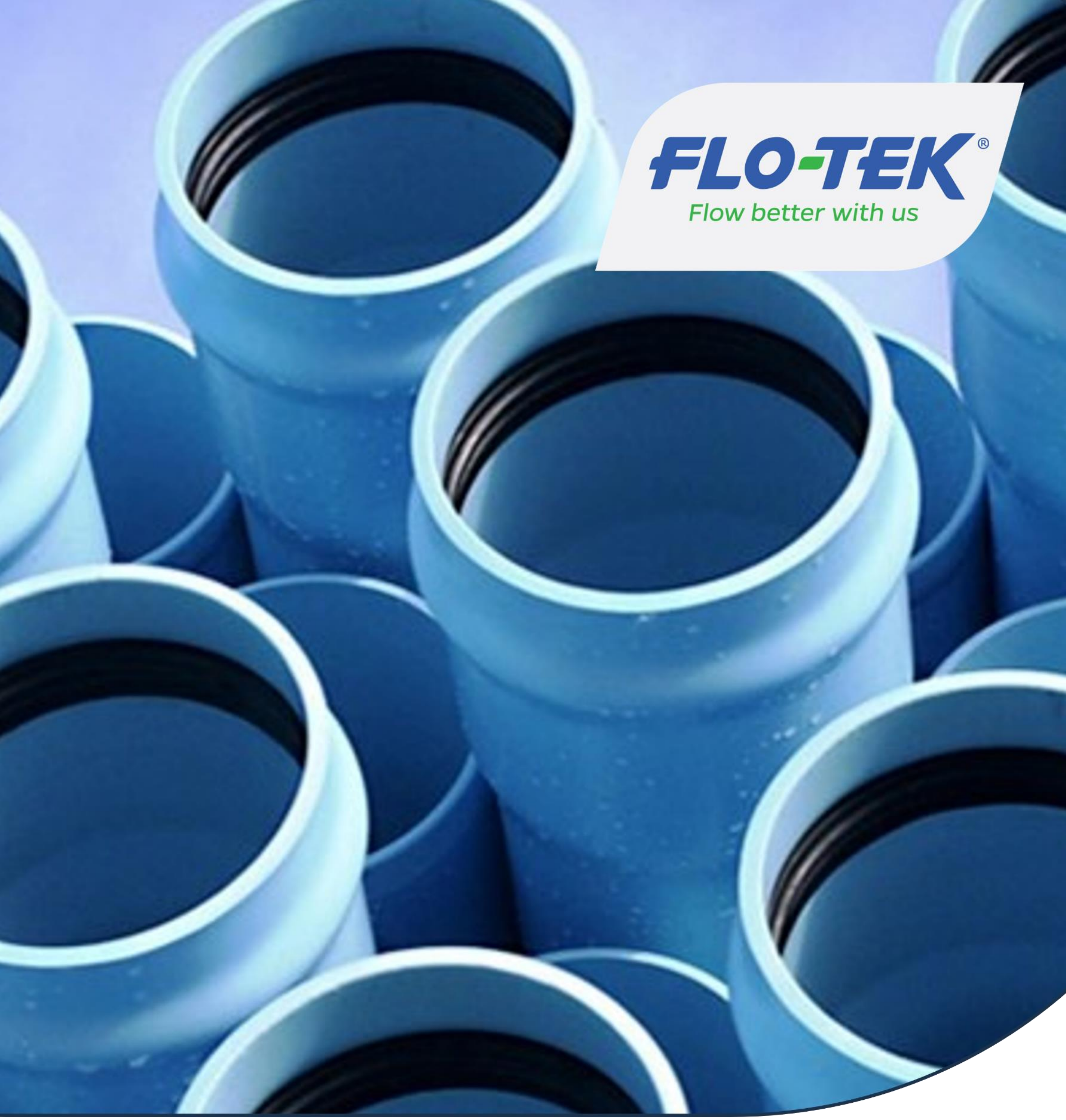


PVC-O *Pressure Pipe Systems*
Biaxially Oriented PVC

Contents

1. INTRODUCTION

Flo-Tek Africa is the recognized leader and pioneer of plastic pipe systems in Southern Africa, serving the water and drainage industries in the building, civils, mining & agriculture sectors.

Radical Investments (Pty) Ltd, trading as Flo-Tek Pipes & Irrigation was established in Botswana in 1998 manufacturing PVC pipes. The company has two manufacturing plants in Botswana (Lobatse and Ramotswa), and has offices in Gabarone (Head Office), Francistown and Phakalane.

The company was established in South Africa in 2005 and an HDPE pipe factory was started in Clayville in August 2007. Flo-Tek South Africa has since opened subsidiary companies in Dundee, Port Elizabeth, Nelspruit and Potchefstroom, and has established operations in Angola, Zambia and Namibia.

Within our South African and Botswana operations, we have trained staff who bring a wealth of knowledge and experience.

Flo-Tek ensures the best quality of products and the highest delivery standards.

