Long term behaviour of PVC Pipe in infrastructure

Joël Fumire Chem. Eng.
PVC4Pipes Av. Van Nieuwenhuyse, 4 B-1160 Brussels Belgium

Abstract

PVC pipes are mainly used in 2 very different applications for infrastructure : sewage pipes and water distribution pipes.

These applications require different sets of properties. In each of these applications, PVC pipes have very specific characteristics but in both cases the high resistance to oxidation or to acid attack is a key element. Besides standard PVC (PVC-U) some specific processing technologies bring particular properties to the pipe as well for drinking water distribution as for the sewer systems. These technologies and the related material properties will be reviewed in the presentation.

PVC pipes are used in very different applications, the two main ones are :

- Pressure pipes : characterised as the transport of clean water under pressure (typically 6 to 25 bar)

- Sewer pipes : characterised by the absence of pressure but the necessity of a significant Stiffness (or rigidity) of the pipe.

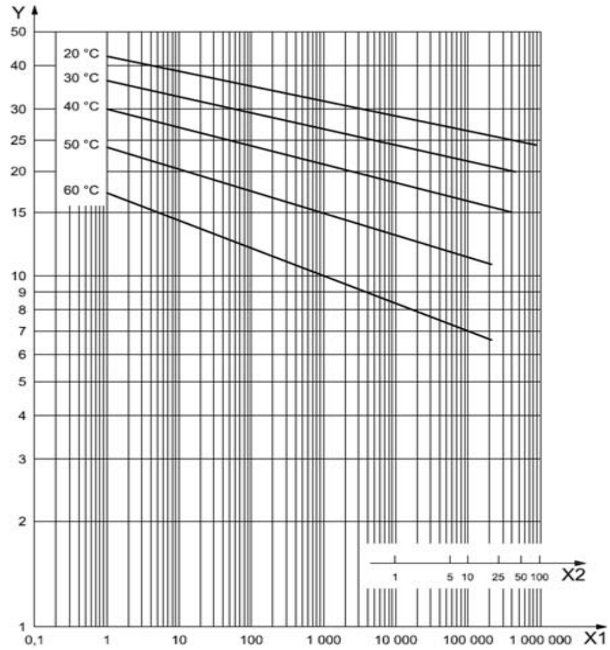
1. Pressure pipes

The main requirements of these pipes are :

- Need for long term pressure resistance
- The pipe should bring no influence on drinking water
- The pipe should be resistant to the disinfectants commonly used to protect the drinking water against microbial growth.

In PVC pressure pipes a particular development technology is expanding today : the use of molecularly oriented PVC or "PVC-O".

Standard PVC pipes (or PVC-U pipes) are used since > 70 years for drinking water distribution. They are described by EN-ISO 1452 and particularly the pressure resistance and its extrapolation to 50 years of use.



Key
X1 time, *t*, to fracture, in hours
X2 time, in years
Y hoop stress, σ, in megapascals

Figure 1 — Minimum reference curve for PVC-U 250

In the past each PVC composition used by the pipe producer had to be assessed by a burst pressure curve realised by an accredited organisation to prove that the composition showed the right pressure behaviour.

Considering the reproducible behaviour of PVC, the certification and the standard have been simplified in 2009 [1] since the material is always complying with the requirements. So today it is sufficient to show 5 points above the reference MRS-curve (see Fig. 1) to prove the conformity of the material.

2. Development : PVC-O

Molecular Orientation is:

A stretching of the wall realised at a temperature > Tg. For PVC it has to be realised > 80°C and is typically realised at temperatures close to 100°C.
This stretching is followed by a rapid quenching to room temperature in order to "freeze" the elongated or oriented structure of the polymer chain.

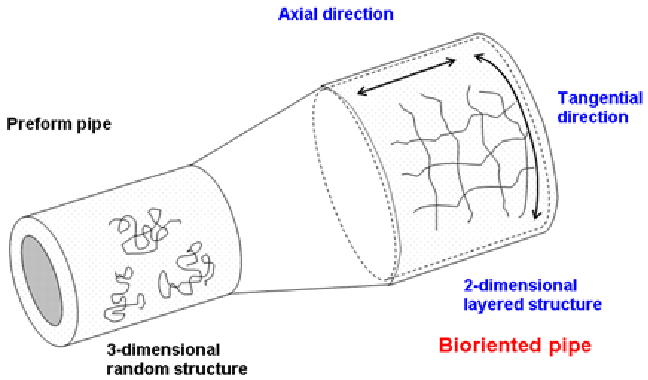


Fig. 2 Biorientation process

This stretching treatment brings a preferential orientation of molecules parallel to the surface of the pipe. The microscopic result is a quasi-lamellar structure of the wall [2].

