SAPPMA

southern african plastic pipe manufacturers association

Technical Manual
5th Edition

SAPPMA

WHO IS SAPPMA?

SAPPMA is a voluntary, self-regulating association incorporated under Section 21 as a company not for gain (registration number 2008/019270/08). The company is registered with the Receiver of Revenue for Value Added Tax (VAT number 4320219878).

It represents plastic pipe manufacturers and other stakeholders in the plastic pipe industry with membership comprising most of the major industry players in Southern Africa.

The SAPPMA logo is a registered trademark and members who comply with requirements are allowed to use the logo on pipes and fittings they manufacture. The SAPPMA brand is well known and is recognised by design engineers and customers as an additional safeguard against poor quality.

The requirements of the Competitions Act 89 of 1998 are strictly adhered to in all areas of operation. A policy of total transparency is followed and all meetings are minuted in detail as well as digitally recorded.

The Purpose of SAPPMA is to create absolute customer confidence in the Plastic Pipe Industry and to ensure the long term sustainability of the Industry, with top quality piping systems.

PIPELINES

Pipelines are one of three key elements of a country's infrastructure, together with the electrical grid and road/rail networks. Infrastructural elements are long-term investments in order to provide essential services to citizens with minimum interruption. Well-designed plastic pipelines made with modern polymers are easily capable of lifetimes of 50 years or more.

There are many reasons why plastic piping systems have become the material of choice all over the world and conservation of scarce resources is one of them. Electrical energy and water are two of the most precious and scarce resources in many countries, and certainly in South Africa. With excellent hydraulic properties, remaining virtually unchanged over its long life, the total pumping cost/electrical consumption required is significantly lowered with plastic pipe. It is furthermore noted that the embedded energy (total energy required to produce the raw material and the final product) of plastic pipe is lower than most other pipe materials.

Plastic pipes are high quality, energy conserving, infrastructural elements, capable of providing essential services for very long times.

The main focus areas of SAPPMA are quality, information, standards and training

BENEFITS TO DESIGN ENGINEERS AND CUSTOMERS

- Pipes and fittings produced by SAPPMA members are clearly identified with the SAPPMA logo; this should be proof to engineers or customers of the commitment to quality and differentiation of SAPPPMA members
- SAPPMA pipe members are subject to regular and strict factory audits. Audit certificates can be a useful tool for customers in assessing potential suppliers
- Valid customer complaints addressed to SAPPMA are handled without any financial prejudice
- Availability of the SAPPMA Technical Design Handbook
- SAPPMA members are self-regulating and bound by a strict Code of Conduct underwritten by the company's chief executive
- By insisting on the SAPPMA mark when specifying or purchasing plastic pipes, additional quality assurance is obtained
- Conducting regular country wide product quality surveys of all SABS mark bearing piping systems.

FOREWORD

The importance of plastic piping systems in the infrastructure of a country cannot be overemphasised. This is underlined by the fact that on a worldwide basis well over half of all pipelines for water, sewage and gas distribution are constructed using plastic pipe.

Plastic piping systems are a vast topic with an incredible number of important factors that need to be taken into consideration for the successful design and construction of a pipeline.

It is now eleven years since SAPPMA started publishing an independent technical manual on the use of plastic pipes. This is our 5th edition, which we believe is yet another big step forward in terms of accuracy and ease of use. As always, one of our biggest challenges when compiling this manual, was deciding what to exclude. To this end, we have imposed the following criteria on ourselves:

- Ensuring the information published is technically sound and up-to-date
- Confirming that the content is comprehensive in terms of general design considerations
- Communicating the information in a way that is user-friendly and easy to understand.

We are proud of our latest accomplishments and that we have managed to produce yet another successful manual, despite limited funding and only relying on our own technical resources.

In your hands you now have a tool which we believe will assist you in selecting the best pipe for a particular project, based on sound design principles and the correct installation procedures; thereby producing a pipeline that will operate effectively and efficiently for a very long time.

Jan Venter
SAPPMA CEO
September 2017

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CHAPTER 1:
INTRODUCTION

PURPOSE AND SCOPE

Although plastic piping has been widely used for more than sixty years, it is still something of an unknown in certain circles. Of particular concern is that engineering students do not seem to get adequate training about the ins and outs of selecting the right plastic material, completing an accurate design and ensuring the correct installation procedure is followed.

Publications such as the SAPPMA Technical Manual, therefore, fulfill an indispensable role in equipping designers and the end-users of plastic pipes to successfully select, design and construct plastic piping systems with confidence.

This publication is not an attempt to replace other textbooks and standards on the subject. Instead, our hope is that it will serve as a basic, user-friendly guide throughout the various steps of design. Furthermore, it is very important to note that the information contained in this manual is objective and free of any commercial influence (SAPPMA is a registered non-profit organisation).

We strive to verify the accuracy of all information in this publication. Nevertheless, pipe designs must be carried out by properly qualified persons who have specific experience in the design, detailing, specification, construction, quality control, commissioning, operation, repair and maintenance of piping systems.

THE NEED FOR PIPELINES

Pipelines are one of three key elements of a country's infrastructure, together with the electrical grid and road/rail networks. Infrastructural elements are long-term investments necessary to provide essential services to citizens with minimum interruption. Well-designed plastic pipelines made with modern polymers are easily capable of lifetimes exceeding 50 years.

There are many reasons why plastic piping systems have become the material of choice all over the world, a key one being the conservation of scarce resources.

Electrical energy and water are two of the most precious and scarce resources in many countries, and certainly in South Africa. With excellent hydraulic properties, remaining virtually unchanged over its long life, the total pumping cost/electrical consumption required is significantly lowered with plastic piping systems. It is furthermore noted that the embedded energy (total energy required to produce the raw material and the final product) of plastic pipe is lower than that of most other pipe materials.

Plastic pipes are high quality, energy conserving, infrastructural elements, capable of providing essential services for a very long time.

THE PARTIES INVOLVED

- User/Public: Responsible for electing Government representatives whose mandate it is to ensure the relevant resources are allocated to deliver services to the public.
- Local Authorities: Elected by Government to mandate and maintain the delivery of services to the public.
- Suppliers/Manufacturers and Installers: Employed by the client to ensure that the correct products and services are commissioned to ensure that service requirements are being achieved.
- Designers: Employed by the client to ensure the correct products in terms of standards and quality are chosen to meet and exceed the service expectations of the client.
- Client: Employed by local authorities to manage and ensure that the necessary services are being delivered.
- Government Institutions: Elected to ensure that resources are managed and allocated adequately to allow local authorities to deliver the necessary services to the public/user.

APPLICATION OF PLASTIC PIPES

Plastic pipe materials are extremely versatile and are used in a wide variety of industries. These include the following:

- Water distribution, stormwater and sewage disposal
- Chemical effluent
- Slurries
- Air
- Gas distribution
- Irrigation
- Hot and cold water plumbing
- Telecommunication cables
- Rehabilitation of old pipelines

SIGNIFICANCE OF QUALITY

In all pipe systems, including plastic pipe systems, quality in the manufacture and installation practices and procedures is of paramount importance to prevent failures from occurring and to ensure that the system will perform in the manner it is intended for throughout it its entire service life. Where quality is compromised it can have devastating effects influencing all facets of our daily lives, including, but not limited to:

- Economic impact: The cost resulting from loss of drinking water, the cost resulting from damage to property, legal costs, the cost of rehabilitation, repairs, etc.
- The social impact on communities: The amount of time during which the pipeline is out of service, impact on the flow of traffic, the impact on provision to other industries in the delivery of other services, i.e. energy, power generation, manufacturing etc.
- Impact on the environment: Pollution of ground water, sub-surface drainage water, contamination of drinking water, etc.

It is the responsibility of the manufacturer and/or distributor to prove compliance to a specific standard including, but not limited to, the quality of the raw materials being used in the manufacturing process. For example, the use of external recycled material should be condemned to prevent the possibility of pipe material contamination, which can impact the overall quality of the pipe in the long-term. This is one area where manufacturers can reduce their cost by not using high quality virgin material in the manufacture of their pipes. Pipes produced from contaminated regrind material can appear visually indistinguishable from pipe of superior quality and, since some defects may not be detected when purchasing a product from a supplier, it is of utmost importance that clients insist only on products manufactured according to the necessary standards, and that quality assurances are supplied.

Another area where quality could be compromised to cut down on material cost would be for a manufacturer to purposefully use less material or take shortcuts in the manufacturing process, resulting in irregularities in wall thicknesses along the length of the pipe. This would mean that the pipe has not been manufactured according to the necessary standards specified by the designer, which could lead to pipe failure before the anticipated service life of the pipe ends.

Although the service life of plastic pipes is generally considered to be 50 years, it is worth mentioning that, when high quality plastic pipes are manufactured according to the relevant standards and the correct quality assurance measures are maintained to produce high quality plastic pipes and fittings, it has been proven over the years that the anticipated service life of high quality plastic pipes may well exceed this, up to 100 years and beyond.

Note: the design life of the pipe and the design life of the joints need to be evaluated separately. It is clear that the long-term performance of quality plastic pipes offers a direct advantage to society and for this reason should not be compromised.

ENVIRONMENTAL CONSIDERATIONS

With the dramatic increase in population, industrialisation, and urbanisation in the modern world, people are fast coming to realise that present energy resources are limited and bound to run out unless better preserved. This is also leading to renewed efforts to develop alternative energy sources on an economic and commercial scale.

THE ENERGY FOOTPRINT OF PLASTIC PIPE

INTRODUCTION

Energy is subject to the law of conservation of energy, stating that energy cannot be created or destroyed, but can be transferred or transformed from one form to another (including transformation into or from mass, as matter). The total amount of energy in a closed system never changes.

All of this has led to an increasing awareness of the quantum of energy required to produce, operate, and maintain systems. Piping systems are costly elements of infrastructure and it is therefore appropriate to evaluate the energy costs associated with it.

Here it is worth noting that, while the manufacturing of plastics uses only 4% of all oil and gas, the use of plastics contributes significantly to energy saving and reduction of emissions.

PLASTICS

The Denkstatt study, an intensive investigation funded by the European Association of Plastics Manufacturers, analysed the environmental impact of 173 plastic products throughout their entire life cycle. The study's report, Plastics' Contribution to Climate Protection, identifies plastics' share of citizens' carbon footprint and provides a carbon lifecycle analysis of plastics compared to their alternatives in packaging, transportation, building and construction, and eco-product enablement (e.g. solar panels, wind turbines).

Initial results revealed that, while the carbon footprint of an average EU 27+2 (Norway and Switzerland) consumer amounts to about 14 tonnes CO2 per capita, **a mere 1.3% (or 170kg) stem from the use of plastic products.**

The preview data released during this event reveals that plastic saves 2 300 million GJ in energy per year. This equates to 50 million tonnes of crude oil: the load of 194 very large oil tankers. These savings prevent the emission of 120 million tonnes of greenhouse gases per year, thereby reducing the greenhouse effect within the earth's atmosphere.

EMBEDDED/EMBODIED ENERGY OF PLASTIC PIPE

The aim of embodied energy analysis is to quantify the amount of energy used to manufacture a material or product. It involves the assessment of the overall expenditure of energy required to: extract the raw material; manufacture the products; and maintain them.

Basic factors influencing the embodied energy of a piping system are:

- Pipe size (quantity of material used)
- Material used
- Durability and design life of the system
- The energy required to pump the fluid
- Amount of maintenance required over its life
- The use of recycled material
- Can the material be recycled after its useful life?

Studies done in Australia and Europe have shown that the embodied energy of plastic pipe is significantly lower than that of competing materials. A further major benefit of plastic pipe systems is the reduction of pumping cost. This is due to the fact that the hydraulic properties of plastic pipes remain virtually unchanged throughout their lifespan, as opposed to other materials which corrode and eventually restrict flow. Thermoplastic pipe, in addition, is easily recycled and thus does not contribute to environmental waste.

Studies in Australia were done using 1 000 metres of 100 mm nominal size pipes, arriving at comparative sizing based on a flow rate of 10.4 l/s and head loss 7.84 m with the following results:

TABLE 1.1: EMBODIED ENERGY COEFFICIENTS FOR PIPE TYPES (GJ):

Pipe Material	Embodied Energy GJ
DI (DUCTILE IRON)	1 100
PE 80 PN 12.5	500
PVC-U PN 12	312
PE 100 PN 12.5	312
PVC-U S2 PN 12	300
PVC-M S1 PN 12	225
PVC-M S2 PN 12	205
PVC-O S1	200
PVC-O S2	175

TABLE 1.2: ENERGY REQUIREMENT IN MANUFACTURING OF 1KM 110MM PIPE (MT OIL EQUIVALENT)

CI	GI	RCC	PVC
19.7	10.0	6.0	3.5

CI=Cast Iron; GI=Galvanised Iron; RCC=Reinforced Concrete; PVC=Polyvinylchloride

TABLE 1.3: IN ANOTHER STUDY DONE IN EUROPE THE FOLLOWING RESULTS WERE OBTAINED:

	PVC	PE-HD	PP	PET	Clay	DI
Material energy MJ/kg	56	76	73	83	10	25
Pipe weight Kg/m	5.7	5.4	4.4	5.8	33	40
Energy MJ/m	319	410	318	481	330	1000
Oil consumption Kg	6.9	8.9	6.9	10.5	7.2	21.7
CO2 emitted Kg	20.8	26.8	20.7	31.4	21.5	65.2

Even though the material energy of ductile iron is a lot less than that of plastics in terms of mass (MJ/kg), the picture reverses when the wall thicknesses and mass per meter are taken into consideration (MJ/m). The amount of carbon dioxide emitted by the production of plastic pipe is likewise far below that of ductile iron.

TRANSPORT

Because of its low mass, the cost of transporting plastic pipe is considerably less than for the equivalent in steel or concrete.

COST OF PUMPING

It is crucially important to consider the electricity used in pumping fluids through pipelines. It is estimated that 60% of the world's electricity is used by electric motors, and that 20% of this is used for pumping.

Because of the specific properties of plastic pipe, the walls offer very limited resistance to flow (low friction) and, even more importantly, remain virtually unchanged throughout the pipe's design life.

Comparative calculations show that the increase in power or pumping cost after 50 years is only 13.6% for thermoplastics, contrasted with a massive 62.6% for steel, and the discrepancy gets much worse beyond 50 years.

TABLE 1.4: APPROXIMATE MASS IN KG OF 1 M PIPE OF 110MM DIAMETER:

PVC	GI	CI	RCC
1.7	10.0	15.0	27.0

TABLE 1.5: INCREASE IN PUMPING COST IN MANUFACTURING OF 1KM 110MM PIPE (MT OIL EQUIVALENT)

Years	0	10	20	30	40	50	% increase	100	% increase
Thermopl's	33 446	34 288	35 163	36 073	37 019	38 004	13.6	43 352	29.6
DI	38 004	40 100	42 380	44 865	47 581	50 560	33.0	67 008	76.3
Steel	43 595	47 581	52 159	57 451	63 618	70 867	62.6	114 059	161.6

These results are graphically represented in the figure below.

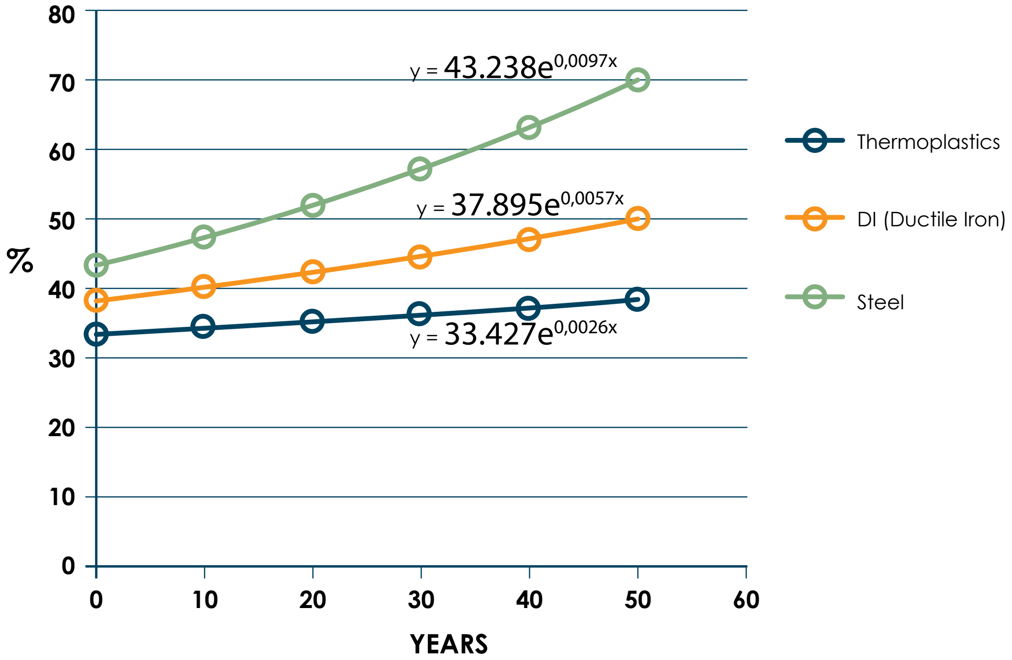


FIG 1.1 PUMPING COST COMPARISON OF VARIOUS MATERIALS OVER TIME

TABLE 1.6: A SPECIFIC STUDY OF PUMPING COST HAS SHOWN THE FOLLOWING RESULTS:

Material of riser pipe	Average power consumption kWh
Polyethylene	6 120
Galvanised iron	10 000

Study done with submersible pumps and pipe diameters of 4", 6" & 8". Results based on an average for one year.

TABLE 1.7: IN ANOTHER ACTUAL TEST 130 METERS 250MM PVC PIPE WAS COMPARED TO THE EQUIVALENT IN MILD STEEL IN TERMS OF FLOW RATES AND PUMPING ENERGY:

	Unit mass kg/m	Measured Flow M^3/hr
PVC	10.7	540
Mild Steel	26.4	370

This translated into an annual energy saving of 131,300 kWh when using PVC pipe

GENERAL

Every METRIC TON of plastic pipe that replaces the equivalent in steel saves about 23 MW of power.