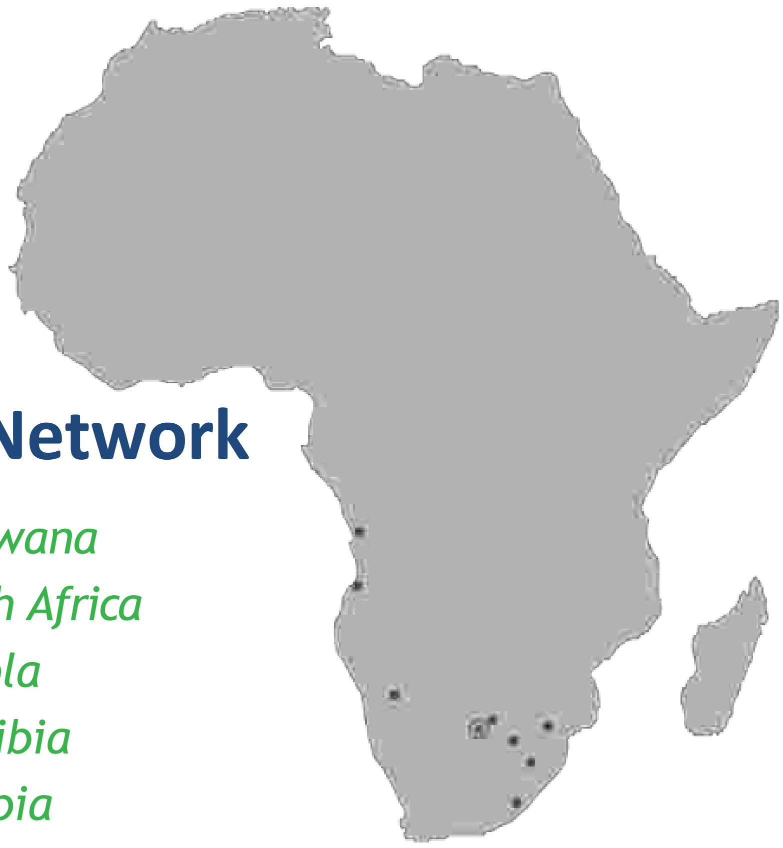
www.flotekafrica.com

Flo-Tek's core business is the manufacturing and distribution of Plastic pipes and fittings including PVC-O, PVC-U and PVC-M Pressure Pipes & Fittings, HDPE Pipes & Fittings, Sewer Pipes & Fittings, Corrugated Pipes (CorDrain and CorDuct Piping Systems), Irrigation, packaging and a variety of Rotomoulded products. We also produce Borehole Casings, Screens and PVC Cable Ducts.

Our ISO 9001-2015 certified factories in Botswana and South Africa enable us to manufacture pipes and tanks as well as to distribute across the SADC region. Our factories have fully equipped laboratories which ensure Flo-Tek manufactures to SANS, BOBS, ISO and SAPPMA specifications, assuring clients of the highest quality products.

Sectors Serviced

- ◊ *Civil & Infrastructure (Water & Sanitation)*
- ◊ *Mining & Industrial*
- ◊ *Irrigation*
- ◊ *Plumbing Solutions*
- ◊ *Packaging*



Our Network

- *Botswana*
- *South Africa*
- *Angola*
- *Namibia*
- *Zambia*

2. OVERVIEW

ABOUT PVC

Polyvinyl Chloride or PVC is one of the most versatile pipe materials. It is produced by the polymerisation of vinyl chloride which is made from coal (or oil) and common salt. In fact, salt makes up over 50% of the polymer, thus making PVC one of the most environmentally friendly plastic materials, being least dependent on hydrocarbon resources.

The unique properties of PVC can be enhanced by the addition of special additives, for example, to create strong yet tough pipe materials such as modified PVC [PVC-M), foamed multilayer sewer and drainage pipes, and weather resistant above ground drainage pipes. These additives, as well as heat stabilisers and lubricants, which are necessary to facilitate the extrusion of the pipes, are added to the PVC raw material in special high-speed mixers to produce a dry blend specially formulated for the pipe extrusion process.

During the manufacture of the pipe the dry blend is mixed in the extruder and through a combination of heat and shear, the material is 'gelled' into a homogeneous molten mass ready for passage through the die and calibrator to form a pipe which has tight tolerances in terms of outside diameter, wall thickness and mechanical properties.

The integral pipe end rubber ring socket is formed at the end of the extrusion line and the sealing ring fitted. A similar process is used in the injection moulding of the fittings; the material is gelled in the barrel and screw of the machine and then injected into the mould where it is cooled to form the fitting.

Rubber sealing rings and retainer caps are fitted during subsequent assembly of the finished fitting.

It should be noted that heat stabilisers and lubricants have been changed from lead-based compounds to alternative, environmentally friendly materials such as organic and calcium/zinc compounds.

PVC-O (BIAXIALLY ORIENTED PVC)

Flo-Tek has introduced a World Class technology producing biaxially oriented PVC-O pressure pipe with exceptional strength and toughness properties. PVC-O is a material and energy efficient product which offers considerable advantages over traditional and other plastic pipes for high pressures. These include superior flow capacity and lower power costs for water and sewer pumping at pressures up to 25 bar, while still retaining all the benefits associated with PVC-U, PVC-M and HDPE pressure pipes.

