might also be the result of changes in PVC recipes and process development. The most significant changes are listed below:

- 1965 : Change from emulsion to suspension PVC.
- 1971 : The use of powder instead of granular PVC.
- : Change of molecular weight (K-value)
- : Development of one-pack stabilisation systems.
- : Increased output by improved design of extruders.
- : Improved gelation during processing.

Functional properties.

The product performance was determined by the following tests:

* Specific Tangential Initial Stiffness (STIS) according to ISO/DP9969.
* Creep ratio according to ISO/DP9967.
* 3 points bending modulus according to ISO/178.
* Tensile impact test according to DIN 53448
* Internal pressure tests according to ISO 1167
* Pipe deformation measurements according to an internal Wavin method.
* Tensile test

On four of the 19 samples, deformation measurements were carried out. The method is described extensively in Reference 3. Vertical and horizontal pipe deflection was determined before and after digging up by means of a continuous reading over the pipe length.

The objective of these measurements was to determine the actual deformation of the pipe when buried, and also to what extent the pipe recovered after being dug up.
This recovery is a measure of changes in material morphology over the many years of use.
In References 1, 3 and 5 more detailed information is given about this subject.

RESULTS

The principal test results will be discussed in this section. The other results are listed in Enclosure 1 for reference purposes.

Material and process characterisation.

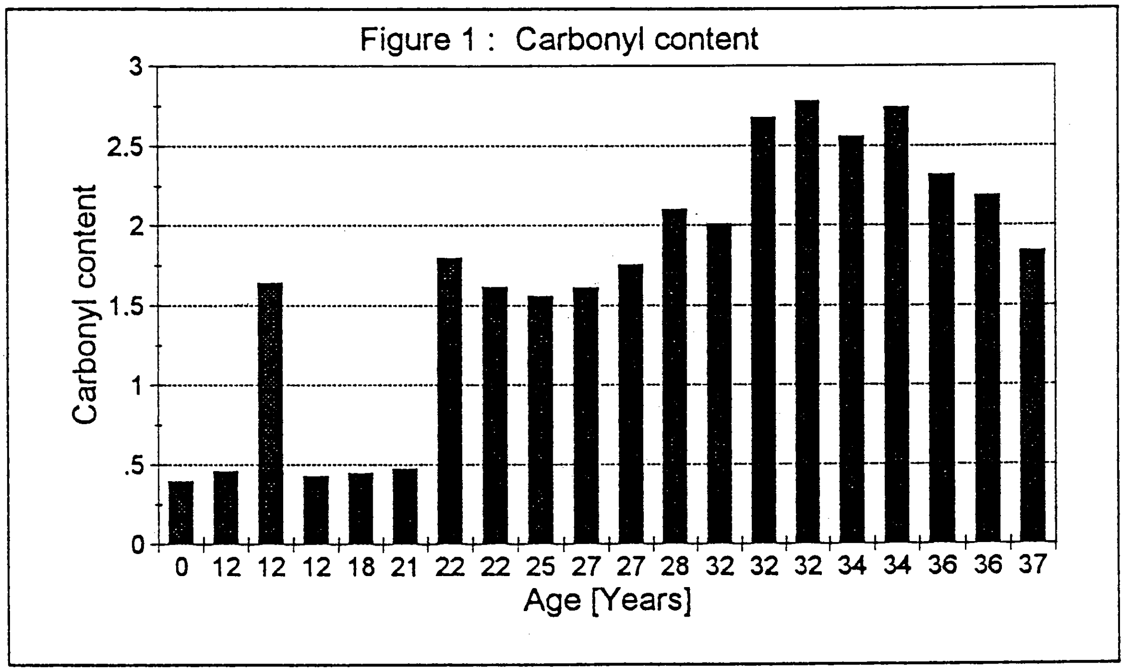
Table 1 lists the results with respect to raw material and process characterisation. The results are listed in order of pipe age.

Table 1: Results of raw material characterisation.