RECOVERY & RECYCLING

Plastic pipe can easily be recycled. Indeed, because of the high value of polymer it is recycled on a relatively large scale, and it is difficult to find old, unused pipe. A recent survey indicated that about 14 000 tons of HDPE & PVC pipe was recycled in 2009 at external facilities. In-house recycling by pipe manufacturers is estimated at 8 000 tons, bringing the total for these two pipe materials to about 22 000 tons per annum. It is common knowledge that plastic pipe is not wasted and therefore does not contribute to environmental pollution.

It is noted that 100% of recycled pipe can be re-used, although strict quality requirements by SAPPMA mean that most of it goes into noncritical applications.

Ductile iron and steel pipe can also be recycled, although the energy cost to do so is considerably higher than for plastics.

Note: Manufacturers need to ensure compliance with the minimum requirements of the recycled material to the relevant standard for HDPE and PVC.

Basic calculations show that the power consumption to recycle plastic pipe is about R0.09/kg. The corresponding figure for steel is estimated to be between R0.23 and R0.45/kg, bearing in mind that many steel pipelines are internally lined with material that needs first to be stripped from the steel.

NOTE: The figures given under the recovery and recycling section apply only to South Africa.

REFERENCES:

Piping Systems Embodied Energy Analysis

By M.D Ambrose, G.D Salomonsson
and S. Burn of CSIRO

'Plastics Recycling Survey 2009'

Plastics Federation of SA

SAPPMA Technical Committee

The European Association of Plastics Manufacturers

Ahmedabad Municipal Corporation

Sasol Polymers

KEY FACTS: PLASTICS AND PLASTIC WASTE

In 2009, around 230 million tonnes of plastic were produced; around 25% of these plastics were used in the EU (Mudgal et al., 2010). About 50% of plastic is used for single-use disposable applications, such as packaging, agricultural films and disposable consumer items (Hopewell et al., 2009).

Plastics consume approximately 8% of world oil production: 4% as raw material for plastics and 3-4% as energy for manufacture (Hopewell et al., 2009).

Bioplastics make up only 0.1 to 0.2% of total EU plastics (Mudgal et al., 2010).

It is estimated that plastics save 600 to 1300 million tonnes of CO_2 through the replacement of less efficient materials, fuel savings in transport, contribution to insulation, prevention of food losses, and use in wind power rotors and solar panels (PlasticsEurope, 2010).

CHAPTER 2:
BASIC DESIGN CONSIDERATIONS

BASIC PRINCIPLES

The primary function of any pipeline is to convey a fluid. Its size is based on predictions of future demand. It is usually not economical to design for the maximum predicted future flow since, if a pipeline proves to be too small at some future date, an additional pipeline can be constructed with minimal or no disruption to the operation of the existing one.

To meet this primary requirement the pipeline must also meet the secondary or supporting requirements of *strength*, *water-tightness* and *durability*. The secondary requirements of a pipeline system are as important as the primary to ensure the demands for service delivery (fitness for purpose) over the life-span are satisfied. Whether a pipeline is designed to serve a 20 year, 40 year, or some other predicted population or demand, it must be designed to meet the secondary requirements based on the worst-case scenario. If it fails to meet these requirements, any remedial work will cause a major disruption to its operation and may necessitate its replacement even though it still has the required *hydraulic capacity*.

When there are junctions, transitions, or changes in vertical or horizontal alignment, access is generally needed. This takes the form of chambers, manholes or other appurtenant structures. In the case of pressure pipelines, the accumulation of air in the pipeline-system and structures should also be considered, and air relief valves or other devices should be placed throughout the system where necessary to manage this. As these are vertical structures, the loading on these is different from that on the adjacent sections of pipeline that are loaded with soil. As a result, there can be relative movement between these structures and the adjacent pipes.

Failures on pipelines frequently occur at joints and interface structures such as manhole chambers. If the correct measures are not taken to minimise disruption of flow through these structures, and the associated energy losses are not factored in, the hydraulic performance of a pipeline can be seriously compromised. If measures are not taken to accommodate any potential relative movement between pipes and these structures, pipes can crack or deform, resulting in leakages.

The structural design of buried pipelines involves the understanding of a complex system consisting of soil and traffic loads, soil properties, water movement through the soil, appurtenant structures, and the properties of pipe made from a wide range of materials. The designer can do little about the installation conditions, but can make decisions regarding the requirements the pipe must meet and then choose the most appropriate pipe material for the conditions on a particular project.

There are two broad categories of pipelines – *pressure* and *gravity* systems – which operate very differently to one another. There are also two broad categories of pipe materials – rigid and flexible – which respond to loads very differently. It is essential that the designer understands these two sets of differences.

GRAVITY AND PRESSURE SYSTEMS

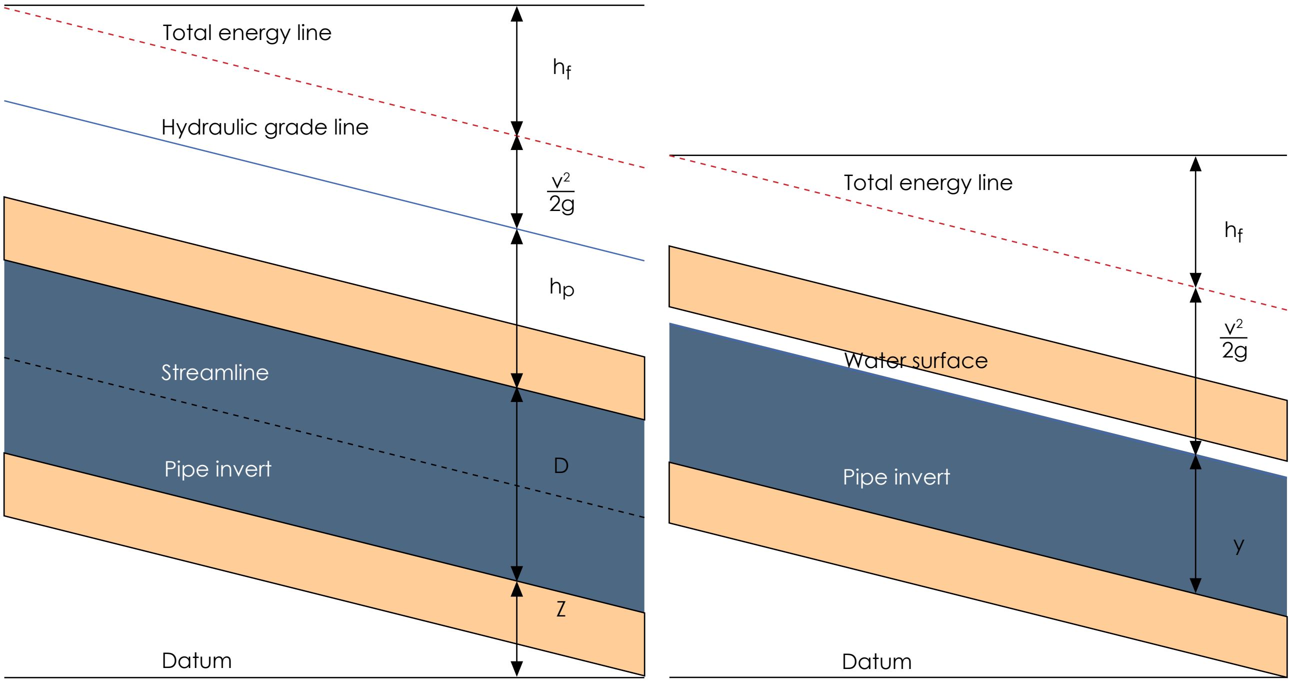
Pressure pipelines flow full, and the energy in them has three components in addition to pipe diameter: velocity head; pressure head; and frictional losses. With pressure pipelines it is the energy difference between the inlet and outlet that determines the discharge capacity. As the hydraulic performance of this type of pipeline is not dependent on its gradient, the vertical alignment is essentially determined by the ground surface, and it is placed at relatively shallow depths. The dominant stresses in the pipe wall will be those due to the internal pressure, though the influence of external loads cannot be ignored.

On the other hand, gravity pipelines, especially stormwater drains and sewers that flow partly full, have no pressure component to their energy, and can thus flow only downhill. This means that, for efficient operation, gravity pipelines must be laid at gradients that will ensure self-cleansing velocities. With gravity pipelines it is the gradient of the flattest section that will determine the capacity. To maintain self-cleansing velocities it may be necessary to install such pipelines in deep trenches and at gradients that are not parallel to the ground surface.

To achieve this they are frequently placed at depth below the surface. As a result the dominant stresses developed in the pipe wall are due to the external earth loads, although under certain circumstances internal pressure may also have to be considered. When pipes are used for low pressure or gravity applications it is the external loads that will determine the required wall thickness or pipe stiffness.

It needs to be appreciated that the way in which a pipe handles internal fluid pressures and external earth loads is different. Internal pressure generates direct tension in the pipe wall, whereas external earth and traffic loads are non-symmetrical and cause circumferential bending of the pipe wall. In most soils the vertical loads will exceed the horizontal loads, in which case the pipe will deform to form a horizontal ellipse.

This effectively activates lateral soil pressures resulting in the transfer of load to the surrounding soil.



(a) PRESSURE CONDUIT FLOWING FULL **(b) GRAVITY CONDUIT FLOWING PARTLY FULL**

FIGURE 2.1: DIFFERENCE BETWEEN GRAVITY AND PRESSURE PIPELINES

Where: hf - head loss due to friction (m)
V - velocity (m/sec)
g - acceleration due to gravity (m/sec^2)
hp - pressure head (m)
D - pipe diameter (m)
Z - height above datum (m)
Y - Depth of flow partially full pipe (m)

SOIL STRUCTURE SYSTEMS

The way in which the loads are carried will depend on the relative stiffness of the pipes and the surrounding soil. SANS/ISO 10102 part I (p18), uses the approach given in Young and Trott, namely:

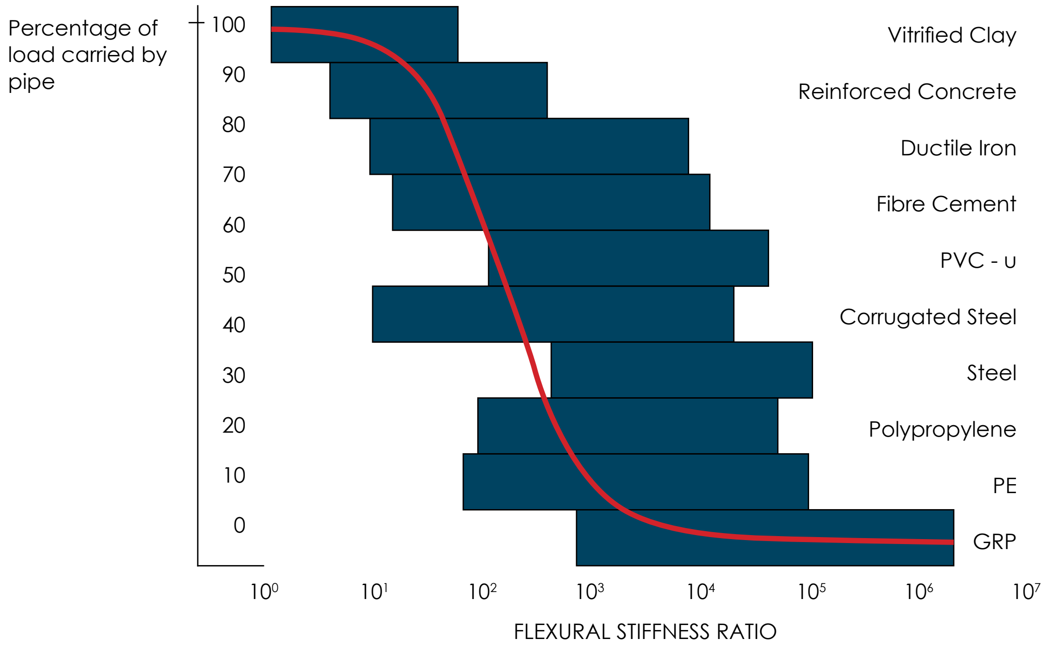


FIGURE 2.2: RANGE OF FLEXURAL STIFFNESS RATIOS FOR PIPE MATERIALS USED IN SOUTH AFRICA

$$\mathbf{Y = E'/S_R} \qquad \mathbf{(1)}$$

$$\mathbf{S_R = EI/D^3} \qquad \mathbf{(2)}$$

Where Y - flexural stiffness ratio
E' - the soil stiffness
S_R - pipe ring stiffness
E - elastic modulus for pipe material
D - undeformed vertical diameter of pipe
I - moment of inertia of section

This ratio 'Y' is directly proportional to soil stiffness and indirectly proportional to pipe ring stiffness, or flexural stiffness as it is defined in this document. Soil stiffness can vary from 1 to 20 MPa. Pipe ring stiffness ranges from 1kN/m/m for flexible pipes where the pipes deform and shed the load to the surrounding soil, to >2,000kN/m/m for rigid pipes where the pipes carry the load directly by moment and shear. The 'Y' value of a rigid system is thus two to five orders of magnitude less than that of a flexible system. A comparison of the pipe materials commonly used in SA is shown in Figure 2.2.

As the flexural stiffness ratio increases, so the strength of the pipe/soil system becomes more dependent on the properties of the surrounding material. The emphasis shifts from ensuring that the pipe produced in a factory has the required strength to carry the loads, to ensuring that the embedment around the pipe, constructed on site, has the strength to provide the pipe with the required lateral support.

This figure also shows the difference between the various types of plastics, which the civil designer frequently does not appreciate. It should be recognised that there is a significant difference between the performance of the thermoplastics such as PE and PVC and the thermoset plastics such as GRP. In the case of PE and PVC pipes, the development of high strains will not cause structural failure of the pipe wall. The same cannot be said for GRP pipes where strain is a limiting factor. Excessive deflection of all flexible pipes could however cause operational problems for example the watertightness of joints and accessibility for maintenance.

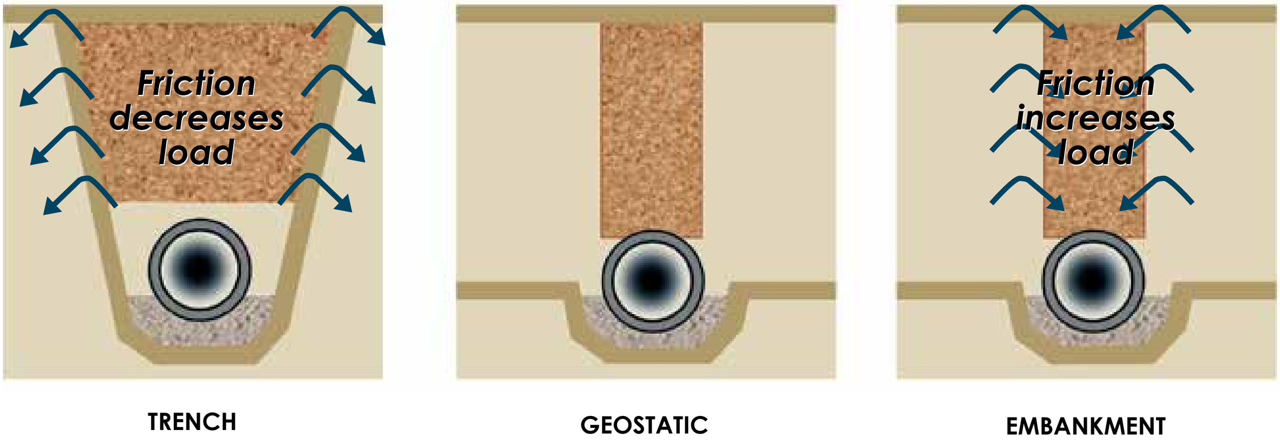
No matter what pipe material is used, care must be taken to ensure that the foundation support is uniform.

FLEXIBLE AND RIGID PIPES

Rigid pipes have to carry the imposed loads on their own, and the critical structural parameter is their strength. The main determinant of these loads is usually the installation condition. Flexible pipes, on the other hand, deflect under imposed loads. They are thus reliant on the horizontal soil support that develops, where the critical structural parameter is the soil stiffness around them. The main determinant of deflection will be the stiffness of the surrounding material.

Note: Regardless of what pipe material is chosen for a given application, proper design and construction methods for effective jointing as well as the overall pipe structure cannot be underestimated.

The standard installation conditions for rigid pipes are illustrated in Figure 2.3. A useful concept is the geostatic load, which is the load on the pipeline due to the prism of material directly over it. With a trench installation the loading will always be less than the geostatic loading because the frictional forces act upwards and reduce the loading on the pipe. With an embankment installation the loading will always be greater than the geostatic load because the frictional forces act downwards and increase the loading on the pipe.



TRENCH

GEOSTATIC

EMBANKMENT

FIGURE 2.3: COMPARISON OF INSTALLATION CONDITIONS FOR RIGID PIPES

The geostatic load on a flexible pipe will be the column of earth directly on top of it. The pipe will deform more under this load than the columns of earth on either side of it and as a result upward frictional forces will develop between the column of earth directly above the pipe and the columns of earth on either side of the pipe. The vertical load on the pipe will therefore be less than the prism load. Irrespective of the installation condition the load on a flexible pipe will always be less than the geostatic load calculated by using its outside diameter.

The basic formula for calculating the soil load on a buried pipe is:

$$W_E = C_E \gamma B^2 \qquad (3)$$

Where W_E - total earth load in kN/m of pipeline
C_E - earth load coefficient
γ - fill material density
B - outside pipe diameter (B_C) or trench width (B_T)

For *embankment* installations the most severe loading on a rigid pipe occurs when the founding conditions are unyielding and the whole pipe projects above the founding level.