LOCAL MANUFACTURE

Flo-Tek's PVC-O pressure pipes use a revolutionary new technology and local raw materials. Traditional PVC-U and PVC-M pipes are produced by an extrusion process but with little orientation of the molecules.

The molecular orientation process is used in the manufacture of plastic products where increased strength is required. A good example is polypropylene (PP) strapping tape where the PP molecules are oriented only in the length direction giving exceptional strength to the tape, making it very suitable for strapping of heavy crates and bundles. The process is known as mono-axial orientation.

In the case of PVC-O pipes the process is one of biaxial orientation where the molecules are stretched (oriented) in both circumferential and axial directions thus providing strength in both directions.

Since the stress distribution in a pressurised pipeline is such that the hoop stress is twice the axial stress, therefore greater molecular orientation is required in the hoop than in the axial direction.

3. PVC-O PROPERTIES

Features and Benefits

- ***Superior Strength:*** *Greater resistance to internal hydrostatic pressure under all operating conditions*
- ***Higher Flow Capacity:*** *Savings in energy through lower pumping costs.*
- ***High Impact Strength:*** *Superior resistance to damage from handling, transport and installation.*
- ***High Toughness:*** *Excellent resistance to the initiation and propagation of cracks.*
- ***High Resistance to Surge and Fatigue:*** *Greater safety in design and operation.*
- *Energy Efficient: Critical savings in energy due to material efficiency and lower operating costs.*
- ***Low Mass:*** *Easier handling and quicker installation and transport energy savings.*
- ***Standard SABS Dimensions:*** *Standard fittings and fully compatible with PVC-U and PVC-M pressure pipes and fittings.*
- ***South Africa Product:*** *Manufactured in South Africa from locally made PVC and raw materials hence support of local industry.*

MANUFACTURING PVC-O

A small diameter, thick wall pipe is extruded and then stretched under controlled conditions of temperature and pressure to achieve optimum molecular orientation and consequent improvement in strength in the two directions.

The resultant increased resistance to internal pressure makes the product extremely well suited to higher pressure applications.

Biaxial orientation also leads to a marked increase in toughness-related properties.

It is this combination of strength and toughness which leads to the unique properties of PVC-O High Pressure Pipes.

4. PIPE DESIGN & PERFORMANCE

PVC-O pipes are made to SABS ISO 16422-2: Pipes and joints made of oriented unplasticised poly (vinyl chloride) (PVC-O) for the conveyance of water under pressure Bar +2: pipes.

It should be noted that PVC-O is not a new product; the pipe has been used successfully in several countries (in Europe, USA and Australia) at pressures up to 25 bar for more than 30 years.

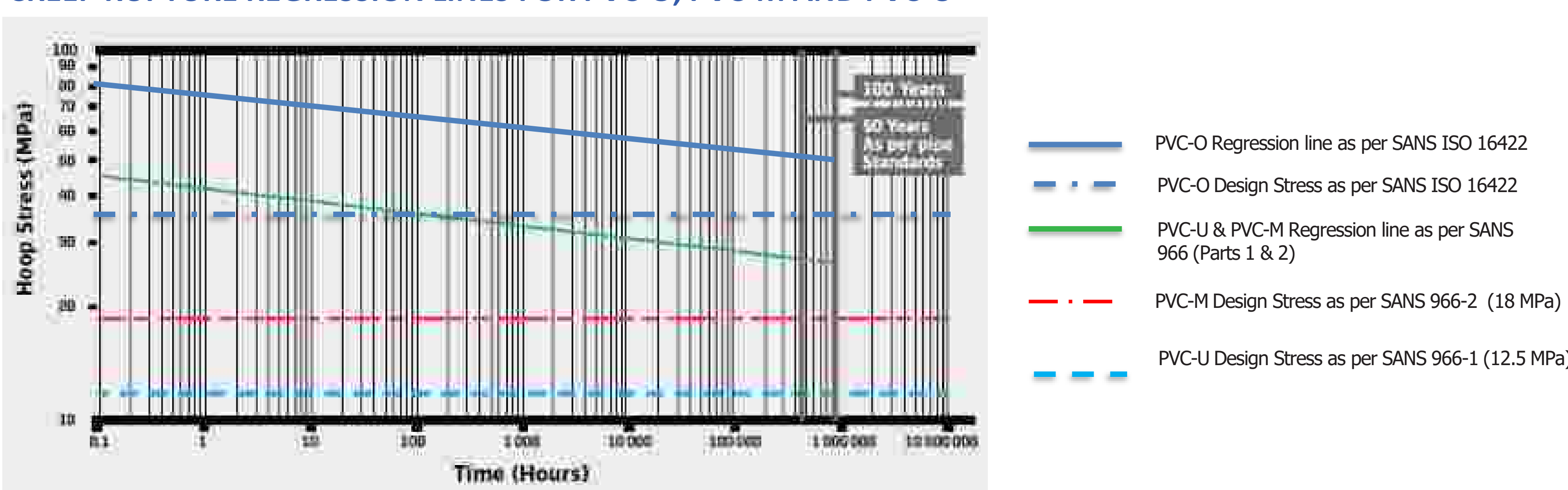
Over time improvements have been made to existing manufacturing technologies and the development of new ones. Flo-Tek's process has been developed to provide improvements in both strength and toughness.