Ref_name	Installed [Year]	Age [Years]	K-value	Vicat [°C]	Gelation [%]
Ref1	1990	0.00	67	83.60	83.00
wmo10	1980	12.00	67	83.20	
wmo15	1980	12.00	67	83.20	80.00
wmo5	1980	12.00	68	83.30	
wmo16	1976	18.00	67	83.20	73.00
wmo9	1971	21.00	67	80.20	
wmo14	1970	22.00	67	80.50	95.00
wmo4	1970	22.00	69	80.60	
wmo19	1969	25.00	67	80.10	80.00
wmo13	1965	27.00	73	79.50	92.00
wmo3	1965	27.00	69	78.90	
wmo8	1964	28.00	75	78.90	
wmo12	1960	32.00	75	77.80	82.00
wmo2	1960	32.00	72	79.30	
wmo7	1960	32.00	72	78.30	
wmo17	1960	34.00	69	77.60	51.00
wmo18	1960	34.00	75	77.30	56.00
wmo1	1956	36.00	73	79.30	
wmo11	1956	36.00	74	79.80	90.00
wmo6	1955	37.00	73	79.20	

The results of the gelation tests show that most of the pipes are poorly gelled. Over the years the gelation levels have increased due to improved processing.
From the Table 1 it is also clear that the Vicat temperatures have changed over the years, as a result of changes in recipe. The general rule is that the higher the Vicat temperature the better the pipe performs in the internal pressure test. Note also that the earlier K-values were higher as a result of using emulsion PVC.

The presence of carbonyl groups was measured by means of FTIR. The amount of carbonyl is a measure of the level of oxidation of the material.
The results are shown in Figure 1.



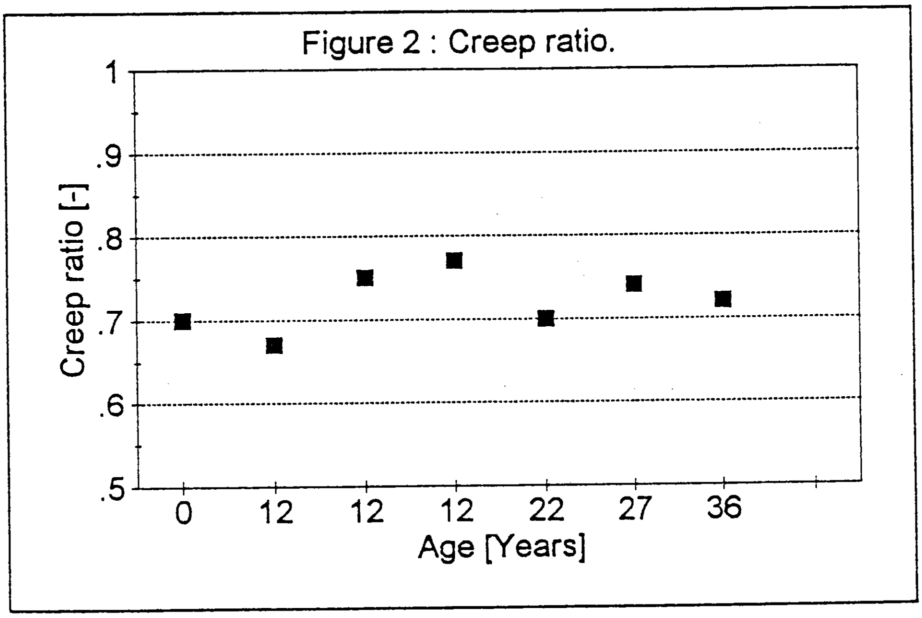
Carbonyl groups can be formed at different stages. First, oxidation can take place during the production of the raw material. Then during extrusion, when the material is exposed to high temperatures, and during product use oxidation can take place. The oxidation processes are very much temperature dependent and carbonyl groups are more easily formed at elevated temperatures. Therefore they will most likely develop during processing.
As the results show, pipes older than about 22 years show significantly higher carbonyl content than those from more recent times. This coincides very well with the change in processing of the PVC in the early seventies, when the use of powder instead of granular PVC began. Before that time PVC granular material was gelled at high temperatures in compounding extruders, before being extruded into pipe. This means that the material was exposed twice to a significant temperature load, causing the formation of carbonyl groups. Apart from this no clear effect of age on carbonyl group formation is found, indicating that the pipes have not deteriorated during usage.