Once the fill height exceeds ± 1.7 B_C there is a straight line relationship between load and fill height and there will be no limiting value to the load. These earth loads will be:

$$W_E = 1.69 \gamma B_c H \text{ in sand} \qquad (4)$$

$$W_E = 1.54 \gamma B_c H \text{ in clay} \qquad (5)$$

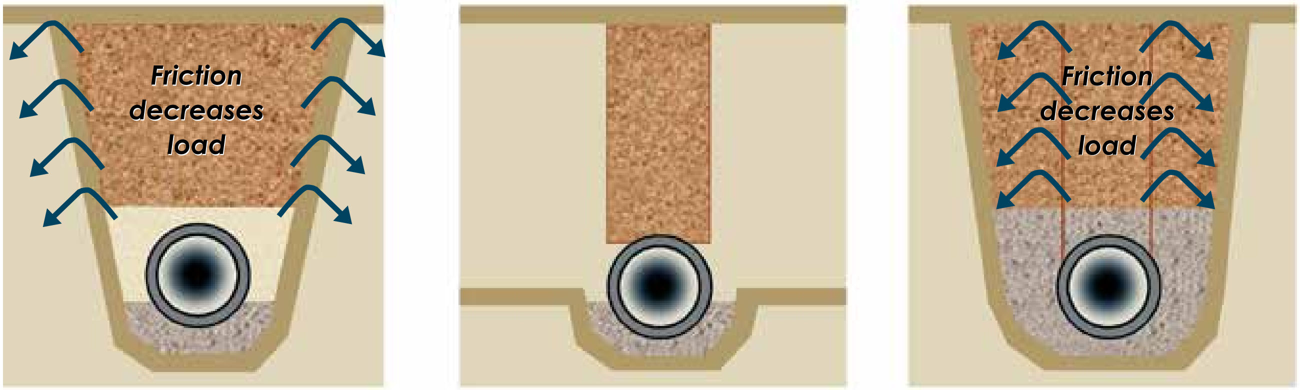
For *trench* installations, upper limits to loading on a rigid pipe occur when complete arching action occurs.

$$W_E = 2.63 \gamma B_t^2 H \text{ in sand} \qquad (6)$$

$$W_E = 3.84 \gamma B_t^2 H \text{ in clay} \qquad (7)$$

In practice the walls of a trench dug through a sandy material will not stand and the equation (6) is hypothetical. Open trench installations are seldom so deep that full arching action and limiting loads can be achieved, and hence it would be uneconomical to use these values to determine the required pipe strength.

A comparison of the loading on rigid and flexible pipes under trench installation conditions is given in Figure 2.4.



RIGID **GEOSTATIC** **FLEXIBLE**

FIGURE 2.4: COMPARISON OF RIGID AND FLEXIBLE PIPE IN A TRENCH INSTALLATION

As the thermoplastic pipes such as those made from PVC, PE, and PP have a high strain tolerance, they will deform more than the columns of earth next to them and the frictional forces that develop between the columns of earth will act upwards and reduce the load on the pipe. If the fill height is great enough, full arching will take place and the earth load will have an upper limit as given by formulae (6) and (7) where the trench width is replaced by the outside diameter of the pipe. This approach, however, is seldom taken.

PVC, PE & PP pipe have a proven track record of over 40 years. In the absence of details of actual soil properties and installation conditions the earth loads on flexible pipes can conservatively be taken as:

$$W_E = \gamma B_c H \qquad \textbf{(8)}$$

Where the terms are as defined as for equation (7).

COMPARISON OF VARIOUS FLEXIBLE PIPES

There are significant differences between plastic pipes and steel pipes both in terms of their properties and applications. Some of the differences between PE, PVC and steel are listed in Table 2.1.

TABLE 2.1: COMPARISON OF VARIOUS FLEXIBLE PIPES

PE	PVC	Steel
Flexibility		
• Less affected by soil settlement • Can be wound onto drums in diameters [Up to 160 mm in SA] • Suitable for relining and ploughing in • Cold bending radius at 20°C = 30D • Suitable for temperatures down to minus 40°C • Can withstand crushing	• Affected to some extent by soil settlement • Only corrugated pipes can be wound onto drums (single wall) • Limited use for relining • Cold bending not possible • Laying at sub-zero temperatures risky for PVC-U, less so for PVC-M and PVC-O • PVC-U cannot withstand crushing, PVC-M can withstand to some extent, and PVC-O can withstand crushing	• Affected to some extent by soil settlement • Cannot be wound onto drums • Difficult to use for relining pipe • A limited amount of bending is possible
Jointing Technique		
• Can be fusion welded • Joints have good tensile strength • Special equipment required	• Bonded joints with good tensile strength. Can be bonded without costly special equipment • Mechanical restrained joints • Push-in joints easily made • Victaulic restrained joints	• Can be welded • Joints have good tensile strength

PE	PVC	Steel
Chemical Resistance		
• Resistant to acids, alkalis, solvents, alcohol • Not resistant to oxidizing acids, ketones, aromatic hydrocarbons and chlorinated hydrocarbons • Resistant to microbial corrosion • Resistant to all natural gas constituents	• Resistant to acids, alkalis, salt solutions and many organic compounds such as fats, oils, aliphatic hydrocarbons. • Resistant to microbial corrosion • Resistant to natural gas	• Limited resistance to chemicals • Unsuitable for concentrated oxidizing acids • Not resistant to microbial corrosion • Not resistant to acid containing condensates (corrosion)
Weather Resistance		
• Due to the required carbon black additive, outdoor weathering has virtually no effect on creep rupture properties • Cannot be painted	• Normal periods of outdoor storage present no loss in creep rupture strength. Addition of stabiliser products to improve UV resistance is required • Can be painted	• UV resistant • Corrosion could be a problem • Can be painted
Thermal Expansion		
• 0.2mm/m/°C	• 0.07mm/m/°C	• 0.012mm/m/°C
Abrasion (depends on type of material being pumped)		
• 0.25mm after 600 000 cycles	• 0.75mm after 600 000 cycles	• Wear rate 1.42
Flammability		
• Normal flammability: ignites on contact with flame. Continues to burn when the ignition source is removed and melts with burning drops	• PVC pipe is self-extinguishing	• Non flammable
Young's Modulus (E)		
• 800 - 1100 MPa (Short Term)	• 3000 - 4000 MPa (Short Term)	• 210 000 MPa

PIPE SIZE

HYDRAULICS

The three principles used in the hydraulic design of pipelines are *continuity, energy,* and *momentum*. The continuity principle states that the flow rate at one section of a pipeline will be the same as at any other section, provided there is no change in the discharge and the material density remains constant.

$$\mathbf{Q = A\,V = Q_1 = A_1 V_1 = Q_2 = A_2 V_2} \qquad \textbf{(9)}$$

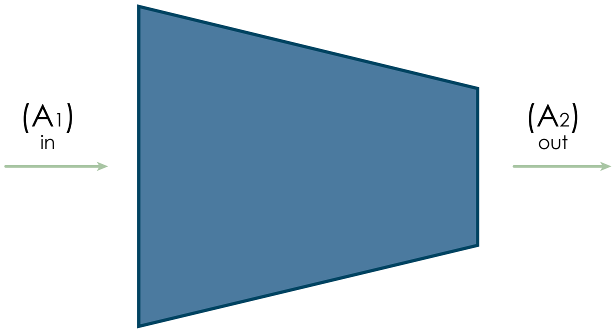


FIGURE 2.5: CONTINUITY PRINCIPLE: PIPE FLOW

The **energy** or Bernoulli equation expressed in SI units states that

$$\mathbf{V_1{}^2/2g + p_1/\gamma + Z_1 = V_2{}^2/2g + p_2/\gamma + Z_2 + h_L} \qquad \textbf{(10)}$$

Where,

V – velocity in m/s
A – cross-sectional area of pipe's internal diameter / volume of liquid (m^2)
G – acceleration due to gravity in m/s^2
S – hydraulic gradient in m/m (hf / length of pipe)
P – pressure in kPa (1 Bar = 100 kPa, 1 Bar = 14.5 Psi)
γ – unit weight of fluid kN/m^3
Z – height above datum
h_L – head loss between sections along length, 1 and 2 in m
Q - volumetric flow rate in m^3/sec

The **momentum** principle states that the change in momentum between two sections of a pipeline equals the sum of the forces causing the change.

$$\mathbf{\Delta Fx = \rho Q \Delta V_{\varkappa}} \qquad \textbf{(11)}$$

Where,

F - force in direction $\varkappa$ in kN/m^2
ρ - unit mass of fluid in kg/m^3
Q - volumetric flow rate in m^3/s
V - velocity in m/s

Subscript $\varkappa$ refers to the velocity in the '$\varkappa$' direction

The hydraulic capacity of any conduit will be determined by a combination of factors: the energy difference between the inlet and outlet; the geometric properties of pipe; pipeline alignment; and the physical properties of pipe material. The energy losses in a pipeline are due to friction and transitions.

Friction is developed as a fluid moves past the pipe wall. The rougher the surface, the higher the energy required to overcome this friction. In a pipe flowing full, the energy to overcome friction is provided by the pressure gradient, whereas in an open channel this energy is provided by the weight of the water running down the slope. In a closed conduit the friction resisting the flow is distributed around the whole boundary. In an open channel there are two types of surfaces: a free air water interface where there is negligible friction; and the interface between the fluid and the pipe wall, where friction is developed.

In its simplest form the velocity through a conduit can be described by the Chezy equation.

$$\mathbf{V \;=\; C\;\; RS} \qquad \textbf{(12)}$$

Where,

V - is the velocity
C - the Chezy coefficient
R - describes the conduit geometry
S - describes the gradient

There are several derivatives of this basic equation. Equations such as Manning and Hazen-Williams are based on empirical roughness values, whereas Colebrook-White is theoretically correct and based on absolute roughness values.

The empirical equations are easier to apply and are adequate for most applications.

Manning is used both for pipes flowing full and partly full.

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad \textbf{(13)}$$

Where V - velocity (m/s)
n - roughness coefficient
R - hydraulic radius (m)
S - slope of energy line for pipes flowing full (m/m) slope of pipeline for pipes flowing partly full (m/m)

Values of the roughness coefficient for use in the **Manning** equation are given in table 2.2.A.

TABLE 2.2.A: PIPE ROUGHNESS COEFFICIENT (MANNING)

Material	n (mm)
Polyethylene	0,009
PVC	0.010
GRP	0.009
Steel, new	0.012
Galvanised Iron, new	0.016
Ductile Iron, new	0.013
Uncoated Cast or Ductile Iron	0.013
Corrugated Steel	0.024
Concrete	0.015
Vitrified Clay	0.013
Brick and Cement Mortar	0.015
Wood Stave	0.011
Rubble Masonry	0.021

The **hydraulic radius** of a pipe flowing partly full:

$$R = A/Pw \qquad \textbf{(14)}$$

Where, A - Cross-sectional area of section flow
Pw - Wetted perimeter of flow

Hazen-Williams is the preferred formula for pipes *flowing full* and has a similar format.

$$V = k\,C\,R^{0.63}\,S^{0.54} \qquad \textbf{(15)}$$

Where, V - velocity (m/s)
k - unit conversion factor (0.849 for SI/Metric Units)
C - roughness coefficient
R - Hydraulic Radius (refer to equation 14)
S - hydraulic gradient (m/m)

Values of the roughness coefficient for use in the **Hazen-Williams** equation are given in table 2.2.B.

TABLE 2.2.B: PIPE ROUGHNESS COEFFICIENT (HAZEN-WILLIAMS)

Pipe Material	New	25 yrs old	50 yrs old	Badly corroded
PE, PP & PVC	150	140	140	Do not corrode
Smooth concrete & FRC	150	130	120	100
Steel - Bitumen lined/ galvanised	150	130	100	60
Cast iron	130	110	90	50
Vitrified Clay	120		80	Does not corrode

For diameters smaller than 1000mm reduce the value of C by

$$0.1\ (1 - \mathrm{Dia(mm)})\ C \qquad \textbf{(16)}$$

Colebrook-White gives a more rigorous formula which accounts for the **absolute roughness** of the pipe material and the viscosity of the fluid. The values are more accurate, but also more difficult to calculate, and it is not so easy for the designer to develop a feel for how the formula responds to changes in the variables. It is expressed as:

$$V = -2\sqrt{2gDS}\,\log(k_s/3.7D + 2.51v/D\sqrt{2gDS}) \quad (17)$$

Where k_s - absolute roughness of pipe material (mm)
v - kinematic viscosity of fluid (m^2/s)

The other symbols are already defined. It should be noted that "v" is temperature dependant and this must be taken into account when accurate results are required.

A comparison of different **absolute roughness** values is given in Table 2.3.

TABLE 2.3: ABSOLUTE ROUGHNESS VALUES (COLEBROOK-WHITE)

Material	k_s (mm)
Polyethylene & PVC	0.002
GRP	0.01
Steel, new	0.05
Galvanised Iron, new	0.15
Ductile Iron, new	0.5 – 1.0
Ductile Iron, corroded	1.0 – 1.5

For a quick determination of flow parameters, the nomograph in Figure 2.6 can be used. However, when accurate values are required, they should be calculated.

For practical reasons the velocities in pressure pipelines should fall in the range of 0.8 to 2.5 m/s, the lower limit to maintain self-cleansing flow and the upper limit to minimize air release at high points.

The velocity range in gravity systems is the same, with the provision that downstream velocities should not be appreciably lower than upstream values, to prevent the deposition of the bed load being carried. A drop in velocity to 0.7 of the upstream value is probably the maximum that should be allowed. Another factor to consider in pipes that flow partly full is super critical flow. When this occurs the velocity should not exceed 2.5 m/s, or the velocity head should be contained in the pipe.

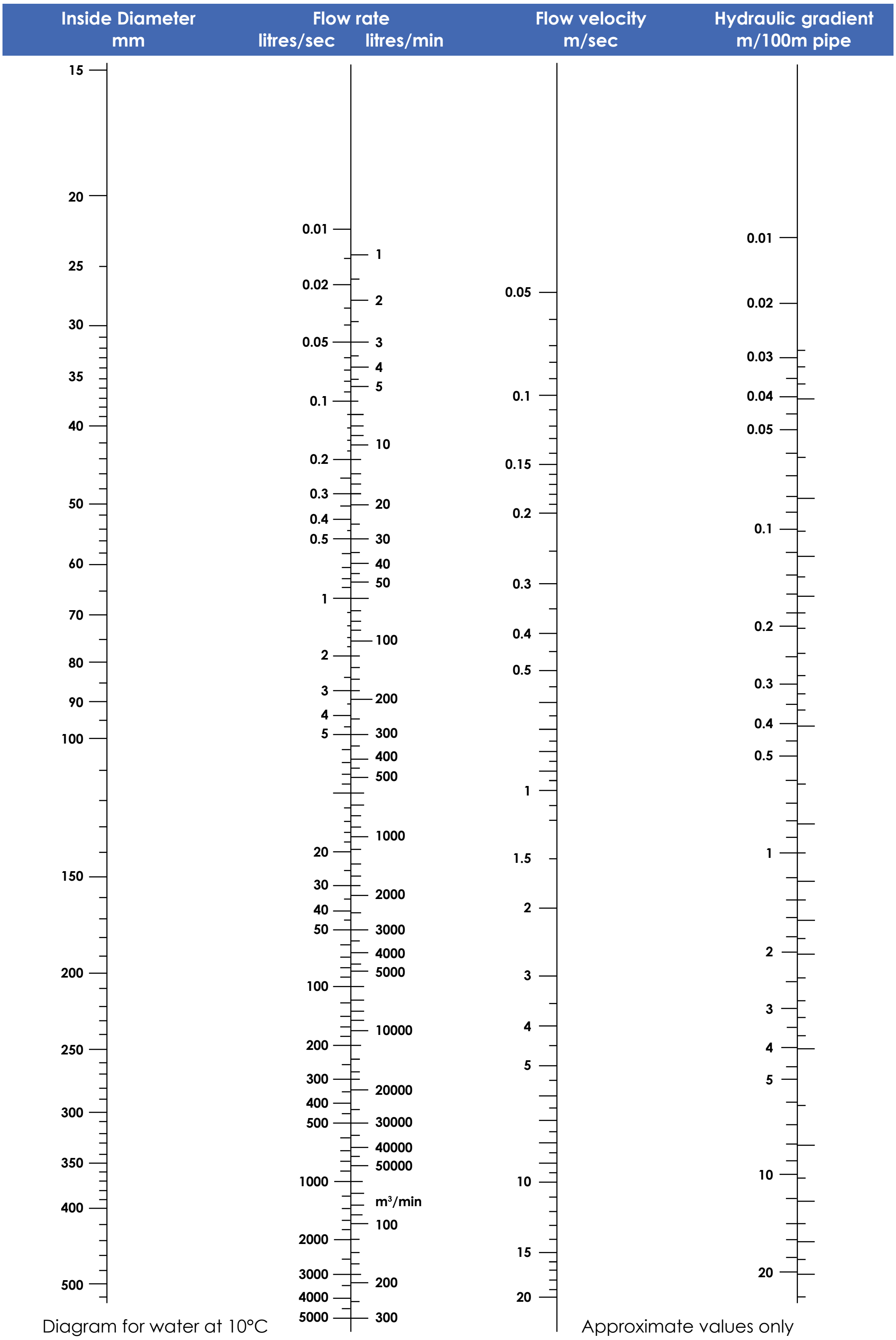


Diagram for water at 10°C

Approximate values only

- NOTE: For sizes not covered by Nomogram, please contact the manufacturer's Technical Support Department
- Disclaimer: The nomograph may not be accurate and should only be used as a guideline for a preliminary quick determination; all values calculated should be verified by the formulas provided

FIGURE 2.6: NOMOGRAPH FOR SOLVING COLEBROOK WHITE, APPLICABLE TO PVC OR PE

OPERATING PRESSURE, HOOP STRESS AND WALL THICKNESS

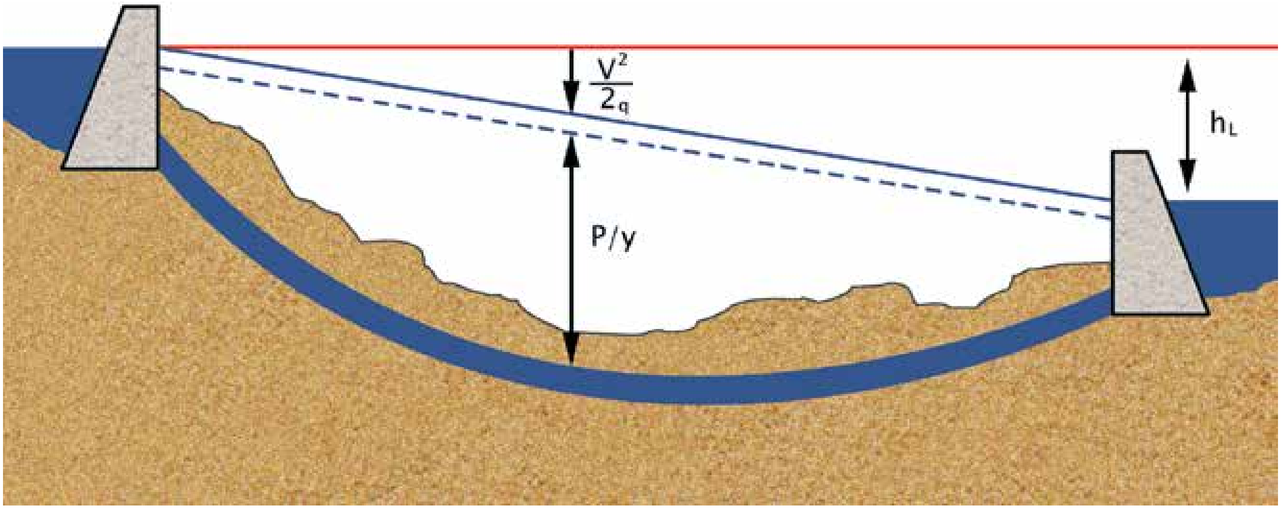


FIGURE 2.7: FLOW IN A PRESSURE PIPELINE

The operating pressure at any section along a pressure pipeline will be determined by the vertical alignment and the energy losses that occur.