5. STRENGTH PROPERTIES

The strength of plastic pipes can be defined in terms of the maximum stress to cause failure in a given time; the strength at 50 years is determined at various extended times according to the procedure given in ISO 9080.

The results are graphically illustrated by plotting the circumferential stress against time to rupture on a log scale as shown below for PVC-O, PVC-U and PVC-M.

CREEP RUPTURE REGRESSION LINES FOR PVC-O, PVC-M AND PVC-U



From the 50-year failure stress the Minimum Required Strength (MRS) is determined and the Design Stress (σ_s) by applying a Design Coefficient (safety factor) (C):

Formula: $$\sigma_s = \frac{MRS}{C}$$

Since the design stress is the constant stress that the pipe wall can resist for 50 years, the safety factor applies at 50 years.

These properties are summarised in the table below:

Summary			
MATERIAL	MRS (50 YEAR STRENGTH) (MPa)	SAFETY DESIGN COEFFICIENT (C)	DESIGN STRESS σ_s (MPa)
PVC-O (SANS ISO16422-2)	50	1,4	36
PVC-U (SANS 966-1)	25	2,0	12,5
PVC-M (SANS 966-2)	25	1,4	18

5. STRENGTH PROPERTIES (Continued)

For PVC-O the 50-year service design coefficient (safety factor) is 1.4 and the design stress is 36 MPa.

The wall thickness for each pipe diameter and pressure class (PN) is determined from the ISO formula:

$$e = \frac{p\ x\ d}{2\sigma s + p}$$

Where:

e = minimum wall thickness (mm)

p = maximum operating pressure (MPa)

d = mean diameter (mm)

σs = design stress (MPa)

It should be noted that the regression line – more correctly, the 'stress-time' line – does not indicate a loss of strength with time, rather that the material can support lower stresses for longer times.

With each new loading, for example, water hammer or pressure surges, the material acts according to the short-term strength properties. The stress-time line shows vastly superior short-term strength which accounts for the high resistance to water hammer and pressure surges.

In addition, the short-term strength is independent of how much time has passed since the first loading – the pipe acts as a new pipe.

The effects of the process of biaxial orientation can be seen in the remarkable increase in the 50-year strength of PVC-O, i.e. 50 MPa, twice that of PVC-U and PVC-M

It is the superior strength of PVC-O which allows for the manufacture of pipes with, thinner walls and larger bores than other pipes.

PVC-O is thus more material and energy efficient and provides significant energy savings both during manufacture and operation.

6. TOUGHNESS & IMPACT PROPERTIES

In addition to strength, toughness is the other important property of plastic pipe materials. PVC-O is unique in that it has both high strength and high toughness. Long-term pipeline performance is dependent on both of these properties.

Toughness can be defined as resistance to crack growth, i.e. toughness prevents cracks from starting (initiation) and also prevents the transfer (propagation) of cracks through the pipe wall.

Cracks or notches may be initiated during handling or installation and result in the stress concentration effects in the pipe wall which can lead to failure. It is the toughness property of PVC-O which prevents common cause of pipeline failure.

6. TOUGHNESS & IMPACT PROPERTIES (Continued)

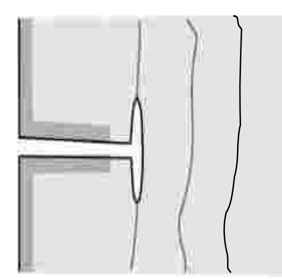
The outstanding toughness properties arise from the biaxial orientation of the molecules which gives a layered or laminar structure.

This is shown in the photographs or illustrations below:

These images above show the laminar structure of PVC-O pipes

Notch with high stress concentration

Interface opens to reduce stress concentration at tip of the crack, preventing failure



Laminar or Layered Structure
The above images show the Toughness Mechanism 'Type 2' of PVC-O Pipes

If cracks do form, high stresses arise at the crack tip because of stress concentration effects. However, with a layered structure the stress concentration is reduced at the interface of each discrete layer and the crack ceases to propagate.

6. TOUGHNESS & IMPACT PROPERTIES (Continued)

As a flexible, energy efficient plastic pipe, oriented PVC is virtually indestructible under the most severe conditions; this is shown in the various photos. The one below is of a 160mm class 16 PVC-O pipe after being impacted by a 20 kg metal dart dropped from a height of 20 m. The laminar structure can be seen and the stress whitening clearly illustrates ductility and toughness.