Biorientation provides to the material :

- Largely improved impact strength
  (approx. 2 times higher rupture energy of the falling dart)
- Higher pressure resistance (depending on degree of orientation)

The improved mechanical properties allow a reduction in wall thickness.
This reduced wall thickness brings a weight reduction : > 40% this means an improvement of environmental burden and a reduction of pipe cost.

<u>Techniques for molecular orientation:</u>

Today mainly 3 techniques exist on the market.

a. Batch Process (in 2 steps) :

In the 1st step a rather thick pipe is produced by Standard Extrusion of the PVC material. This preform pipe is cut after cooling and stored, waiting for the 2nd step.

The 2nd step needs handling of the preform pipes, heating to ~ 100°C (in hot water), stretching by swelling of the pipes and cooling of the molecularly oriented pipes.

This is a stable process giving high quality pipe but with rather high energy consumption for the process and a high manpower cost compared to the extrusion of standard PVC-U pipe.

b. Continuous process

This process is realised in 1one single step : the extrusion of the thick pipe and the biorientation occur in the same line : the extruded pipe is brought at the right temperature in the cooling part of the extrusion line and is pulled over a cone (or mandrel) in order to obtain the desired stretching of the pipe wall. The expanded pipe is cooled in line before finishing.

With this technology the orientation occurs on the mandrel.

The characteristics of this process are the following :
- The stretching is significant in both directions : axial & radial
- The line needs a strong haul off system (friction on the cone)
- The technology allows full choice of the length of the pipe

A significant improvement of the continuous process has been developed recently : The RBlue ® technology (Rollepaal) introduces (among other improvements) an air-flow on the stretching mandrel in order to make the expansion much easier.

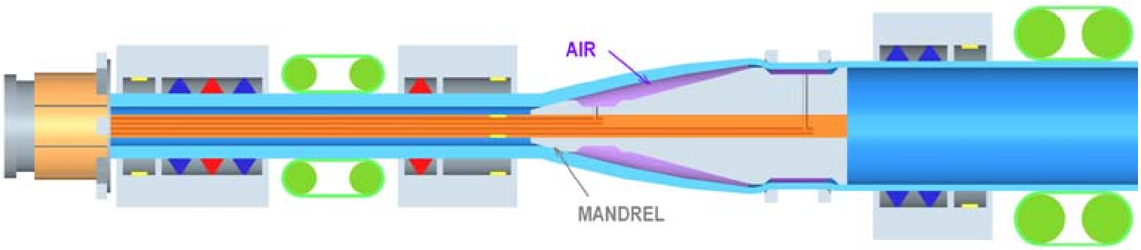


Fig. 3 Expansion of pipe with air flow (RBlue ®)

c. in-line batch process

This process uses several characteristics of the 2 step-process but is fully automatised.
It starts with the standard extrusion of thick pipe.   The pipe segment is automatically

picked-up after extrusion and is introduced in the oven for heat-up without manual operation. When the right temperature is reached, the pipe is introduced into a mould for expansion with air (Molecor®).

Fig. 4 Pipe expansion in Molecor® mould

The orientation occurs in the mould with following characteristics :

- Orientation is mainly in radial direction
- This process is generally used for the production of high MRS classes : 400, 450, 500
- The dimension of pipe is determined by the size of the mould (Diameter and length) and large diameters do not pose particular problems
- Socketing of the pipe does not require an additional step