The total energy as described by Bernoulli's equation, given earlier, is applicable to all sections along a pipeline. The operating pressure will be the total head above the pipe invert less the velocity head. This internal pressure will generate stresses in the pipe wall.

The hydrostatic pressure capacity of plastic pipe is related to a number of variables:

- The ratio between the outside diameter and the wall thickness (standard dimension ratio)
- The hydrostatic design stress of the material
- The operating temperature
- The duration and variability of the stress applied by the internal hydrostatic pressure

Although plastic pipes can withstand short- term hydrostatic pressures at levels substantially higher than the pressure rating, the design is always based on the long-term strength at 20°C to ensure a design life of at least 50 years.

The relationship between the internal pressure, diameter, wall thickness and the hoop stress in the pipe wall, is given by the Barlow formula, which can be conservatively expressed as follows:

$$e = \frac{PD}{2\sigma_s + P}$$

or

$$\sigma_s = \frac{P\,(D-e)}{2e} \qquad (18)$$

Where: P - internal pressure (MPa)
e - minimum wall thickness (mm)
D - mean outside pipe diameter (mm)
σ_s - design stress or hoop stress across the pipe wall (mm)

This formula has been standardized for use in design, testing and research and is applicable at all levels of pressure and stress. For design purposes, P is taken as the maximum allowable working pressure and σ_s the maximum allowable hoop stress at 20˚C.

Minimum Required Strength (MRS) and Design Stress

Pipe materials are classified according to their various MRS values (minimum required strength). The MRS values of pipe are based on a 50 year life and are obtained by multiplying a safety factor for a particular pipe for a specific application to the design stress. The MRS values for the various pipes are covered in more detail in Chapter 3 of this manual under the stress, time, and temperature relationship for the various plastics. The MRS values of the various pipe materials are also covered in this manual, and can be obtained in the relevant sections of this manual dealing with the various different types of plastic pipes.

When this equation is used for the design of an installed pipe it is written:

$$\sigma_s \leq PN \qquad \textbf{(19)}$$

where σ_s - permissible design stress (MPa)
PN - nominal pressure rating (bar)

$$\sigma_s \leq \frac{MRS}{C} \qquad \textbf{(20)}$$

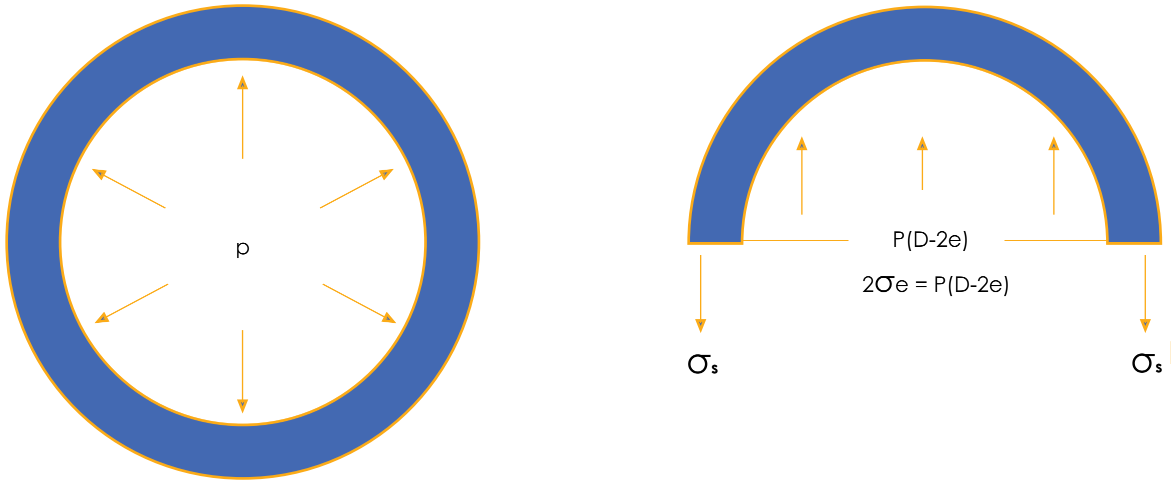


FIGURE 2.8: INTERNAL PRESSURE IN PIPE

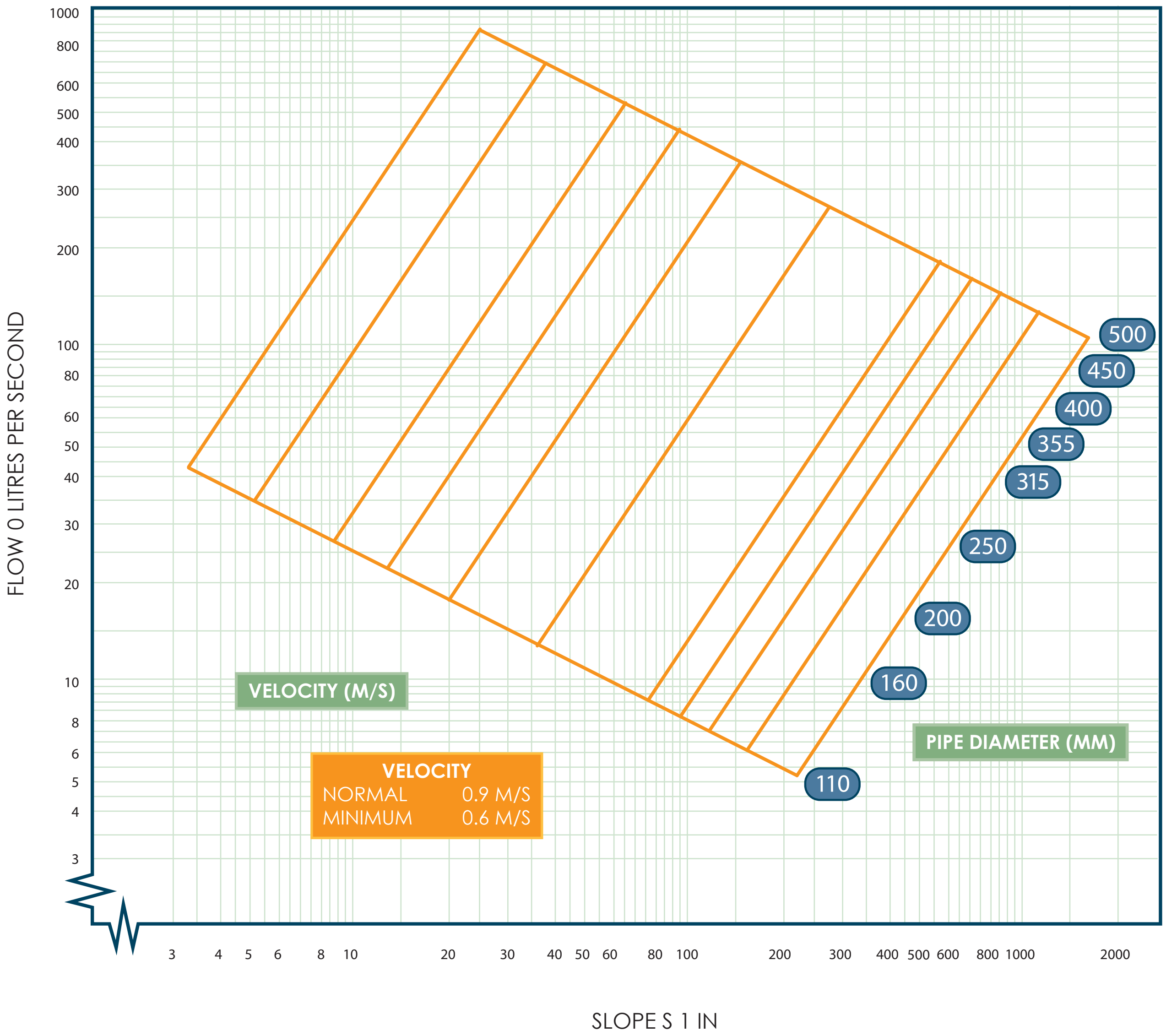


FIGURE 2.9: SEWER AND DRAINAGE PIPE FRICTION CHART

TABLE 2.4: CURRENT SOUTH AFRICAN PLASTIC PIPE RANGES AVAILABLE

Pipe Material & application	Nominal size (mm)	Material Design Stress (MPa)	Pipe Pressure Rating (bar)	Pipe Stiffness (kPa)	Specification	Nominal Stiffness kN/m/m
PVC-U Rigid Pressure Pipe	20 - 630	10, 12.5	4 - 25		SANS/ISO 966:1	
PVC-M Rigid Pressure Pipe	50 - 630	18	6 - 25		SANS/ISO 966:2	
Mine Pipe	55 - 355	10 - 12.5	6 - 25		SANS/ISO 1283	
PVC-O Rigid Pressure Pipe	100 - 1200	36	12.5 - 25		SANS/ISO16422	
PVC Solid Wall Sewer Pipe	110 - 630			100, 300	SANS/ISO 791	2, 6
PVC Multilayer Sewer Pipe	110 - 250			100, 200, 400	SANS/ISO1601	2, 4, 8
PVC –U. Corrugated pipe	110 - 250			400	SANS/ISO 1601	8
PVC-U Soil, Waste & Vent Pipe	40-160				SANS/ISO 967	
PVC-P Flexible Hose	10-50		8.8-17		SANS/ISO 1086	
PE 100 Pressure Pipe	16 -1000	8.0	6-20, 25 and 32		SANS/ISO 4427	
PE 100 Gas Pipe	16 - 630	5.0	10		SANS/ISO 4437	
PE Structured Wall Pipe	280 - 2500			200, 400, 800	SANS/ISO 21138 ISO 9969	2, 4, 8, 16
PE Corrugated Wall Pipe	75 - 160			200, 400, 800	SANS/ISO 21138 ISO 9969	2,4, 8
PP Pipe	8 - 1000	8, 10	6 - 20		SANS/ISO 15494	

These standards are all product/component standards that prescribe the minimum requirements that the products must meet. They do not cover how the product should be selected or installed.

Note: All standards referred to are the latest revisions at the date of publication of this manual.

WATER-TIGHTNESS

Apart from meeting the primary hydraulic requirements, the secondary functional requirements should also be considered to ensure a pipeline fulfills its intended demands. To prevent any form of seepage, losses, contamination, or infiltration within a pipeline system it is important to anticipate all the possible mechanisms in which failure can occur, potentially compromising a pipeline system's permeability and its water-tightness.

The following are some of the most common modes of failure by which a pipeline's water-tightness may be compromised:

- **Component failure:** Where pumps, valves or any other auxiliary system regulating the flow and operational process within a pipeline fail, or are not operated correctly. Failure or improper service of valves, pumps etc. may result in heavy pressure fluctuations within a pipeline; this is known as surge (or "water hammer"). In addition to surges, these pressure fluctuations can also result in suction (vacuum) and air entrapment within a pressure pipe line.
- **Structural pipe failure:** The failure of a pipe occurs primarily where a pipe bursts as a result of surge pressures (water hammer), fatigue, or the accumulation of entrapped air, resulting in additional pressures on the pipe wall. Failure within a pipeline can also result from excessive short duration deflections or buckling pressures caused by suction (vacuum) within an isolated column or portion of length within a pipeline, or additional external loads applied to the pipe. The effects of long term deflections in flexible buried pipes are less problematic if the correct installation procedures are followed; though these should still be taken into consideration when designing a pipeline, since they can potentially influence the hydraulic capacity within a pipeline even if the actual pipe has not yet failed structurally.
- **Joint failure:** Joint failure usually occurs as a result of surge pressures (water hammer and operational fatigue) or where excessive deflections and deformations may cause excessive movement along the pipeline between its supports and joints. In addition, incorrect thermal welding application practices and sub-standard butt-welding of PE pipe joints may also contribute to joint failure.

DEFLECTION LIMITS AND GUIDELINES

PVC, PE and other *thermoplastic* pipes allow high deflections due the high strainability of the pipe material. The strainability and wall stability of the pipe are checked during ring flexibility tests, where pipes are deformed up to 30% deflection. The values recommended are therefore still very conservative in terms of the structural integrity of the pipe itself, however, excessive deflections may compromise a system's water-tightness as a result of joint failure due to an increase in pull-out forces for unbonded joints and seals. In addition to joint failure it should also be appreciated that a 10% increase in deflection within a pipe reduces the discharge capacity up to 2%.

In some cases certain joints offer additional bending capabilities to the piping system. The relevant standards and manufacturer's specifications should be consulted for these possibilities. If necessary, the manufacturer's specifications should also be consulted for allowable pull-out forces and bending moments. For specialised applications, lower values might be required. The deflection values recommended do not necessarily result in pipe failure, but limiting values are suggested for serviceability purposes. The stability of the pipe should be checked against its allowable buckling pressures (refer to *material properties* and *pipe strength sections of this manual)*.

For verification in limit state design, deflections resulting from **short-term** duration loadings and deformations should be limited as follows:

Initial average deflection (*non-pressure pipes*)
PVC-U - ≤ 8 %
PE - ≤ 9 %
Initial maximum deflection (*non-pressure pipes*)
PVC-U - ≤ 10%
PE - ≤ 12%

For verification in limit state design, deflections resulting from **long-term** duration loadings and deformations as for the previous paragraph should be limited as follows:

Final average deflection (*non-pressure pipes*)
PVC-U - ≤ 10%
PE - ≤ 12%

Final maximum deflection (*non-pressure pipes*)
PVC-U - ≤ 15%
PE - ≤ 15%

For thermoplastic pipes in **pressure pipe applications** the short-term deflection should be verified as for non-pressure pipes, but the maximum deflection should be limited to 8%.

Since water hammer is an extremely quick process, the material's apparent stress is increased significantly (refer to the section dealing with *Surge* for more information).

Note: The above guidelines are based on the limit state structural design deflection limits of pipes and may exceed the client and/or end-user's hydraulic requirements.

Deflection: The deflection of flexible pipe is the decrease of the vertical diameter of the pipe (and corresponding increase in horizontal diameter) due to load on the pipe.

Initial deflection: The deflection occurring on the day the backfilling is completed.

Long-term deflection: The final deflection of the pipe. The deflection after several years can be more than twice the deflection immediately after installation.

Average deflection: The average of all pipe vertical deflections that occur along the pipeline. Deflections can vary from point to point along the pipe due to construction variations.

Refer to equations 36 and 37 (page 41) to calculate the deflection on flexible pipe.

SERVICEABILITY AND HYDRAULIC REQUIREMENTS

As a rule of thumb, the discharge capacity will decrease by 2% when the pipe is deflected up to an average deflection of 10% which could be the determining factor when designing a pipeline system, however, a serviceability deflection limit of 5% will satisfy most requirements in terms of long-term, short-term, and serviceability hydraulic limitations.

In the case of the thermoset GRP pipes (Glass reinforced plastic) the diametrical deflections should be limited as follows:

Allowable initial diametrical deflection after installation:

- GRP pipes greater than 300mm diameter (> DN 300) ≤ 3%
- GRP pipes smaller than 250mm diameter (≤ DN 250) ≤ 2.5%

Maximum allowable long-term diametrical deflection:

- GRP pipes greater than 300mm diameter (> DN 300) ≤ 5%
- GRP pipes smaller than 250mm diameter (≤ DN 250) ≤ 4%

These values apply to all stiffness classes for GRP pipes manufactured according to the relevant ISO and EN standards (i.e. Flowtite GRP pipes manufactured in South Africa). The values of other GRP products may vary slightly and should be confirmed by the manufacturer where applicable.

SURGE (WATER-HAMMER), VACUUM AND FATIGUE

It should be noted that the modern thermoplastics such as PE and PVC-O are very tolerant of the rapid loading which occurs with transient pressures. They develop great short term strength and stiffness as the structure of the materials' molecular chain reacts to resist the deformation. Hence, at high pressurisation rates pipes are better able to resist the higher stress

levels associated with surge. The strength of the material increases with high rates of loading. (Refer to Chapter 3: Elastic, plastic & visco-elastic properties of material)

Surge and fatigue are often combined, as conditions often occurring below the rated pressure. Although both phenomena arise from events such as valves closing quickly and pump shut downs, they should be considered separately, since they have different effects on the pipe material.

Surge generates pressures that generally rise above the static rating of the pipeline, and these pressures are applied over very short periods. The initial rate of pressure change is rapid but of short duration. Fatigue is associated with cyclic pressure variations that are repeated over a long period. It is a condition often occurring below the rated pressure.