7. PRODUCT RANGE

The dimensions of the range of PVC-O pipes is given in the following table:

SANS ISO 16422 MRS CLASS 500 BIAXIALLY ORIENTED PVC-O PRESSURE PIPE										
MINIMUM WALL THICKNESS AND MASS PER METER OF RUBBER RING SOCKET TYPE PIPE FOR EACH SIZE AND CLASS										
NOMINAL SIZE (mm)	OUTSIDE DIAMETER		CLASS 12,5		CLASS 16		CLASS 20		CLASS 25	
	MIN	MAX	WALL	MASS	WALL	MASS	WALL	MASS	WALL	MASS
	(mm)	(mm)	(mm)	Kg)	(mm)	Kg)	(mm)	Kg)	(mm)	Kg)
110	110.0	110.4	2.0	1.03	2.40	1.23	3.10	1.58	3.80	1.92
160	160.0	2160.5	2.9	2.17	3.50	2.61	4.40	3.26	5.50	4.05
200	200.0	200.6	3.6	3.37	4.40	4.10	5.50	5.10	6.90	6.35
250	250.0	250.8	4.5	5.26	5.50	6.40	6.90	8.00	8.60	9.90
315	315.0	316.0	5.7	8.40	6.90	10.12	8.70	12.7	10.8	17.04
355	355.0	356.1	6.4	10.62	7.80	12.90	9.80	16.11	12.2	19.92
400	400.0	401.2	7.2	13.47	8.80	16.40	11.0	20.38	13.7	25.2
450	450.0	451.4	8.3	17.5	9.90	20.8	12.4	25.8	15.4	31.9
500	500.0	501.5	9.2	21.5	11.0	25.6	13.7	31.7	17.1	39.3
560	560.0	561.7	9.8	25.7	12.3	32.1	15.4	39.9	19.2	49.4
630	630.0	631.9	11.0	32.4	13.8	40.5	17.3	50.5	21.6	62.6

8. PIPE JOINTING

Each length of pipes has an integral socket fitted with a one-piece composite seal with two components, a reinforcing plastic and EPDM rubber. The seal is securely locked in the socket and provides a combined lip and compression seal. The joints are capable of 22° deflection.

9. FITTINGS

Socketed cast iron fittings, valves and repair couplings can be used in all applications.

10. DESIGN CONSIDERATIONS

PROPERTIES:

Some important properties of PVC-O pipes are given below and compared to PVC-U and PVC-M.

PROPERTIES	PVC-O	M-PVC	PVC-U
Density (kg/m^3))	1.43	1.43	1.45
Coefficient of thermal expansion, per °C	$6 X 10^{-5}$	$6 X 10^{-5}$	$6 X 10^{-5}$
Tensile strength, hoop (short-term) (MPa)	75	48	52
Tensile strength, 50 years (long-term) (MRS) (MPa)	50	25	25
E-Modulus, short-term (MPa)	4 000	3 000	3 300
E-Modulus, long-term (MPa)	1 800	1 400	1 500
Wave celerity (m/s):			
Class 16	309	363	436
Class 20	344	402	495

11. FLOW CAPACITY & ENERGY EFFICIENCY

The excellent strength and toughness properties make PVC-O the most robust and energy efficient piping system for water supply and sewer mains.

Embodied energy is defined as the non-renewable energy consumed in all the activities associated with the pipe's life cycle. This includes raw material extraction (generally from oil), manufacture of the pipes, transport and installation. It requires far less energy to make PVC-O pipes compared to ductile iron, PVC-U and HDPE pipes and less than half the carbon footprint of DI pipes.

11. FLOW CAPACITY & ENERGY EFFICIENCY (Continued)

The superior hydraulic efficiency of PVC-O is shown in the following data and comparisons with PVC-M, PVC-U, HDPE PE100. (Comparisons with ductile iron and GRP pipes are not shown as the dimensions of these pipes are according to a different standard).

The operational savings in power costs associated with PVC-O pipes represent a significant reduction in the life cycle cost of the installation. The operational pumping costs and flow capacities of various pipe materials are compared in the tables that follow:

HEAD LOSSES AND PUMPING COSTS FOR 1000m OF 200mm Class 16 Pipes				
MATERIAL	PVC-O	PVC-M	PVC-U	HDPE PE100
Nominal OD (mm)	200	200	200	200
Average Wall Thickness (mm)	4.7	9.0	12.7	19.1
Average ID (mm)	190.6	181.9	174.6	161.8
Mean Velocity (m/s)	1.4	1.5	1.7	1.9
Head Loss (m)	8.9	10.6	13.0	18.9
Theoretical Power Required (kW)	5.1	6.1	7/5	10.9
MWh consumed p.a.	41.1	48.7	59.7	87.2
Difference in Power Consumed vs PVC-O%	-	+19	+45	+112
Additional Pumping Cost p.a. vs PVC-O per kWh. Rands (@ R2.50 per kWh) (Pipeline 1000m)	-	20 000	20 000	124 600

Assumptions:

- Horizontal pumped line
- Water at 20°C
- Operation for 7 500 hours pa
- Information based on Colebrook-White formula and Harland for friction factor calculation
- Length of line: 1000m
- Flow rate: 40 litres / second
- Roughness coefficient for all pipes 0.03

Note: A roughness coefficient of 0.03mm has been used for PVC-O PVC-M, PVC-U and HDPE pipes (including pipe joints). This is conservative since a roughness factor of 0.003 is often used for PVC and HDPE pipes and the internal bore of PVC-O is much smoother than the other pipes due to the production process.