Product properties

The product properties which are of the greatest interest will be discussed in this chapter.

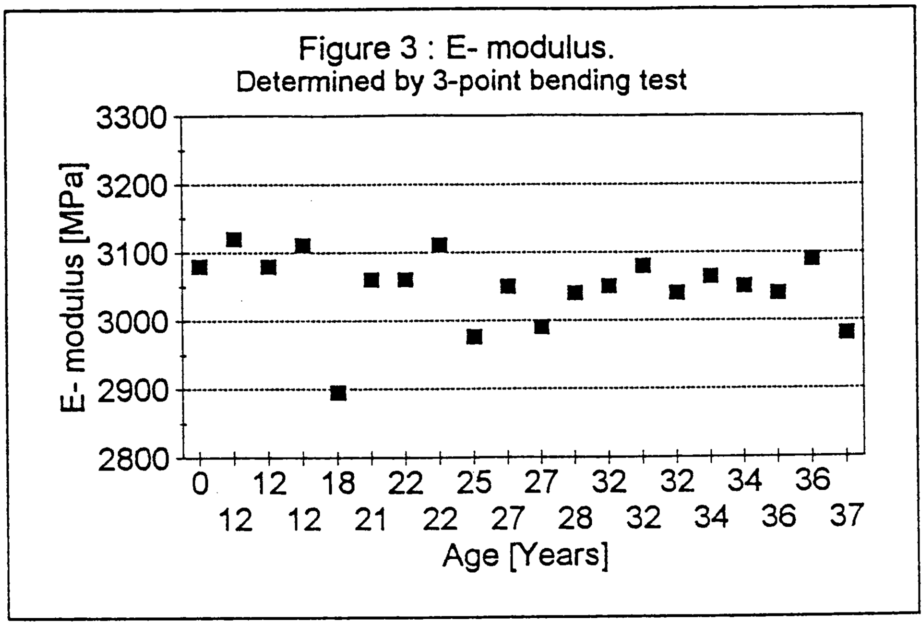
◇ Pipe Stiffness (ISO 9969)
The results are listed in Enclosure 1.
The values found deviate quite considerable from the currently available stiffness classes. This is due to the fact that in earlier years pipe dimensions were not so closely standardized as nowadays.

◇ Creep ratio (ISO 9967)
The creep ratio was determined on 7 samples including a reference, and the results are shown in figure 2.



As can be seen the creep ratios still have the same order of magnitude as the currently produced pipes. The creep ratio is not affected by age. Changes in the morphology of the material would certainly have resulted in a change of creep behaviour.

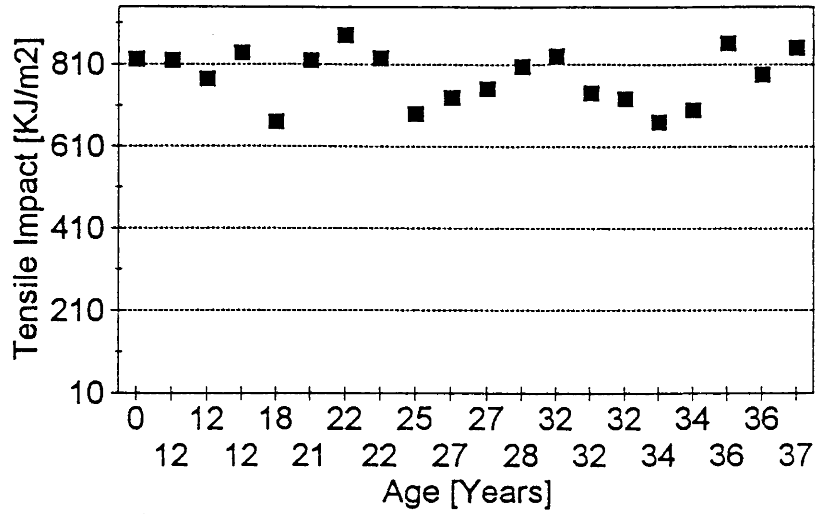
◇ Bending modulus (ISO / 178)
This test was chosen so as to be able to judge how ageing has affected the stiffness of the material by checking if the short term creep modulus shows a relation with age. The results are shown in figure 3.