This is not a problem with the slow daily pressure cycles which frequently occur in distribution systems but, in circumstances where short-term surges may be repeated at frequent intervals, there is concern that the pipes may weaken due to fatigue.

Fatigue response studies show that fatigue cracks initiate from a dislocation in the material matrix, usually towards the inside surface of the pipe, where stress levels are highest and propagate or grow with each stress cycle at a rate dependent on the magnitude of the stress. Ultimately the crack penetrates the pipe wall.

Typically **surge** occurs when valves are opened or closed or pumps are stopped. The pressure change or surge in a pipe line (water hammer) can be determined by applying Joukowsky's equation:

$$\mathbf{rH = C\,rv/g} \qquad \mathbf{(21)}$$

Where,

rH - change in head due to water hammer or increase in pressure height above normal operating and static pressure (m).

C - wave celerity through the pipe material or the velocity at which an elastic wave moves along the pipe. The magnitude depends on the compressibility of the fluid and the elasticity of the pipe wall (m/s).

rv - change in flow velocity of fluid (m/s)

g - acceleration due to gravity (9.81m/s)

Where, the wave celerity can be calculated as follows:

$$\mathbf{C=1/\sqrt{\rho\left(\frac{1}{K}+\frac{ID}{e.E}\right)}} \qquad \mathbf{(22)}$$

Where,

ρ - density of fluid (1000 kg/m3 for water)

K - the compressibility modulus of the fluid (for water 2100 x 10^6 N/m^2)

ID - the internal diameter of the pipe (mm)

e - the wall thickness of the pipe (mm)

E - the elasticity modulus of the pipe material (N/m^2)

The elastic modulus (E) of the pipe under surge pressure is temperature dependent (AND time dependent ONLY where pipes are subjected to constant internal pressure.) Applicable values for PE and PP are given in Table 2.5

TABLE 2.5: ELASTIC MODULUS IN N/mm^2 OF PIPE MATERIALS SUBJECT TO SURGE PRESSURES

Temperature	PE	PP
20°C	1680	1470
40°C	1230	950
60°C	760	560
80°C		390

Because PE has a low elastic modulus, the wave propagation rate and surge intensity are considerably lower than in elastic pipe material (steel, concrete).

In tests with PE pipes under dynamic pressure loading it has been shown that the pressure surges can with good approximation be calculated according to the pressure surge theory of Joukowsky.

Furthermore, it may be concluded from previous tests carried out by Lortsch that surges do not damage PE pipes, provided that the mean stress is not higher than the stress at nominal pressure. For example, for

PE 80 pipe with a SDR 17 (PN 8) pipe at an operation pressure of 8 bar at 20°C, the mean pressure does not exceed 8 bar or a relative stress of 6.3 MPa. The surge amplitude in this case could be ± 8 bar.

EFFECT OF VACUUM IN PIPELINES ON PIPE STRENGTH

A vacuum or sub-atmospheric pressure occurs in a section of pipeline when it is above the total energy line or there is a column break (column-seperation) due to a downstream failure. This should be taken into consideration with low stiffness pipes under certain conditions:

- When they are in saturated soils and the soil support is poor
- Under high fills

Vacuum or negative internal pressure in a pipeline will have the same effect as external pressure on the pipeline, resulting in a compressive hoop stress in the pipe wall. The stress in the pipe walls and the pressure on a pipeline due to a vacuum inside a pipeline can be calculated using equation (23).

$$\sigma = \frac{Pv\,(D-t)}{2t} \quad \text{(a)} \quad \text{or} \quad Pv = \frac{2\sigma}{DR-1} \quad \text{(b)} \qquad \textbf{(23)}$$

Where t is wall thickness in mm
Pv is vacuum or negative internal pressure in MPa
D is mean outside diameter in mm
σ is hoop stress across pipe wall in MPa
DR is dimension ratio or SDR of pipe

This will thus reduce the pipeline's capacity to carry earth loads. The maximum negative pressure that can occur is at an absolute pressure of zero. Hence when designing a pipeline a maximum allowance of 1.0 bar or 100kPa, which has the equivalent effect of 10m of external water pressure, should be made. The critical buckling capacity of a pipe (provided there is no lateral support from the earth) would be the same as for external hydrostatic pressure, as given by equation (24):

$$P_{cr} = 24EI/D^3 = 24PRS \qquad \textbf{(24)}$$

Where P_{cr} is the critical buckling pressure in kPa
E is Young's modulus of pipe material in MPa (Young's modulus for pipe material selected as a function of the load duration)
I is moment of inertia of pipe wall
D is the mean outside diameter of pipe in mm
PRS is pipe ring stiffness in kN/m/m

Based on the above, the buckling capacity for a range of PRS (or SN) values due to vacuum are given in Table 2.6.

TABLE 2.6: INFLUENCE OF VACUUM ON PIPE BUCKLING

PRS – kN/m/m	1	2	4	4.21	>4.21
P_{CR} - kPa	24	48	96	101	*
Water head m	2.4	4.8	9.6	10	*

*Vacuum cannot be less than absolute zero pressure

A pipe with a nominal stiffness of 2kN/m/m has a buckling capacity of 48kPa. This means that if the negative pressure in a pipeline is 48kPa below atmospheric it would cause the pipes to buckle. As the vacuum cannot exceed absolute zero pressure higher stiffness pipes cannot buckle due to vacuum alone.

For most practical applications, when a pipeline is buried there are three basic loading cases to consider:

- **Pipeline is buried and empty.** There is no assistance from internal pressure in carrying load. It is just the external pressure that has to be considered. This is the loading applicable to gravity systems such as sewers and storm water drains even though they do flow partly full.
- **Pipeline buried and flowing under pressure.** The imposed loads are external earth and water pressures and internal fluid pressure. The internal pressure assists in carrying the external loads, however when the pipe has a low stiffness it may be necessary to consider the combined wall stresses on the sides of the pipe
- **Pipeline is buried, empty and subject to a vacuum.** When a pressure pipeline is being emptied it may be subject to a vacuum or negative internal pressure. The negative internal pressure has the same effect as a positive external pressure of the same magnitude. The imposed loads are external

earth and water pressures and the negative internal pressure.

When the pipeline is buried and empty, the structural property of concern is usually deformation. To check its stability against bucking - which can be a problem with low stiffness pipes - at an acceptable deformation, the equations given later in this publication (36 & 37) must be rearranged to give the pressure under the given loading conditions (as done in equation 25). It is extremely unlikely that a vacuum could form in such a pipeline.

$$\gamma H = \frac{\Delta d}{D} \left(\frac{8EI/D^3 + 0.61E'F_d}{K_B\, T_f} \right) \qquad (25)$$

Where Δd is pipe deflection due to soil load in m
D is pipe diameter in m
T_f is a dimensionless time lag factor, having a value between 1.5 and 3.0 that takes into account the increase in soil load due to its consolidation at the sides of pipes with time
K_B is bedding constant, having a value between 0.11 and 0.083, usually taken as 0.1
γH is backfill pressure on the pipe in kN/m^2
EI/D^3 is pipe ring stiffness (PRS) in kN/m/m
F_d is a dimension design factor varying from 0.5 to 1.0 depending on effectiveness of side fill compaction. It converts average to maximum values of deflection.
E' is soil stiffness in kN/m^2

When there is a water table above the pipe the effect of this external water pressure must also be taken into account, and there will be a modification to this formula. To avoid buckling, γH or the adjusted vertical pressure must be less than P_{cr}. In practice a safety factor of 2 is used.

When the pipeline is buried and flowing full under the pressure, "P", the structural property of concern is usually wall stress. Pressure pipelines are generally placed at shallow depths, so the stresses in a pipe wall due to internal pressure are generally far greater than those due to external loads. For low stiffness pipes where the internal pressure is nominal and there is deformation, a check should be done on the combined stresses at the sides of the pipes.

When a pipeline is buried, empty, and subject to a vacuum (as can happen during the emptying of a pressure pipeline or when an unexpected burst occurs), the possibility of negative internal pressure due to a vacuum forming must be added to the external pressures to check against a buckling failure. This is a different loading condition from that covered by equation (24), as the deformation and subsequent buckling of the pipeline is resisted by the external soil support. The critical buckling pressure can be calculated from equation (26) which has been sourced from EN 1295.

$$P_{cr} = 0.6\,(EI/D^3)^{0.33}(1000\,E')^{0.67} \qquad (26)$$

Where P_{cr} is the critical buckling pressure in kPa
E is long term modulus of pipe material in MPa
I is moment of inertia of pipe wall in mm^3
D is the mean outside diameter of pipe in mm
E' is short term modulus of soil in MPa

Table 2.7 gives the combined effect of pipe ring stiffness (PRS) and soil stiffness (E') on the buckling capacity of a pipe. Column 2 shows the buckling capacity without any external soil support. This also shows that the impact of soil stiffness dominates the buckling capacity increases by the ratio of the E' values to the power of 0.67, whereas it only increases by the ratio of the PRS values to the power of 0.33. When the soil support is poor, the calculations give a lower buckling pressure than the unsupported pipe. For these situations the unsupported buckling capacity as given in column 2 should be used.

TABLE 2.7: COMBINED EFFECTS ON PIPE BUCKLING

PRS	Soil stiffness in MPa							
kN/ m/m	0	0.5	1	2	4	8	10	20
1	24	24	38	61	96	152	177	281
2	48	30	48	76	121	192	223	354
4	96	38	61	96	152	242	281	446
8	192	48	76	121	192	305	354	562
10	240	52	82	130	207	328	381	605
20	480	65	103	164	261	414	480	960

Note: PRS refers to the Pipe Ring Stiffness

For this condition the sum of the pressures imposed on the pipe must be less than the buckling capacity divided by a safety factor usually taken as 2 as shown in equation (27).

$$P_{cr} \geq 2\ (Pv + yH + P) \qquad (27)$$

Where P_{cr}, Pv, and yH are defined previously and P is the pressure inside the pipeline.

Depending on the loading condition on the pipeline one or another of these parameters may be zero.

When designing for **Fatigue** of Thermoplastic Pipes it is recommended that the design should be modified for cases where frequent cyclic loading is to be expected. In the case of high quality PE pipes and materials where the stress crack resistance requirements have been satisfied, no de-rating factor needs to be applied. For all lower grade PE pipes and materials which do not comply with the stress crack resistance requirements, or where it has not been tested, the pressure rating should be de-rated according to the number of fatigue cycles anticipated.

For all PVC pipes and those made from materials other than polyethylene, a de-rating factor which allows for the decrease in strength as a result of repeated cyclic loading needs to be applied. The de-rating factors in Table 2.8 should be multiplied to the original predicted pressure and stress ranges, where the de-rating factors in Table 2.8 for all materials are based on data at 20˚C, therefore, additional coefficients as shown in Table 2.9 should be multiplied to the de-rating for pipelines operating at other temperatures exceeding 20˚C. The maximum value for repeated frequent events (i.e. where a pump will start and stop) should be considered when designing for fatigue, however, the frequency and the total number should relate to all the events which could possibly occur. Extreme events, i.e. where the pump will shut down completely, should not be considered as part of the fatigue design, but rather as part of the surge (water hammer) design in order to ensure that extreme high and low pressures are taken into consideration.

PVC-M has a lower de-rating than PVC-U since the stress carrying capacity related to cyclic loading is less sensitive. PVC-O has higher factors, since the stress carrying properties are the same as for PVC-U, but the static design stress is higher. The 0.5 factor for high quality and tough PE materials and pipes indicates that no de-rating needs to be applied.

TABLE 2.8: RECOMMENDED FATIGUE DE-RATING FACTORS FOR PLASTIC MATERIALS

Frequency of cycles			PVC-U	PVC-M	PVC-O	PE-HD
Daily Frequency	Hourly Frequency	Total Cycles in 50 years	Rating Factor	Rating Factor	Rating Factor	Rating Factor
4	0.2	73 000	0.7	1.0	0.6	0.5
24	1.0	438 000	1.3	1.7	0.9	0.5
48	2.0	876 000	1.5	2.1	1.1	0.5
120	5.0	2 190 000	2.0	2.8	1.3	0.5
240	10.0	4 380 000	2.5	3.5	1.5	0.5
1200	50.0	22 000 000	4.0	5.6	2.0	0.5

TABLE 2.9: COEFFICIENTS TO MULTIPLY TABLE 1 DE-RATING FACTORS TO ACCOUNT FOR TEMPERATURE

Temperature (^{0}C)	5	10	15	20	25	30
PVC-M	0.67	0.72	0.85	1.0	1.14	1.3
PVC-U	0.89	0.91	0.97	1.0	1.03	1.07

Note: For PVC-O and PE materials it is recommended that the allowable stress rating be adjusted by 1.3% for every 1^{0}C in excess of 20^{0}C to take general static strength loss into account

For temperatures below 20 deg ^{0}C PE pipe factors are @ 15 ^{0}C = 15% improvement, @ 10 ^{0}C = 30% improvement and @ 5 ^{0}C = 40 % improvement.

MANHOLES & HUMAN ACCESS CHAMBERS

Apart from the upper reaches of reticulation systems, access to pipelines is via manholes and chambers. Manholes are the interfaces between sections of pipeline where changes are made. They are placed whenever there are junctions, transitions and changes in alignment, and where access is needed on long straight sections. As the loading on manholes and chambers is different from that on the adjacent sections of pipeline, there can be relative movement between manholes and pipes.

Many of the failures in sewers occur at joints, and in particular those at the interfaces where changes are made. If measures are not taken to minimize the disruption to flow through these manholes and chambers, and the associated energy losses not considered, the hydraulic performance of a sewer can be seriously compromised. And if measures are not taken to accommodate any potential relative movement between pipes and manholes or chambers, pipes can crack or deform, resulting in leakages.

For more information on thrust blocks, refer to Chapter 6.

FACTORY TESTS

A comprehensive testing program is carried out at plastic pipe factories to ensure that performance requirements of the specifications are met. Of particular significance to the designer are those dealing with structural performance and water-tightness. For details of these tests, refer to the relevant SANS or ISO documents as listed in Table 2.14. These tests, however, do not guarantee the performance of the installed pipeline. For this, it is essential that the pipeline installation is controlled, that all jointing and workmanship is in line with sound civil practices and procedures, and the system is operated within the design assumptions.

List of Factory Tests:

TT	- Type tests
BRT	- Batch Release tests
PVT	- Process verification tests
AT	- Approved testing body tests, quality plan document setting out the specific quality practices, resources and sequence of activities relevant to a particular product or range of products type test

- TTtest performed to prove that the material, product, joint or assembly is capable of conforming to the requirements given in the relevant standard batch release test
- BRTtest performed by or on behalf of the manufacturer on a batch of compound or products, which is satisfactorily completed before the batch can be released for process verification test
- - PVTtest performed by or on behalf of the manufacturer on compound, products, joints or assemblies at specific intervals to confirm that type tests originally performed on the compound, products, joints or assemblies continue to be valid and the process continues to be capable of producing products which conform to the requirements given in the relevant standard audit test
- ATtest performed by a test laboratory on behalf of an inspection body or certification body to confirm that the compound, product, joint or assembly continues to conform to the requirements given in the relevant standard and to provide information to assess the effectiveness of the quality management system indirect test
- ITtest performed by or on behalf of the manufacturer, different from that specified test for that particular characteristic, having previously verified its correlation with the specified witness test
- WTtest accepted by an inspection or a certification body for type testing and/or audit testing, which is carried out by or on behalf of the manufacturer and supervised by a representative of the inspection or certification body, qualified in testing

STRENGTH

DESIGN BASIS FOR BURIED FLEXIBLE PIPES

The strength of a buried pipe must be selected so that it will be strong enough to carry the most severe combination of loads that could be imposed on it. If the imposed loads exceed the pipe strength the pipe will fail.

The failure mode of a pipe can be due to its inability to handle circumferential or longitudinal loading. This section addresses the external loads which cause circumferential stress. Failure can occur due to high bending stresses in the walls of rigid pipes or the excessive vertical deflection of flexible pipes. Buckling is rarely a problem with plastic pipes.

For flexible pipes the stiffness of the surrounding material is more important for limiting deflection than the stiffness of the pipe itself, so controlled backfill is particularly important. The design process consists of determining the load, and then ensuring that acceptable deflection is not exceeded by using an embedment material that has the required properties and compaction.

LOAD CLASSIFICATION

The loads imposed on a buried pipeline are due to primary forces such as soil loads, superimposed traffic loads, internal pressures, and secondary pressures resulting from soil movements (caused by the flow of water, temperature effects, and settlement under buildings). The pipes provide the conduit, and may or may not also provide the structure designed to take the primary forces. The joints are designed to ensure that the conduit remains watertight and copes with secondary forces. While primary forces can be calculated, secondary forces cannot, and hence have to be estimated.

The primary loads on any buried pipe are influenced by the installation conditions, and initially will be the same irrespective of the type of pipe material. However, the way in which the loads are carried will vary significantly depending on the interaction of the components in the pipe/soil system. These components are: the pipes, the virgin soil, the embedment material, and the founding conditions, as shown in Figure 2.10 below.

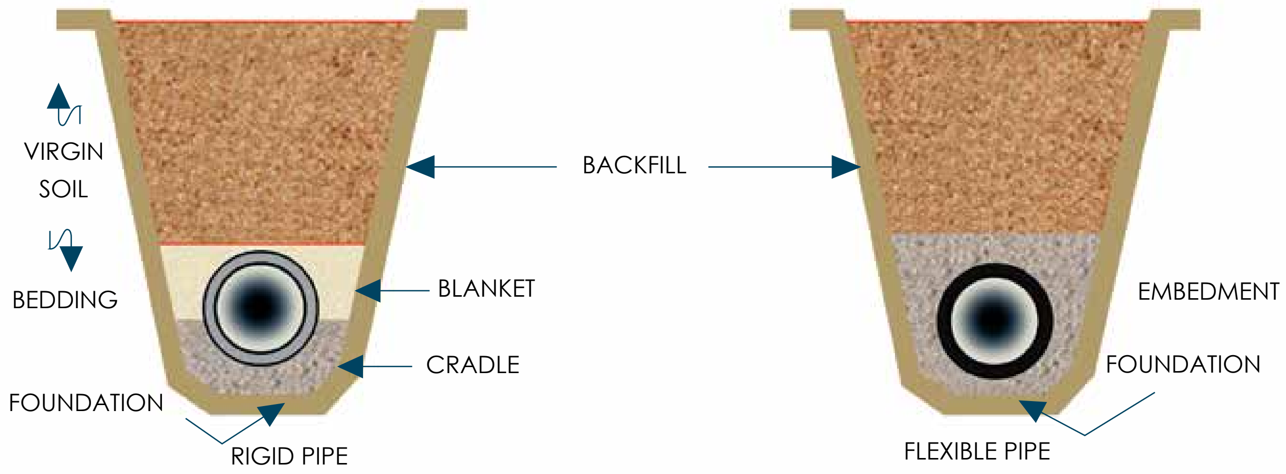


FIGURE 2.10: COMPARISON OF RIGID AND FLEXIBLE PIPE INSTALLATION DETAILS

The interaction of these components will determine how the pipe chosen will handle the load. Hence, any design guidelines must cover the interaction between them, describe what to do as they vary and, where necessary, set limits to their structural properties.