11. FLOW CAPACITY & ENERGY EFFICIENCY (Continued)

FLOW CAPACITY OF PIPES WITH SIMILAR HEAD LOSS FOR 1000m OF 200mm Class 16 Pipes				
MATERIAL	PVC-O	PVC-M	PVC-U	HDPE PE100
Mean Velocity (m/s)	1.76	1.72	1.67	1.58
Head Loss (m)	13.1	13.1	13.0	12.8
Flow Capacity (l/s)	49.0	44.8	40.0	32.5

Assumptions:

- Horizontal pumped line
- Water at 20°C
- Operation for 7 500 hours pa
- Information based on Colebrook-White formula and Harland for friction factor calculation
- Length of line: 1000m
- Flow rate: 40 litres / second
- Roughness coefficient for all pipes 0.03

The above comparisons of power consumption clearly show that significant savings can be achieved in operational costs associated with pumping schemes.

Consideration should therefore be given to total life cycle costs when selecting a pipeline size and material and not just the initial capital outlay.

As can be seen from the above comparisons of power consumption, significant savings can be achieved in operational costs associated with pumping schemes.

Consideration should be given to the **total** life cycle costs when selecting a pipeline size and material, and not just the initial capital outlay.

12. WATER HAMMER AND PRESSURE VARIATION

Water hammer and variations in pressure can be generated in any pressurised piping system if the flowing liquid suddenly changes velocity. The initial rate of pressure change can be very high but of short duration. Some of the most common causes are:

- Opening and closing of valves.
- Starting and stopping of pumps.
- Excessive water velocities.
- Entrapped air in the pipeline.
- Improperly sized pressure reducing valves.

Water hammer can be reduced by:

- Controlling and slowing valve and pump operations.
- Using pipes with a lower elastic modulus.
- Proper layout of network, valves, pumps and air valves.
- Fast acting pressure relief valves.

PVC-O pipes have a high factor of safety on short term high stress events and can withstand water hammer pressures far better than other pipes. This can be seen from the short-term resistance to pressure shown on the stress-time line above.

These high strength pipes can withstand surge pressures of at least twice the rated working Pressure, i.e. hoop stresses well above the 50-year MRS. Furthermore, it should be noted that it does not matter the age of the pipeline, the pipe acts as a new pipe. PVC-O pipes have a lower wave celerity than other piping systems (four times less than ductile iron pipes) and together with the greater flexibility of these high strength pipes means that lower surge pressures develop as a result of lower surge wave velocities.

13. HANDLING & STORAGE

Short-term exposure of the pipe to temperatures in excess of the maximum operating temperature (45°C) can be tolerated during storage.

However, if prolonged storage at high temperatures is expected it is recommended that the pipes be stored in the shade under a material such as shade cloth or hessian, placed so as not to restrict the circulation of cool air.

14. SOIL LOADING & NEGATIVE PRESSURES

The pipe stiffness for a given diameter of pipe is determined from the material modulus and the cube of the wall thickness.

While the modulus for PVC-O is slightly greater than PVC-U or PVC-M, it is the wall thickness which is the important factor affecting the stiffness and hence the pipe resistance of the pipes to buckling.

Ring buckling may be an important factor in the design of pipelines under conditional of internal vacuum (e.g. caused by water hammer and siphonage), sub-aqueous installation, pipes buried in loose soil with no lateral support or pipes having a cover less than two pipe diameters or 500mm (or a combination of these conditions). In such cased the unsupported critical buckling pressure should be considered.

The unsupported buckling pressure for class 16 PVC-O pipes is 200kPa, showing that the pipe can easily support a full vacuum by a factor of two times.

When the pipe is well supported according to good installation practices, the buckling pressure needed to collapse the pipe will be considerably higher.

15. CHEMICAL RESISTANCE

PCV-O has excellent resistance to attack by acids and alkalis, aqueous solutions and most oxidizing agents such as PVC-U and PVC-M pipes.

The advice of Flo-Tek should be sought in special cases (Eg. soil contamination by certain chemicals) or where the pipe is used for the transportation of chemicals.

16. INSTALLATION

The correct installation procedures are a critical component affecting the service life of all pipeline materials.