The E-modulus varies between 2900 MPa and 3120 MPa, and does not show any significant change with time. Therefore it can be concluded that the stiffness of the material when in normal use does not decrease with time. Supporting these findings, more specific long-term laboratory studies presented in Reference 5 showed a significant increase of the E-modulus versus time due to physical ageing (up to 20 % increase after 50 years). In order to try to explain why this increase was not recognized by the field tests under study the following hypothesis is proposed. This implies that the oldest pipes taken from the field could possibly have shown a lower short term E-modulus than measured, had not the physical ageing effect contributed to an increase of the pipe material stiffness. Thus, the old rather "poorly" processed pipes may have proven to be as good as the modern pipes, partly thanks the physical ageing process.- See further references 6.

◇ Tensile impact
This test is performed to check if the pipe becomes more brittle with age. The results are shown in figure 4.

Figure 4 : Tensile impact [KJ/m2]

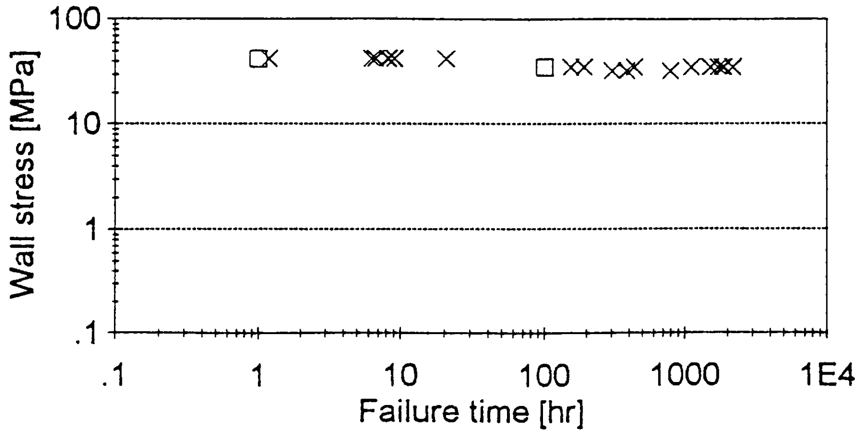


The tensile impact of the old pipes lies in the same range as the values for the reference pipe. Again ageing has not affected this property, which indicates that the material has the same ductility as originally.

◇ Internal pressure tests

From those pipe samples where enough material was supplied internal pressure tests have been carried out with the objective of checking whether the pipes will still be able to fulfil their original strength requirement during the whole predicted service life. Therefore the samples were exposed to stress levels aiming for failure times up to more than 1.000 hr. The results of the 20 ˚C tests are shown in figure 5. In this figure the failures are marked with a "x" and the current CEN requirements at 1 hr and 100 hr are marked with a "□".

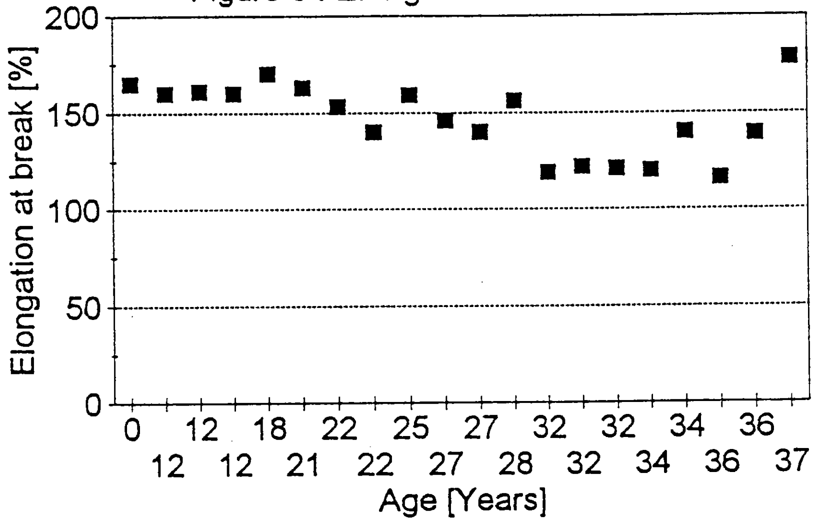
Figure 5 : Internal pressure tests.
at 20 °C