For rigid pipes it is assumed that the reaction from the bedding cradle is vertical only. Hence it is only necessary to provide support around the bottom portion of the pipe. For flexible pipes it is essential that the reaction from the surrounding material also gives side support. This means that the pipes should be encased in a suitable material at least up to the level of the pipe crown. In this case the supporting material is referred to as embedment.

The earth load on a buried conduit is the mass of the earth prism directly above it that is either increased or decreased by the arching action resulting from the friction between adjacent columns of earth above and next to the pipe. The arching is dependent on installation type, founding conditions and properties of *in situ* and backfill materials:

- limiting installation types are narrow trench and complete embankment projection, where the load is minimum and maximum respectively
- limiting founding conditions are yielding and rigid, where the load is minimum and maximum respectively
- the most significant properties of the *in situ* and backfill materials are their mass, stiffness and friction angles. The friction angle is the most significant for rigid pipes, and stiffness the most significant for flexible pipes

In practice most pipelines are installed in conditions falling somewhere between these limiting cases.

Irrespective of the pipe material, the soil loads on the horizontal plain level with the top of the pipe before any deflection has taken place will be the same for any given installation. However, when the material on top of the pipeline is compacted, the critical plane which is the horizontal line over the top of the pipeline will deform either side of the pipeline, depending upon whether the frictional forces that develop act upwards or downwards. With flexible pipes that have the required side support, the pipes will settle more than the adjacent material and the frictional forces will act upwards, reducing the load that the pipes have to carry. The worst combination of values for these limiting factors could result in loads that are in excess of twice the value of those for the most favourable conditions for the same fill height.

Traffic loading is distributed from the contact areas on the surface through the fill. At fill heights greater than ±1.25m earth loads generally make a greater contribution than traffic loads to the total load. At fill heights less than 600mm, or half the conduit's outside diameter, traffic and other transient loads are not uniformly distributed over the conduit and they cannot be evaluated in the same way as earth loads. Notwithstanding the calculated stress distribution it is recommended that the fill height over flexible pipes under a roadway should be at least the larger of 900mm or the pipe diameter.

Although gravity pipelines usually flow partly full, there are times when they may be pressurised due to operating conditions or problems such as blockages. These pipes and their joints should therefore be designed and manufactured to cope with a nominal operating pressure of 1 bar, which is generally well within the capability of pipes supplied for these applications.

PIPE STIFFNESS

Various parameters are used to define pipe stiffness. They all relate to the ability of a pipe to resist deformation. The incorrect understanding of these parameters can lead to serious overloading and deflection of pipes.

Pipe stiffness is obtained from a parallel plate test on a pipe.

$$\mathbf{PS = F/\Delta Y} \qquad \mathbf{(28)}$$

Where: - PS is pipe stiffness usually expressed as kPa (kN/m^2)
- F is force necessary to deflect the pipe by a given percentage taken from the relevant specifications
- ΔY is the vertical deflection of pipe

The pipe stiffness factor used in the DIN standards is calculated from the pipe material properties and the pipe geometry.

$$\mathbf{PSF = EI/r^3} \qquad \mathbf{(29)}$$

Where: - PSF is the pipe stiffness factor in kN/m/m
- E is the elastic modulus of pipe material
- I is the moment of inertia of the pipe wall
- r is the pipe radius

Pipe ring stiffness used in the ISO standards is also calculated from the pipe material properties and the pipe geometry. It is an eighth of the PSF.

$$\mathbf{PRS = EI/D^3} \qquad \mathbf{(30)}$$

Where: - PRS is the pipe ring stiffness in kN/m/m
- E is the elastic modulus of pipe material
- I is the moment of inertia of the pipe wall
- D is the pipe diameter

The relationship between these three factors is:

$$\mathbf{0.149\ PS = PSF = 8\ PRS;\ PS = 6.71\ PSF = 53.69\ PRS} \qquad \mathbf{(31)}$$

For some pipes PRS is referred to as the nominal stiffness, SN.

TABLE 2.10: RELATIONSHIP BETWEEN PS, PSF AND PRS

PIPE STIFFNESS kPA PS=F/Δy	PIPE STIFFNESS FACTOR kN/m/m PSF=EI/R³	PIPE RING STIFFNESS kN/m/m PRS=EI/D³
100	14.9	1.860
200	29.8	3.725
300	44.7	5.588
400	59.6	7.450

LOADS ON FLEXIBLE CONDUITS

The vertical soil load is generally the dominant loading causing the deflection of flexible pipes or circumferential bending of rigid pipes. Most pipes are laid in trenches. The loading will be reduced by the friction and cohesion between the backfill material and the trench walls. Hence some load is transferred to the trench walls. The load in kN/m of pipe length is:

$$\mathbf{W_E = C_t\ \gamma\ HB} \qquad \mathbf{(32)}$$

Where C_t is obtained from Figure 2.11 as a function of H/B and k tan θ, where k is the ratio of lateral to vertical soil stress and θ is the soil angle of friction.

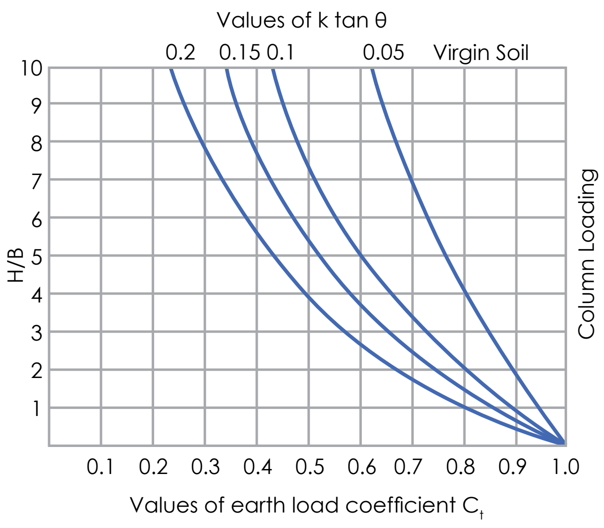


FIGURE 2.11: LOAD COEFFICIENTS FOR TRENCH CONDITIONS

When the side fill is correctly compacted, flexible pipes deform more under load than the material adjacent to them. Load is shed to the side fill so the final load on the pipe is less than what the column theory indicates. The actual soil load on a flexible pipe will then be:

$$W_E = C_t \gamma HD \qquad (33)$$

The calculation of C_t involves determining the soil properties, which can be complex. For practical reasons the conservative approach to calculating the load on a flexible pipe can be done using equation (33) with C_t having a value of unity.

Hence for flexible pipes, irrespective of whether they are installed under embankment or trench conditions, the vertical load at the level of the top of the pipe can be evaluated using column theory:

$$W_E = \gamma HD \qquad (34)$$

Where:
- W_E is the vertical or geostatic load on pipe (kN/m)
- H is Depth (m)
- γ is Unit weight of the soil (kN/m3)
- D is External pipe diameter (m)

There are various ways of calculating the live or traffic loads on a buried pipe. Some of these are tedious to apply by hand and do not give answers that differ much from the simple approach of distributing the load through the fill material at 45°, as shown in equation (8).

The load on a pipe at a depth, H below the surface in kN/m due to a live load of P (see figure 2.12) at the surface is:

$$W_L = \frac{P \times D}{(x + 2H)(y + 2H)} \qquad (35)$$

Where x and y are the footprint dimensions for the load P at the surface. The other symbols are defined elsewhere. When loaded areas from adjacent wheels overlap, the calculation of the load intensity at this depth is determined by distributing the load at 45° through the fill in both directions from the perimeter of the loaded area on the surface. Field loads on flexible pipe are normally light. Heavier loads should be accommodated by placing pipes in sleeves or paving over them with a concrete slab. The live load WL can be distributed to shed the load but, as it is only temporary, it activates a higher pipe modulus, E, than the soil load does.

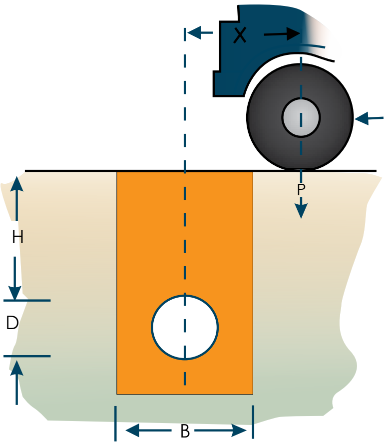


FIGURE 2.12: WHEEL LOAD ON BURIED CONDUIT

However, during construction any buried pipeline could be subject to the same traffic loads as carried when in use under a public road, because there are deliveries to site. In South Africa the legal limit for road vehicles is a 40 kN wheel load. A typical wheel layout is given in Figure 2.13. Table 2.11 has been compiled for two such vehicles parked next to each other with a space of 400 mm between them.

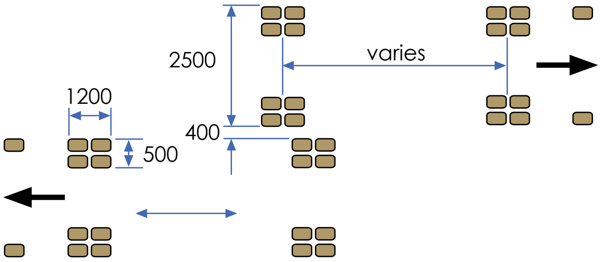


FIGURE 2.13: WHEEL PATTERN OF TWO TYPICAL HIGHWAY VEHICLES WITH 40 KN WHEEL LOADS WHEN PASSING

TABLE 2.11: LOADS IN KN/m OF BURIED CONDUIT FROM A GROUP OF 40 KN WHEELS

PIPE OD MM	FILL HEIGHT OVER PIPES IN M										
	0.6	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0
50	1.18	0.69	0.41	0.27	0.20	0.15	0.11	0.09	0.06	0.04	0.03
90	2.13	1.25	0.74	0.49	0.35	0.26	0.20	0.16	0.11	0.08	0.06
110	2.60	1.52	0.91	0.60	0.43	0.32	0.25	0.20	0.14	0.10	0.07
160	3.79	2.21	1.32	0.88	0.63	0.47	0.36	0.29	0.20	0.14	0.11
200	4.73	2.77	1.65	1.10	0.78	0.58	0.45	0.36	0.25	0.18	0.13
250	5.92	3.46	2.07	1.37	0.98	0.73	0.57	0.45	0.31	0.22	0.17
315	7.46	4.36	2.60	1.73	1.23	0.92	0.71	0.57	0.39	0.28	0.21
355	8.40	4.91	2.93	1.95	1.39	1.04	0.80	0.64	0.44	0.32	0.24
400	9.47	5.54	3.31	2.19	1.56	1.17	0.91	0.72	0.49	0.36	0.27
450	10.65	6.23	3.72	2.47	1.76	1.31	1.02	0.81	0.55	0.40	0.30
500	11.83	6.92	4.13	2.74	1.95	1.46	1.13	0.91	0.62	0.45	0.34
560	13.25	7.75	4.63	3.07	2.19	1.64	1.27	1.01	0.69	0.50	0.38
630	14.91	8.72	5.21	3.46	2.46	1.84	1.43	1.14	0.78	0.56	0.43
710	16.80	9.83	5.87	3.90	2.77	2.07	1.61	1.29	0.87	0.63	0.48
800	18.93	11.07	6.61	4.39	3.13	2.34	1.81	1.45	0.98	0.71	0.54
900	21.30	12.46	7.44	4.94	3.52	2.63	2.04	1.63	1.11	0.80	0.61
1000	23.67	13.84	8.26	5.49	3.91	2.92	2.27	1.81	1.23	0.89	0.67

The design traffic loading on buried conduits under highways is significantly higher than the legal limits. For most circumstances the NB36 design vehicle as described in TMH7, the Code of Practice for the Design of Highway Bridges and Culverts in South Africa, would give the critical loading conditions. This has 90kN wheels with 300mm by 300mm contact areas and the wheel pattern shown in figure 2.14. The loads from this vehicle using the TMH7 procedure are given in Table 2.12.

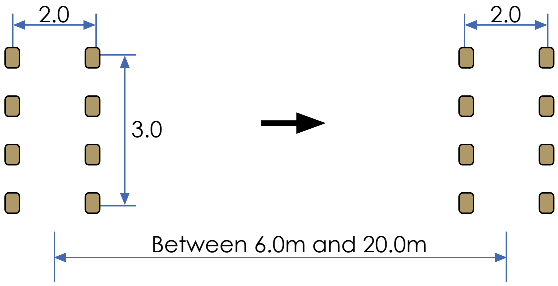


FIGURE 2.14: WHEEL PATTERN OF NB36 VEHICLE

TABLE 2.12: LOADS IN KN/m OF PIPE ON BURIED PIPES FROM NB36 GROUP OF 90KN WHEELS

PIPE OD MM	FILL HEIGHTS OVER PIPES IN M										
	0.6	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0
50	5	2	1	1	0	0	0	0	0	0	0
90	8	4	2	1	1	1	0	0	0	0	0
110	10	4	2	1	1	1	0	0	0	0	0
160	14	6	3	2	1	1	1	1	0	0	0
200	17	8	4	2	2	1	1	1	0	0	0
250	20	9	5	3	2	1	1	1	1	0	0
315	25	11	6	4	2	2	1	1	1	0	0
355	27	13	7	4	3	2	1	1	1	1	0
400	30	14	7	4	3	2	2	1	1	1	0
450	32	15	8	5	3	2	2	1	1	1	0
500	35	17	9	5	4	3	2	2	1	1	1
560	38	18	10	6	4	3	2	2	1	1	1
630	41	20	11	7	5	3	3	2	1	1	1
710	44	22	12	8	5	4	3	2	2	1	1
800	48	25	13	8	6	4	3	3	2	1	1
900	52	27	15	9	7	5	4	3	2	1	1

VERTICAL DEFLECTION OF FLEXIBLE PIPE

The vertical deflection of a flexible pipe is limited by lateral soil resistance that develops as the pipe deforms horizontally into it. The load is carried through the arching action of the soil rather than circumferential bending of the pipe. Hence, the wall stresses in a flexible pipe are considerably less than those that develop in the walls of a rigid pipe. In simple terms, the deflection of a flexible pipe is expressed in formula (36).

$$\Delta d = \left(\frac{W}{(PS+SS)}\right) \qquad \textbf{(36)}$$

Where: - Δd is pipe deflection
- W is load on pipe in kN/m
- PS is pipe stiffness factor in kN/m/m
- SS is soil stiffness factor in kN/m/m

This deflection is usually determined using the Iowa formula as one or its derivations, such as formula (37)

$$\frac{\Delta d}{D} = \left(\frac{T_f\, k_B\, \gamma H}{8EI/D^3 + 0{,}061 F_d\, E^I}\right) \qquad \textbf{(37)}$$

Where: - Δd is pipe deflection due to soil load in m
- D is pipe diameter in m
- T_f is a dimensionless time lag factor, having a value between 1.5 and 3.0 that takes into account the increase in soil load due to its consolidation at the sides of pipes with time
- K_B is bedding constant, having a value between 0.11 and 0.083
- γ is backfill density in kN/m³
- H is fill height on pipe in m
- EI/D^3 is pipe ring stiffness (PRS) in kN/m²
- F_d is a dimension design factor varying from 0.5 to 1.0 depending on effectiveness of side fill compaction. It converts average to maximum values of deflection.
- E^1 is soil stiffness in kN/m²

Table 2.13 gives the maximum fill that can be taken over a combination of pipe ring stiffness, PRS and soil stiffness, E^I values, assuming:

- short term deflection after installation of 3%
- virgin soil and embankment soil are the same material
- time lag factor, T_f of 1.5
- design factor, F_d of 0.67
- bedding factor of 0.07
- material density of 20 kN/m³

TABLE 2.13: MAXIMUM FILL HEIGHTS FOR A 3% DEFLECTION AT GIVEN, PIPE RING STIFFNESS AND E¹ VALUES

PRS kN/m/m	Embedment and soil stiffness, E¹ kN/m/m									
	1000	1500	2000	2500	3500	4000	5000	10000	15000	20000
2	0.81	1.10	1.40	1.69	2.27	2.56	3.15	6.07	8.99	11.91
4	1.04	1.33	1.62	1.92	2.50	2.79	3.38	6.30	9.22	12.13
8	1.50	1.79	2.08	2.37	2.96	3.25	3.83	6.75	9.67	12.59
12	1.96	2.25	2.54	2.83	3.41	3.71	4.29	7.21	10.13	13.05

Since E decreases with age (for pipelines under constant stress) the 50 year E value could be used for soil load deflection calculation as a conservative assumption. For live loads a separate calculation using the short term E value could be used, assuming the wall is not stressed to the limit. The deflections due to soil and live loads should then be added to give the total deflection.

Deformation due to live loads is calculated from formula:

$$\frac{\Delta d_L}{D} = \left(\frac{k_B \ \text{x} \ W_L/D}{8EI/D^3 + 0{,}061 \ F_d \ E^1} \right) \qquad \textbf{(38)}$$

Where: - Δd_L is vertical deflection due to live or traffic loading
- W_L is traffic loading on pipe in kN/m

For low stiffness pipes such as PE and PVC that can tolerate significant strain, the deflection is almost exclusively determined by the E^1 of the soil, and the use of short or long term E values for the pipe material will have little impact. It is essential therefore that the E^1 value of the supporting material surrounding the pipe has a value of at least 5 MPa.