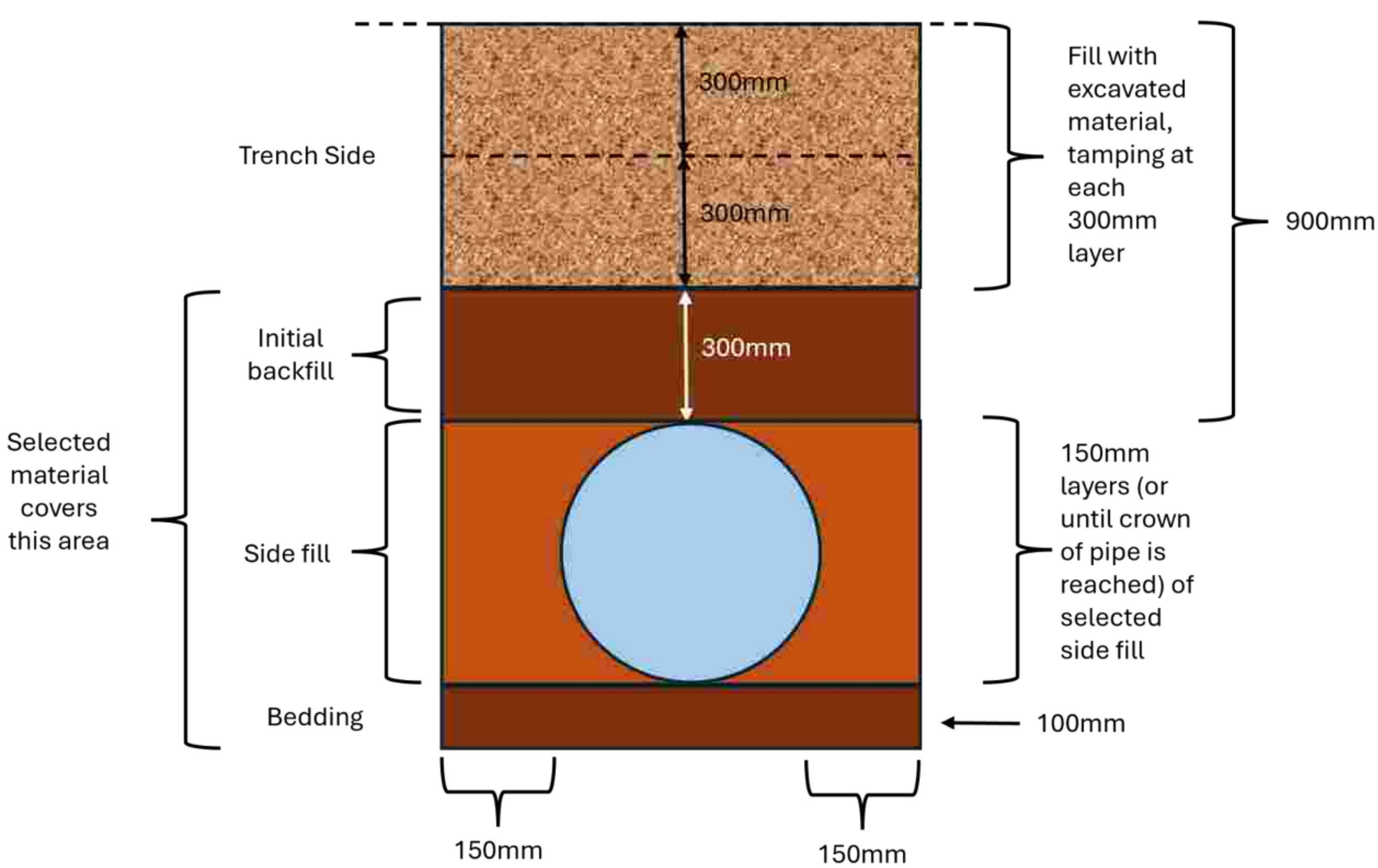
The following points represent the most important aspects of the procedure, which are generally in accordance with the requirement of SANS 1200, the Standard Specification for Civil Engineering Construction.

Note that these recommendations may be subject to change to suite the conditions, as detailed in the individual project specification.

The following points represent the most important aspects of the procedure, which are generally in accordance with the requirement of SANS 1200, the Standard Specification for Civil Engineering Construction. Note that these recommendations may be subject to change to suite the conditions, as detailed in the individual project specification.

TRENCHING, BEDDING AND BACKFILLING

- Excavate trenches to allow a minimum of 900mm cover over the crown of the pipe.
- The trench width should be kept to a minimum (pipe diameter plus 300mm) allowing only sufficient room for jointing and initial compacting of the fill material around the pipe. Do not ope the trench too far in advance of pipeline installation.
- The bottom of the trench should be free of hard objects and backfilled with selected material and compacted to a depth of 100mm to the specified density to provide a level and uniform bed for the pipe.
- Each length of pipe must be immediately backfilled after installation in order to contain expansion and contraction. Joints must be left exposed until completion of pipeline testing.
- Selected backfill material (as defined by SANS 1200) must be placed in layers of 150mm to a height of 300mm above the crown of the pipe. Each layer to be firmly hand-tamped. The remainder of the trench to be filled in layers of 300mm with light machine compaction to the specified density.