<u>How do these PVC-O pipes compare with standard PVC-U pipes ?</u>

a. Regarding long term pressure resistance

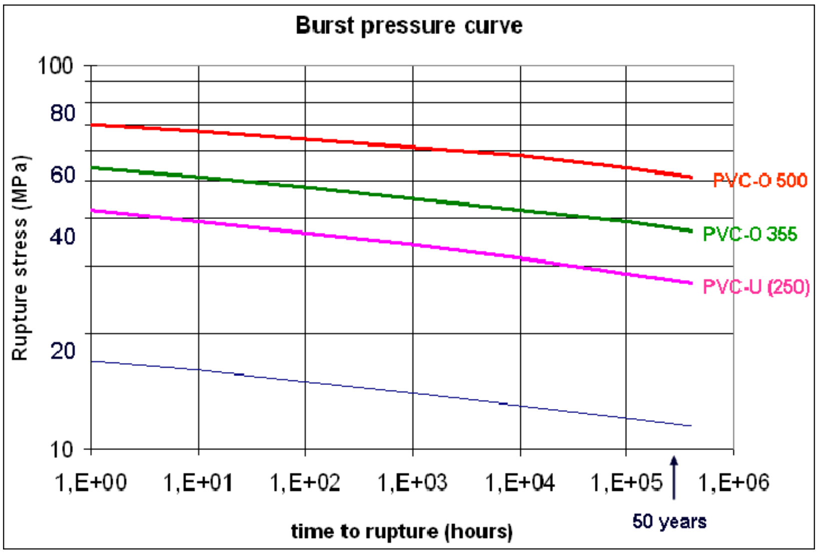


Fig. 4 Burst pressure curve for different grades of PVC-O

The pressure resistance is significantly higher, which is reflected in the MRS classes.

b. Regarding resistance to disinfectants

Drinking water often contains disinfecting agents : for example : NaOCl / Cl_2
This chemical is efficient as disinfectant but has the disadvantage of bringing an unpleasant smell and taste at moderate to high levels (> 0.5 ppm)

ClO_2 is also used : it is highly efficient and does not give unpleasant smell to the drinking water. It is considered as a stronger oxidising agent.

Other chemicals also used are : Ozone, chloramine, etc ...
Some plastics get damaged by the oxidising agent and are subject to failure after a limited number of years after installation.

PVC4PIPES checked already that standard PVC pipes were not affected by these chemicals [3].

Chemical resistance of pipe materials is assessed by ISO 4433. According to this standard, the elongation at break of the material is compared between unexposed and exposed situation.

When elongation at break of the exposed material is > 50% of the unexposed pipe, the resistance is considered to be satisfactory.

Various PVC pipes were exposed to very high disinfectant level (ISO 4433 ; 2010)

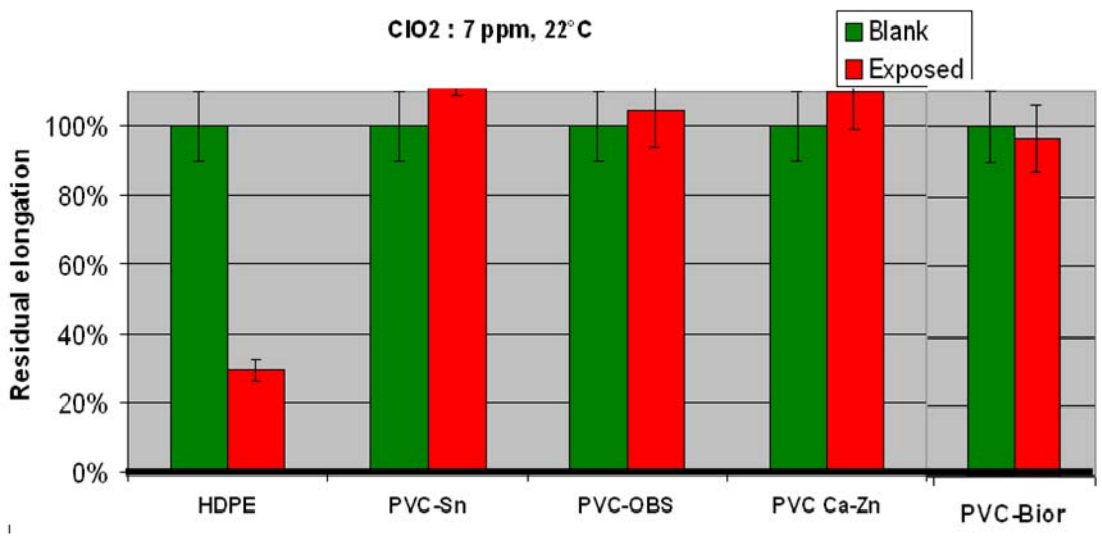


Fig. 5 Behaviour of various pipe materials with ClO2

We see that PVC-Bior. (or PVC-O) shows the same residual elongation as the different compositions of standard PVC-U and is perfectly resistant to the disinfectant.

3. Sewer pipes

The main requirements of these pipes are :

- High resistance to acids and to oxidants
- Long term stiffness

A special technology is more and more used for these pipes in order to save weight: the use of foam core PVC pipe.

Standard PVC-U sewer pipes have already been assessed in a TNO-study on Excavated PVC-U pipes [4] and in other studies [5].

In that study several pipes from 1973 to 1986 from various manufacturers have been examined thoroughly. The main results were the following (see CEOCOR Luzern 2012) :

Pipes appear with some change in colour related to a thin degraded layer (10 – 100 µm). This thin degradation appears to be not harmful for the mechanical integrity of the pipe and no polymer degradation was registered to the main material.