ADDITIONAL FACTORS UNDER CRITICAL CONDITIONS

WALL STRESS

There are other design parameters that should be checked with critical loading conditions such as buckling, wall stress and wall strain. For thermoplastics such as PVC and PE-HD the critical parameter is wall stress, and for the thermosets it is wall strain. The maximum wall stress around a pipe circumference is due to a combination of ring bending under vertical load, and arching. The critical condition for wall stress occurs at the haunch when pipes are empty. For thermoplastic pipes it is calculated from:

$$f = \frac{W_E}{2t} \ \text{x} \left(\frac{20 \ Et^2/D^2 + E^1}{24 \ Et^3/D^3 + E^1} \right) \qquad \textbf{(39)}$$

Where: - f is wall stress at haunch (MPa)
- W_E is the earth load (kN/m)
- t is wall thickness (m)
- D is outside diameter of pipe (m)
- E^1 is soil stiffness (MPa)
- E is elastic modulus of pipe material (MPa)

BUCKLING

The buckling of **pipes at shallow depths** should be checked using the Timoshenko equation which ignores soil support. This formula also applies to trenchless pipes, or pipes installed above ground:

$$P_{CR} = (24EI/D^3)/(\eta) \qquad \textbf{(40)}$$

Where: - P_{CR} is external pressure causing buckling kN/m²
- EI/D^3 is pipe ring stiffness (PRS) (kN/m/m)
- η is Poisson's ratio for material. If it is taken as zero the error will be small and conservative.

The buckling of unsupported, exposed PVC and HDPE pipes can be checked using the following formula:

$$Pcr = \frac{2380 \ \text{x} \ E}{(DR-1)^3} \qquad \textbf{(41)}$$

Where, Pcr = Critical buckling pressure in kPa
E = Modules of elasticity in MPa
DR = Dimension ratio of the pipe (PVC and HDPE) = Average outside diameter (OD) / Minimum wall thickness (mm)

Since the Elasticity and the pipe ring stiffness are both dependant on temperature and time, the values should be reduced by applying the appropriate derating factors.

For pipes where the soil support can be guaranteed, the critical buckling can be calculated using the Luscher equation:

$$P_{CR} = (32 \ E^1 \ EI/D^3)^{1/2} \qquad \textbf{(42)}$$

The critical buckling formula applies to pipes subjected to external loads, but can also be used for buckling as a result of internal pressures such as vacuum, where the appropriate E value for short duration loading should be applied. In both cases the long and short term buckling should be considered and added together to ensure that the total buckling remains within limits.

It is recommended that installation conform strictly to the requirements of the relevant sections of the SANS/ISO 1200 and/or manufacturers' specifications/ requirements. This calls for a material with a low compaction factor to be compacted to 90% or more of modified AASHTO density. This will result in an E^1 value of at least 5 MPa for the selected material. Good bedding will also reduce deflection and circumferential wall stress.

When very low stiffness pipes are used, an embedment material with higher stiffness is required. The amount of compactive effort needed to obtain sufficient support from a low stiffness embedment for a low stiffness pipe (< 4 kN/m/m) will cause the pipe to deform into a vertical ellipse during the side fill compaction, and then into a square shape when the material above the pipe is compacted.

SECONDARY LOADS

Secondary loads are not as easy to determine as the primary loads, because they are variable, unpredictable, and localised. They can, however cause considerable damage to a pipeline due to differential movements between pipes, and between pipes and other components. It is therefore essential that their potential impact be recognised and that precautions be taken where necessary. Examples of factors that could cause secondary loads are:

- Volume changes in clay soils due to variations in moisture content
- Pressures due to growth of tree roots
- Foundation and bedding behaving unexpectedly
- Settlement of embankment foundation
- Elongation of pipeline under deep fills
- Effects of thermal and moisture changes on pipe materials and joints
- Effects of moisture changes and movements on bedding
- Restraints caused by bends, manholes etc.
- Materials swelling and loss of E-modulus as well as related forces

It is preferable to avoid or eliminate the causes of these loads rather than attempt to resist them. Where this is not possible, particular attention must be paid to pipe joints and the interfaces between the pipeline and other structures, such as manhole-chambers, to ensure that there is sufficient flexibility. The reader is referred to the section in this manual which deals with joints (Chapter 4 and Chapter 6).

DURABILITY

The properties of any pipeline with the greatest impact on its long term performance are those relating to durability and its ability to handle installation and operating conditions. In general terms, relating to the operating conditions, the durability of a pipe can be summarised as the pipe's ability to resist erosion (degradation of material properties due to environmental and/or other service condition factors, where the functional working abilities for which the pipe was intended for are lost). Handling and installation of pipes are covered in greater detail in Chapter 6 of this document.

Plastics are in general inert to a very wide range of aggressive elements in the soil and in the effluents that may be conveyed in a pipeline. Appendix B gives a comprehensive list of the chemical resistance offered by the thermoplastics used for pipe manufacture to a wide range of potentially aggressive substances. The effect of temperature, which could be a significant factor for industrial applications, is also covered in these tabulations.

The greatest durability concerns in pipes are;

- Corrosion
- Abrasion
- Degradation of material properties and other environmental influences, which include thermo-oxidative, UV, and chemical degradation, etc.

CORROSION

In most non-plastic pipelines degradation due to corrosion is the main governing factor that reduces the lifespan of a pipeline. Corrosion in most cases results from chemical attack in conjunction with mechanical wear, resulting in a gradual thinning of the pipe wall thickness. Thinning of the pipe wall will eventually result in elevated local stresses which will cause the pipe to rupture. All pipes, regardless of the material chosen, will suffer some form of degradation of the pipe material over time, impacting the actual service life of the pipe. The main concern with materials subjected to chemical attack resulting in corrosion is that the time relationship in the degradation process is almost impossible to predict.

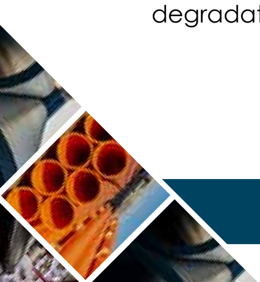
The advantage of plastic pipes manufactured today is that they are virtually completely resistant to corrosion as a result of chemical attack in most environments, unlike ductile iron, steel, etc. The degradation of plastic pipes over time is therefore different to that described above.

Like any other organic material, plastic will deteriorate over time as a result of UV-radiation, thermal oxidation, or the absorption of the material conveyed in the pipeline. To prevent or retard this process, manufacturers of plastic pipes add various kinds of stabilisers like carbon black and other types of antioxidants. These additives significantly retard, or in some cases completely prevent, this degradation process.

In plastics, the main time-dependant deterioration factor to consider is the temperature the pipe is exposed to over time. In recent years, many studies have investigated this phenomenon in order to quantify the degradation rate of time/temperature in plastic pipes, whereby the relevant reduction factors to extend the service life of plastic pipe were derived. Material-specific properties dealing with this phenomenon are covered in more detail in Chapter 3 of this manual.

ABRASION

In most cases engineers take special care when designing pipeline systems in terms of hydraulic capacity. As a result it is very uncommon for pipes to fail as a result of exceeding the pipe's mechanical strength. The effects of abrasion, on the other hand, can easily be overlooked or misrepresented. Since abrasion occurs over time and is very difficult to quantify in theoretical terms, it can be considered as the second most important factor in material degradation over a period affecting a pipe's durability and effective service life.



The frictional properties of plastic pipes in most applications are far better than other materials, as long as the temperature of the material conveyed is limited and/or taken into consideration, since the strength of plastic pipes over time is temperature dependant. Since the abrasion resistance of pipes is difficult to predict or quantify, and usually only becomes a concern when conveying effluents like liquid sludge and slurries, it is appropriate to reference experiments conducted to compare the effects of abrasion on various types of pipe materials.

From experiments conducted and reported on by Lars-Eric Janson in the 4th Edition of his book *Plastic Pipes for Water Supply and Sewage Disposal*, comparisons between the various materials based on experimental data provide insight into how the different materials are affected by abrasion. The effects of abrasion were compared by considering the weight and volume loss of the different materials exposed to abrasion experiments. The reduction in wall thickness of the pipes was considered the most effective manner to evaluate various pipes long term abrasion resistances, since this increases the localised stress in the wall of the pipes, affecting durability and resulting in rupture failure over time. The simulation of the effects of abrasion was done by the rotation of pipes mixed with water, sand, and slurry. Authors of the test results are credited individually; the experiments were as follows:

Experiment 1 (Schreiber, Germany): Performed on pipe elbows in HDPE and steel Ø50mm in 15% sand mixed with water traveling at a velocity of 7-8 m/s at water temperature 30-35˚C. Since abrasion takes longer on straight pipelines it was decided in this experiment to use elbows instead.
Results: The wear suffered by the pipes was as follows:

- HDPE - 4mm decrease in pipe wall thickness after 1600 hours
- STEEL - 4mm decrease in pipe wall thickness after 1000 hours

In terms of abrasion converted to a PN10 pressure pipe of Ø 250mm, the results will be a 10% increase in the pipe wall stress above the design stress of an HDPE pipe, at which point the steel pipe would have ruptured already.

Experiment 2 (T. Meland, Norway): A 1:20 sand-water mixture in Ø250mm pipes made up of four different materials under the same conditions. The results are recorded by the relative increase in pipe wall stress:
Results:

- PVC - 3%
- LDPE - 0.3%
- Asbestos Cement - 13%
- Steel - 7%

Experiment 3 (Nöthen, Germany): Ø250mm pipes. The results are recorded by the relative increase in pipe wall stress with the same abrasive effects:
Results:

- PVC - 0.6%
- Steel - 6%
- Cast Iron - 2%
- Stoneware - 2%
- Concrete - 5%
- Asbestos Cement - 9%

It should be noted that the abrasion resistance of (HDPE) PE 100 was found to be more than double that of the best ranked LDPE.

DEGRADATION OF MATERIAL PROPERTIES AND ENVIRONMENTAL INFLUENCES

Additional factors which can result in the degradation of the pipe should also be considered when choosing the correct type of pipe in a specific environment. Environmental factors which may cause pipe material degradation can include bacteria, rodents, parasites, plant growth, etc. Other factors, like fouling of the pipe's surface as a result of water pollution, should also be considered.

The material properties of the pipe should also be taken into consideration, where in some cases the polymer can be degraded as a result of certain types of bacteria and other types of life forms. It is also important to consider whether the material properties of a pipe may assist in the nutritional needs of certain life forms, whereby growth is stimulated or some components in the pipe material's properties may even act as a fertiliser to a particular life-form the pipe will be exposed to. It is common knowledge that PVC and PE pipes are particularly resistant to microbial growth, which is a great advantage where pipes are used for municipal services, such as drinking water to the public.

CHOICE OF PIPE MATERIAL

Plastic pipes can be used in a wide variety of applications. The primary hydraulic capacity requirements, and the future demand of service delivery which will determine the internal diameter (ID) of the pipe, are not the only considerations to ensure that the pipeline does not fail. It is imperative to consider the secondary requirements to ensure that the pipeline does not fail. These requirements can be summarised as follows:

- Water-tightness – The ability of a pipeline system to prevent leakages and infiltration under specified applications and conditions.

- Strength – The ability of a pipeline system to withstand applied external forces so that it will not collapse or deform to the extent that it is rendered inadequate for its intended purpose (this is especially true in gravity systems). For pressurised pipeline systems, the strength is mainly dependant on the pipeline system's ability to withstand the pressures induced internally that could cause the pipe or its connections to burst, break, or collapse under negative internal pressures (vacuum).

- Durability – The performance, service conditions and the physical and mechanical properties required for the pipeline to last effectively within its surrounding environment throughout its service life.

When these requirements are given proper consideration in choosing the correct pipe material, the pipeline will last throughout its service life without any complications. All plastic pipes have significant qualities and advantages. Some of the most common known advantages to consider when choosing the correct pipe material can be summarised as follows:

- Polypropylene (PP) – Can operate constantly at higher than ambient temperatures
- Polyethylene (PE) – Can operate in difficult and more unstable soil conditions where flexibility is required. (i.e. dolomite areas)
- Polyvinyl Chloride (PVC) – Inexpensive, very easy to install, requires no specialised equipment or labour.
- Glass-reinforced Plastic (GRP) – Where larger diameters and higher pressure ratings are required.

CHAPTER 3:

TYPES OF PLASTIC PIPES (MATERIAL PROPERTIES AND BEHAVIOUR)

ELASTIC, PLASTIC AND VISCOELASTIC PROPERTIES OF MATERIALS

Most materials used in the construction industry today can, for all practical purposes, be considered as elastic. In the case of ideal elastic materials, the relationship between stress and strain are linear and independent of loading time at ambient temperatures. For these materials Hooke's law can easily be applied to determine the modulus of elasticity; therefore, up to a certain stress limit for a particular material, the material will deform under a load and return to its original shape once the load is removed.

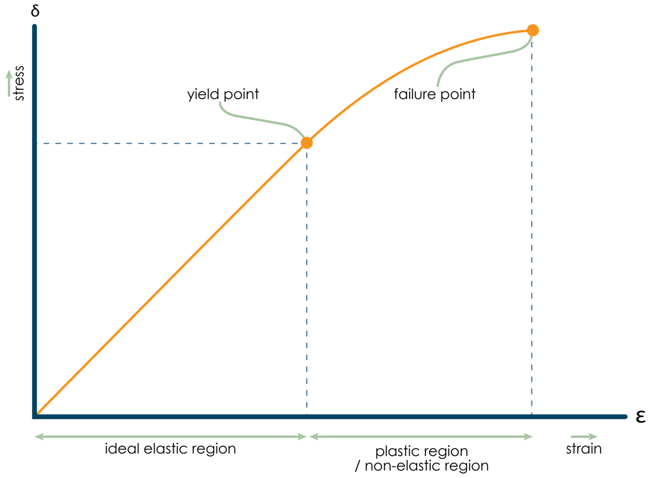


FIGURE 3.1: STRESS-STRAIN CURVE FOR AN ELASTIC MATERIAL

Hooke's Law:

$$E = \delta / \varepsilon_1 \qquad \textbf{(43)}$$

Where; δ stress = the force per unit area along an axis to the strain, (ε)

ε_1 strain = ratio of deformation over an initial length

In reality however, if the effects of stress and loading time for these elastic materials are closely observed together with their ability to return to their original state prior to loading once the loads are removed, it becomes apparent that the properties differ considerably from the ideal elastic behaviour. Mathematically however, Hooke's law can still be applied to most of these materials like, concrete, ductile iron, wood, etc. on an approximate elastic basis with acceptable accuracy, since the differences which effect the elastic limit in terms of stress, strain, and loading time are not so great.

Plastic materials, on the other hand, display a completely different characteristic, where the strain is not linearly proportionate to the stress imposed on the material, nor is it independent of the loading time during the period when a force is applied. In plastics, creep is a dominant factor during the period of a particular load. (In fact this is also the case with steel when exposed to high temperatures, which in many instances is not considered or is conveniently ignored.) The creep phenomenon is a basic rule with plastics, and is dependent on both the time period during which the material is under stress or exposed to a certain load, and the temperature to which the material will be exposed during the loading period under a certain stress. It is important to consider that the creep phenomenon in plastics is not directly linked to the actual magnitude of the stress to which the material is exposed, but rather the time period. Failure in structural integrity of plastics will occur after a certain time period regardless of the magnitude of the stress, although the time period at which failure will eventually occur will be related to the magnitude of the stress.

The required service life, as with most other structural materials, is 50 years and above, the allowable design stress is therefore derived from this requirement. All materials display a degree of elastic and a plastic behaviour, regardless of temperature and time. Essentially it is this behaviour that makes plastics very favourable in conveying basic services for different applications and environments. From figure 3.2 the behaviour of plastic can be summarised as follows:

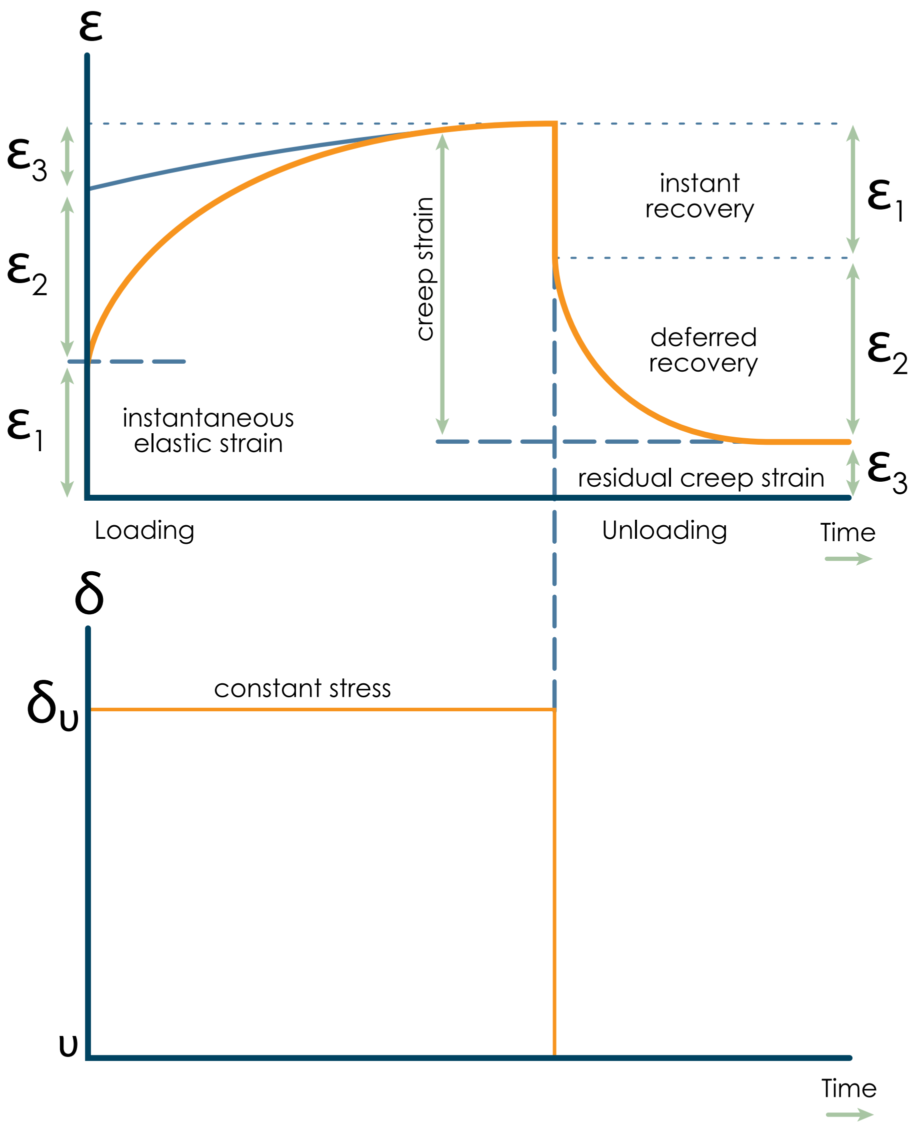


FIGURE 3.2: THE RELATIONSHIP BETWEEN STRAIN AND TIME FOR A PLASTIC MATERIAL UNDER CONSTANT STRESS

Where,

ε_1 = in plastics, the theory of Hooke's law applies in this zone where the immediate recovery to the material's original state occurs

ε_2 = "retarded" elastic strain, or, "primary creep", which will gradually recover, over time; once the load is removed the material will recover or nearly recover to its original state.