16. INSTALLATION (Continued)

LAYING PROCEDURE

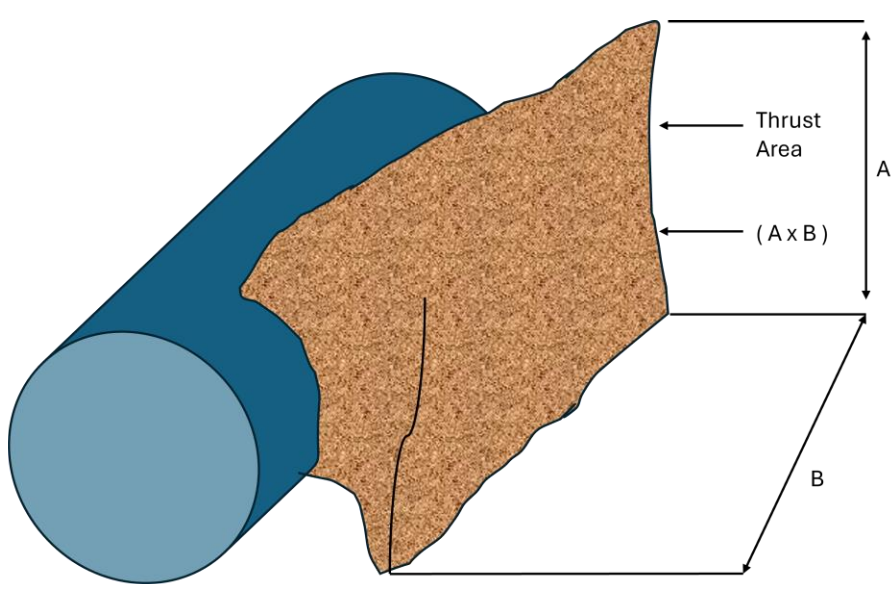
- Plan the installation so that the spigot end of the pipe is inserted into the socket of the pipe already lad, in the direction of flow.
- Ensure that the spigot end is chamfered to 15° and that the depth of entry line is clearly marked on the pipe.
- Check that the seal is clean and inserted correctly in its housing.
- Apply lubricant to the spigot end as well as the seal. *Do not use automotive lubrication grease as this will permanently damage the seals.*
- Align the spigot end of the pipe both horizontally and vertically with the socket.
- Push the pipe into the socket ensuring that the depth of entry mark is just visible. The joint is now complete.
- Should the joint be difficult to make, withdraw the spigot form the socket and check that the seal has not been dislodged.
- If the pipe needs to be cut, use either a fine-toothed hacksaw or angle grinder ensuring that the pipe is cut square to its length.
- Chamfer the pipe to the required 15° using the angle grinder or a medium file and remove all burrs.
- Redraw the depth of entry to the correct position.

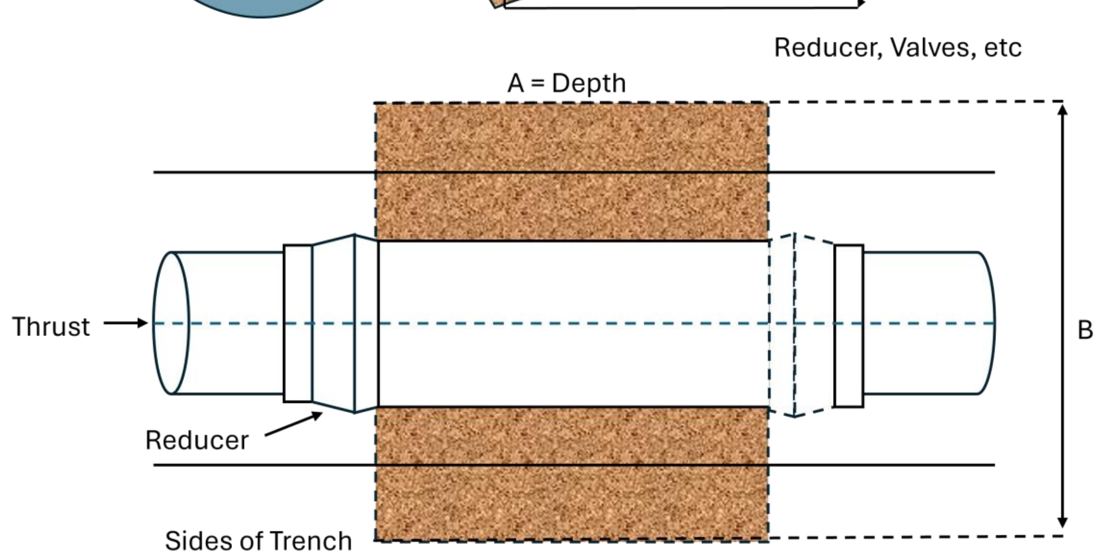
THRUST SUPPORT

Thrust's function is to transmit the loads imposed on them by the pipeline to the adjacent soil.

Thrusts are placed at:

- Changes in direction
- Closed valves
- Tees
- Blank ends





16. INSTALLATION (Continued)

TESTING AND COMMISSIONING

- Concrete thrust blocks must be provided, prior to filling of the line, at bends, tees, reducers and stop-ends so as to prevent movement of the fittings. The size of the thrust blocks should be according to the project specification and is dependent on the pipe size and the load bearing capacity of the soil as well as the test pressure or maximum pressure that the pipeline will be subjected to.

- It is recommended that the first 500 meters of the pipeline be pressure tested (with joints exposed) according to the project specification, thereafter every 1000 meters. The recommended test pressure is 1.25 x the rated pressure of the pipe or . X the operating pressure of the pipeline, or as noted in the project specification.

- It is essential to fill the line slowly from the lowest point, with all air valves fully functional and branch lines and hydrant valves open so at to 'bleed' the line of all air.

- Progressively close the bleed points from the lowest to the highest point of the line when all the air has been removed. Thereafter slowly bring the line up to the required test pressure.

- The result of the pressure test will be determined according to the project specification or as detailed in the SANS specification, based on the allowable leakage rate for the size and length of pipe being tested and the test pressure.

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