A very important characteristic of sewer pipes is the Resistance to chemicals and particularly to acids : H_2S, H_2SO_4 since these acids have a high probability of occurrence in sewer systems [6].
PVC is intrinsically highly resistant to these acids as can be recorded from ISO/TR 10358.

ISO/TR 10358

No.	Chemical	m.p. °C	b.p. °C	Concentration %	T °C	PE-LD	PE-HD	PP	PB	PVC-U	PVC-C	ABS	PVDF
383	Sulphuric acid			50	20	S	S	S	S	S	S	S	S
					50						S	L	S
					60	S	S	L	S	S	S		S
209	Hydrogen sulphide, dry gas		-61	tg-g	20	S	S	S	S	S	S	S	S
					50						S	S	S
					60	S	S	S	S	S	S		S
265	Nitric acid			30	20			S	NS	S	S	NS	S
					50						S	NS	S
					60			NS	NS		S		S

Table 1. Examples of resistance of plastics to chemicals

4. Development : Foam core pipes

As stiffness of a pipe is mainly related to thickness of the wall, PVC pipes can be made lighter by coextrusion of a foam layer between the thin compact layers.

Foams in pipes have a density of approx. 0.7 g/cm³ (compared with 1.4 g/cm³ for standard PVC).

Fig. 6. Foam core pipe

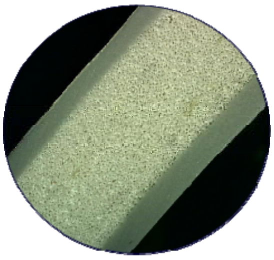


Fig. 7 Detail of foam core wall

The environmental burden is lower because of the lower weight/metre but this burden is generally further reduced by incorporating significant levels of recycled material in the central layer of the pipe.

Stiffness & flexibility of a PVC pipe

For all materials exposed to a permanent stress, a long term deformation or creep of the item is registered. For foam core PVC pipe, this reduction in long term stiffness was measured in comparison with other plastics and with compact PVC. The long term deformation appears to be lower than from main other plastics and the behaviour is very close to the one of compact PVC.

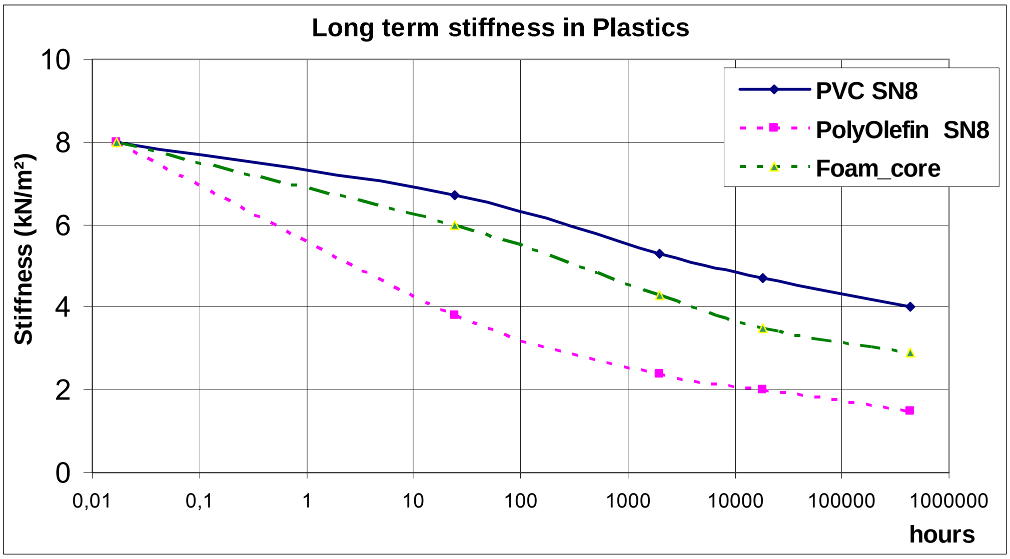


Fig. 8. Long term stiffness of Plastic pipes

Regarding foam core pipe compared with compact pipe, we see that :

A Lower environmental burden is obtained (- 20%) [7].
These pipes represent a more economical solution (~ 30% reduction material cost)

But these pipes keep the high chemical resistance and long term properties of standard compact PVC pipes.

These structured wall pipes are now described in national implementation of EN 13476 (all EU countries between 2007 and 2012), they represent today a sustainable and interesting solution in corrosive sewer conditions.

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