The results clearly indicate that the old pipes after having been in service for about 35 years are still fulfilling the current CEN requirements. If we furthermore recognize that the pipes have not been produced in an ideal way, see for instance the gelation levels, then it is clear that PVC pipes for water pressure will maintain their strength for significantly more than 50 years, and probably up to 100 years or more for modern PVC pipes.

◇ Tensile test.
The tensile test was performed to check the strainability of the old pipes. For buried pipes, strainability is a very important and in many cases an underestimated property. The ability to follow soil movements without failure or leakage at joints is one of the most important advantages of thermoplastics pipe systems.
The elongation at break is shown in figure 6. The tensile strength is listed in Enclosure 1.

Figure 6 : Elongation at break



This graph shows that the strainability is not significantly affected by age.

◇ Results of pipe deformation measurements.
The results are shown in table 2.

Ref_name	Installed [Year]	Age [Years]	Soil type	Diameter [mm]	STIS [kN/m^2]	Pipe deformation [%]	Recovery [%]
wmo16	1976	18.00	sand	160.00	6.09	.50	.50
wmo19	1969	25.00	sand	160.00	3.35	2.00	.50
wmo17	1960	34.00	sand	160.00	18.65	.50	.50
wmo18	1960	34.00	peat	160.00	19.83	.50	.50

The table shows that the pipes are virtually circular, except for the thin walled sample "WMO19" which shows a marginal deformation of only 2 %. Furthermore, when this pipe is unloaded it recovers quickly to it's original shape. The recovery shown in the table is the value measured 30 minutes after the pipes were dug up.

CONCLUSIONS

* It has been shown, that old PVC water pressure pipes still fulfil the most important functional requirements. Strainability, ductility and resistance to internal pressure have been virtually unaffected by ageing, and are still on the same level as for new pipes.
* It was also shown that pipe production has been improved continuously since the early days. Most of the older pipes showed gelation levels which are significant less than those currently considered to be needed to get a good long life performance.
* Based on the above results it can be expected that PVC pipes produced according to current CEN requirements and given the improvements in PVC materials and pipe extrusion technology, will maintain their functional properties for periods well in excess to 50 years.

ACKNOWLEDGEMENT

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Enclosure 1

Ref_name	Installed [Year]	Age [Years]	Diameter [mm]	STIS [kN/M2]	Tensile strength [MPa]	Elongation at break [%]
Ref1	1990	0.00	110.00	5.40	48.60	165.00
wmo10	1980	12.00	110.00	6.10	50.70	161.00
wmo15	1980	12.00	110.00	6.30	50.30	160.00
wmo5	1980	12.00	110.00	6.50	50.70	160.00
wmo16	1976	18.00	160.00	6.09	50.40	170.00
wmo9	1971	21.00	107.00	7.00	49.90	163.00
wmo14	1970	22.00	107.00	6.60	51.10	140.00
wmo4	1970	22.00	107.00	7.90	51.20	153.00
wmo19	1969	25.00	160.00	3.35	52.10	159.00
wmo13	1965	27.00	107.00	7.00	48.30	140.00
wmo3	1965	27.00	107.00	7.10	49.90	146.00
wmo8	1964	28.00	107.00	7.30	50.80	156.00
wmo12	1960	32.00	107.00	11.80	52.40	121.00
wmo2	1960	32.00	85.00	15.00	48.30	119.00
wmo7	1960	32.00	125.00	8.90	51.50	122.00
wmo17	1960	34.00	160.00	18.65	50.00	120.00
wmo18	1960	34.00	160.00	19.83	51.00	140.00
wmo1	1956	36.00	107.00	21.70	50.90	116.00
wmo11	1956	36.00	107.00	7.90	50.50	139.00
wmo6	1955	37.00	54.00	82.80	49.20	178.00