ε_3 = viscous strain or secondary creep, which will never recover.

Viscoelastic materials or viscoelastic properties, on the other hand, produce a different relationship between (ε_1, ε_2, ε_3) strain and time at different stress levels. Linear viscoelastic materials manifest a constant relationship between strain and time for different stress levels.

The zone (ε_1) where a material acts in an ideal elastic manner, where the strain is linearly proportionate to the load applied to it, can be compared to the behaviour of a spring. The loading time in this zone does not affect the relationship between stress and strain, and the spring will return to its original state once the load is removed. On the other hand, the zone (ε_3) where a plastic material reacts in a linear, viscous manner can be compared to that of a dashpot, a piston filled with a viscous fluid like oil, which acts as a damping device. In the case of a dashpot, motion is resisted via the counteracting frictional forces provided by the fluid in the opposite direction than the applied load, slowing the motion of the piston by absorbing the energy. The ends of the piston will move apart at a rate proportionate to the pulling forces applied to the ends. The increase in length between the ends of the dashpot after a certain amount of time during loading represents the viscous strain of the material (ε_3). The dashpot's displacement can be compared to the sliding of the plastic material's molecular chains.

The viscous strain of a material can be calculated using the following equation:

$$\varepsilon_3 = \delta_0 / \mu_3 \qquad (44)$$

Where, μ = the viscosity of the material

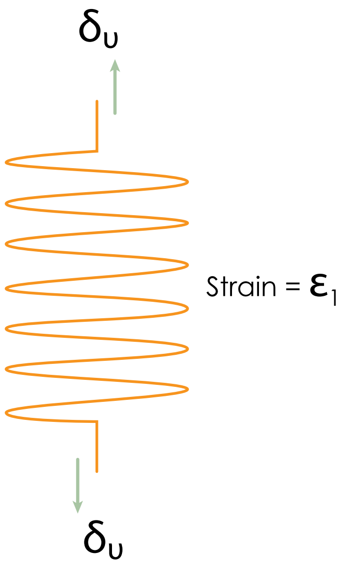


FIGURE 3.3: SPRING SYMBOLISING IDEAL LINEAR ELASTIC BEHAVIOUR

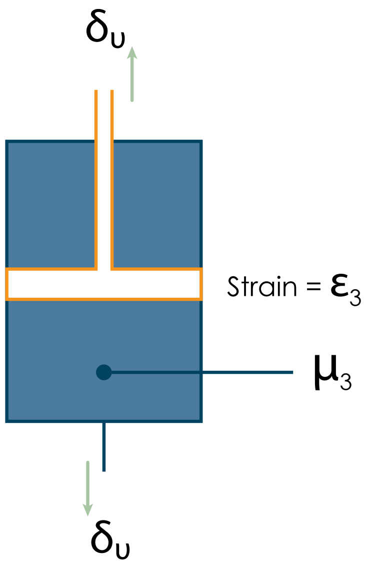


FIGURE 3.4: DASHPOT SYMBOLISING IDEAL LINEAR VISCOUS BEHAVIOUR

When the dashpot and the spring are combined in a series, the total strain is made up from the sum of the elastic and viscous segments of the strain. This combination is known as the Maxwell element. The retarded elastic strain (ε_2), on the other hand, is illustrated by combining the dashpot and the spring in parallel. The elastic and viscous elements in this case will now act together. This is known as the Kelvin-Voigt element.

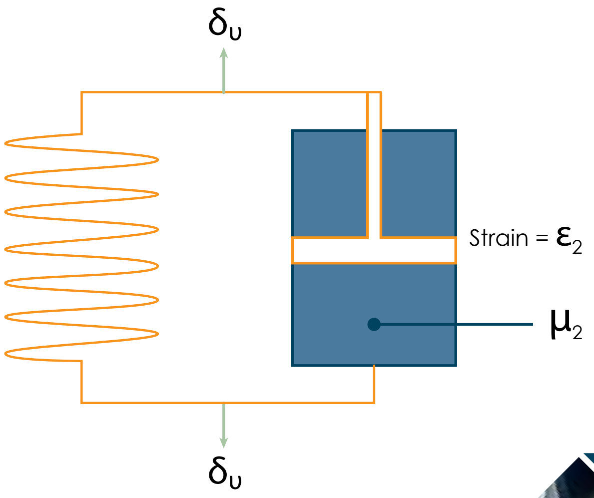


FIGURE 3.5: KELVIN-VOIGT ELEMENT SYMBOLISING THE BEHAVIOUR OF RETARDED ELASTIC STRAIN

When a force is applied to the ends of the spring the dashpot will extend in the direction of the force. The displacement is dependent on the spring-constant, but is simultaneously countered by the dashpot, thereby moving apart at a slower rate due to the frictional forces rendered by the piston. Even though the retarded strain value is finite, it will only be reached over a long time period since the strain is dependent on both the elastic and viscous characteristics of the body. This can be calculated using the following formula:

$$\varepsilon_2 = \delta_0/E_2 \ \ [1\text{-}e\text{^}((\text{-}(E_2\, t)/\mu_3\,)\,)\,] \qquad \textbf{(45)}$$

Once the load is removed, the spring would behave as the elastic component and would attempt to return to its original shape but, similarly to when a load is present, would be countered by the frictional resistance of the dashpot. Over a period of time the piston will gradually return to its original position under the force provided by the spring. This is the same in plastics, where the retarded elastic strain consists of two components: the elastic strain within the molecules of the polymer; and the electrostatic viscous resistance resulting from the bending forces within the polymer molecules. These need to be overcome simultaneously.

Figure 3.6 symbolises a body where the strain consists of an elastic, retarded elastic, and a viscoelastic element. In the case of Polyethylene (PE) the elastic part of the total strain is smaller than for Polyvinyl Chloride (PVC) and Glass-reinforced Plastic (GRP). This is especially true for Low-density Polyethylene (LDPE). The total elastic strain in thermoplastic materials like PE and PVC increases with greater molecular length, whereas in the case of GRP the same can be achieved by increasing the glass content.

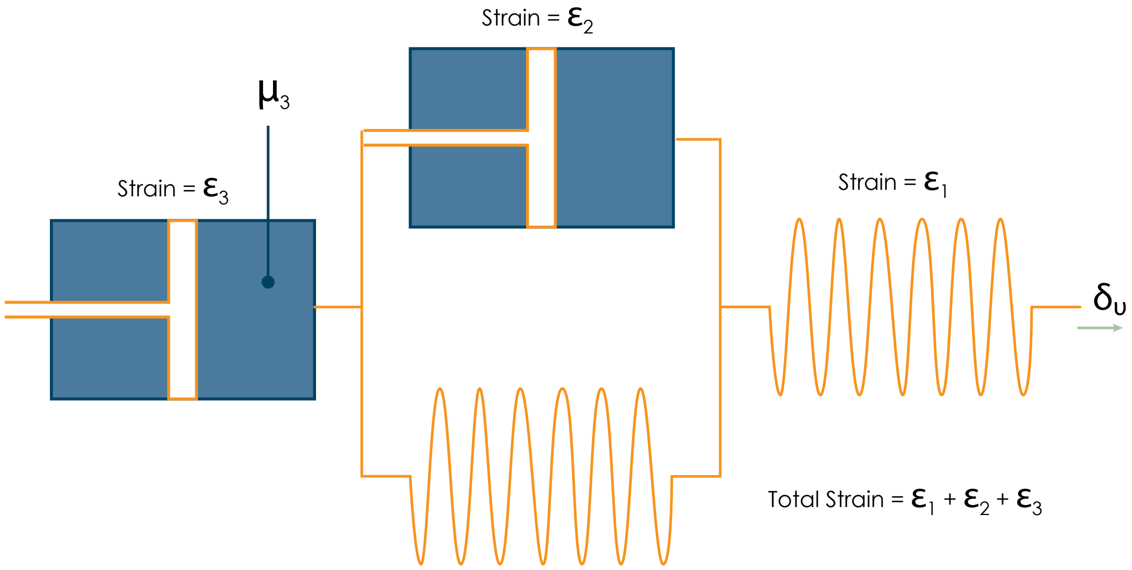


FIGURE 3.6: BODY SYMBOLISING THE BEHAVIOUR OF A VISCOELASTIC MATERIAL WHERE THE STRAIN CONSISTS OF AN ELASTIC, RETARDED ELASTIC AND VISCOUS ELEMENT

Figure 3.7 illustrates a process referred to as stress relaxation, where a plastic material remains under a constant stress (δ). This process is of great significance where a structural components' deformation is prevented or counteracted.

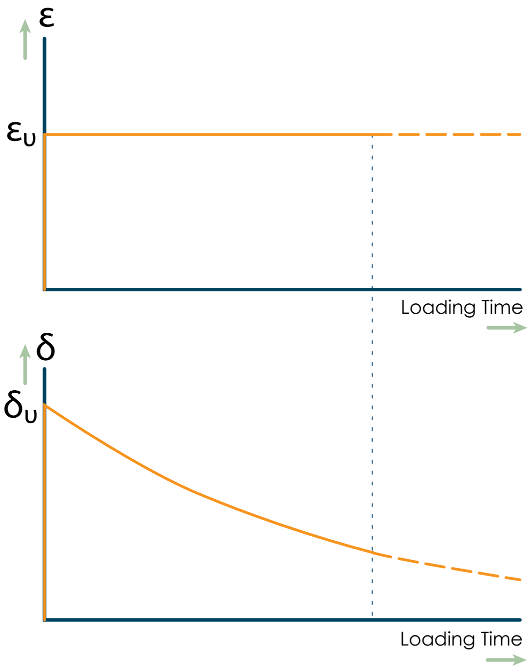


FIGURE 3.7: STRESS RELAXATION OF A PLASTIC MATERIAL UNDER CONSTANT STRESS

The notable effects of time in plastic materials under constant stress are therefore of great importance, and should be considered in the design of pipelines, as this will affect the overall stiffness of the pipe. These effects should be included in the design to ensure a service life of 50 years or more are reached. As a general guideline, the effects of time on the relative stiffness of plastic pipes under constant stress can be observed in figure 3.8 below and can be of great significance to aid in choosing which type of plastic pipe to use for a specific application based on the long term requirements.

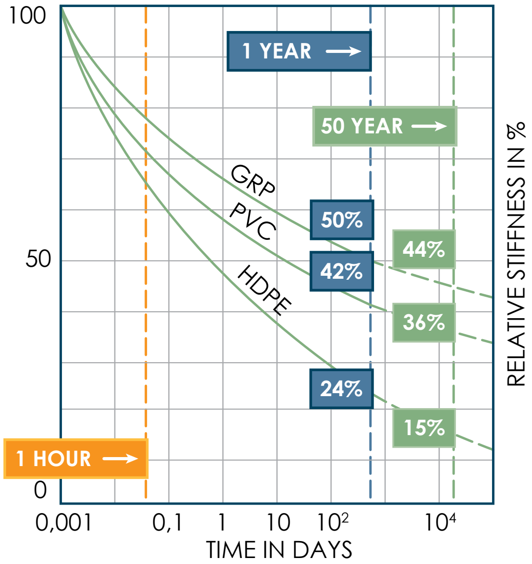


FIGURE 3.8 EFFECT OF TIME ON PIPE STIFFNESS OF PIPES SUBJECTED TO CONSTANT STRESS

Pipe material
- GRP = GLASS REINFORCED PLASTIC
- PVC = POLYVINYL CHLORIDE
- HDPE = HIGH-DENSITY POLYETHYLENE

E Value
- When installed
- When at the end of its design life

THERMOSPLASTICS AND THERMOSETS

Plastics belong to a wider material group known as polymers. The word polymer is derived from the Greek words *poly and meros* meaning "many" and "parts" respectively. A polymer consists of a large molecule, or macromolecule. These molecules are composed of many repeated subunits (hydrocarbons) with various properties, consisting of either synthetic or organic substances. Typically, natural polymers consist of proteins and DNA-strings which are essential to the biological structure of all living organisms. Plastics, on the other hand, cover a wide range of synthetic materials, which can be molded or formed when soft and set. They fall into two broad categories, thermoplastics and thermosets.

All polymers, natural and synthetic, are produced through a process known as polymerisation. The polymerisation process refers to a chemical reaction where many small molecules known as monomers ("one-part") are bound together to form a network of long polymer chains.

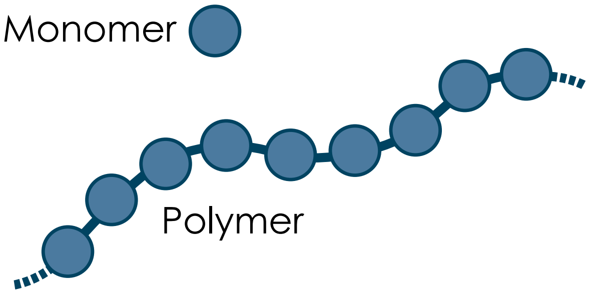


FIGURE 3.9: ILLUSTRATION OF POLYMER CHAIN

In plastics these chains consists of very long threadlike giant molecule strands which may either be independent from one another or cross-linked. Like with most synthetic materials, plastics can be moulded or formed into various shapes when soft. It is this property that generally divide plastics into two categories, namely Thermoplastics and Thermosets.

Thermoplastics consists of non-crosslinked chain molecules. The molecular chain consists of many individual monomer molecules with no covalent bonding between them, the monomer chain are bonded together through intermolecular bonding which will soften when heated and harden when cooled. This cycle can be repeated over and over again to create other shapes. In the case of plastic pipe, the number of cycles is limited to the point at which the minimum material properties have degraded to such an extend so that it no longer complies with the required standards. Thermosets, on the other hand consist of long chains of cross-linked molecules with many covalent bonds between them, the molecules bonded together in a three-dimensional structure which can practically be regarded as a single molecule which, when exposed to heat, will disintegrate before it melts. Thermosets, when processed and shaped, are therefore materials that are hardened by heating. Further heating cannot soften them again. The process to create a thermoset can be compared to boiling an egg, when the egg is exposed to heat it becomes hard, and once the egg is cooked, further exposure to heat cannot melt it again. Since the process of cross-linking takes place during the setting process of the plastic, it is referred to as a Thermoset. An international system for identifying plastics that uses a polymer identifying logo has been developed. This is given in Appendix A. Only some of these materials are used to manufacture pipes.

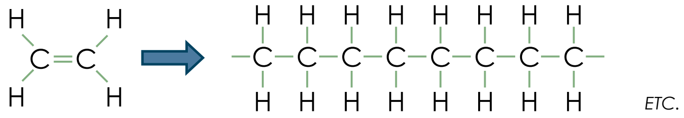


FIGURE 3.10: MONO-ETHYLENE MONOMER AND POLYETHYLENE POLYMER CHAIN

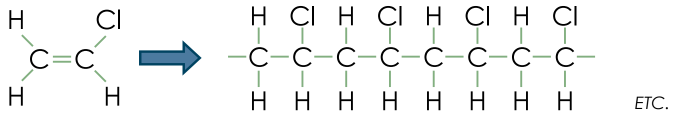


FIGURE 3.11: MONO-VINYL CHLORIDE MONOMER AND POLYVINYL CHLORIDE POLYMER CHAIN

Polyethylene (PE), Polyvinyl Chloride (PVC) and Polypropylene (PP) are the predominant thermoplastic materials used for the manufacture of sewer and water pipes. Polypropylene is mostly used inside of buildings for plumbing purposes, to distribute hot water as a modern alternative to copper pipes. Thermosets, like Glass-reinforced Polyester (GRP), are used as an alternative to concrete pipes due to their large diameters. Several methods can be employed to manufacture GRP pipes which varies in the material used as a filler material, as well as the application methods and materials in the resin. In recent years various methods have been developed in the production of medium density polyethylene (MDPE) to produce resins which are more flexible but just as strong as HDPE, and even stronger at elevated temperatures (such that they even compete with PP for the production of hot water pipes). Several methods have also been developed to cross-link the Polyethylene molecules to achieve greater heat resistance. These cross-linked PE materials are commonly referred to as PEX, and can be used in indoor hot-water applications.

PRODUCTION OF THERMOPLASTIC POLYMERS

POLYETHYLENE

PE100 high density polyethylene (HDPE) is produced by the polymerisation of ethylene, a feedstock derived from oil or gas. Reactor conditions are carefully controlled to ensure that the correct physical properties are built into the material.

All modern generation PE100 HDPE grades are bimodal, and the correct amount of high molecular weight material is built into the material during the polymerisation phase. Longer polymer chains give the material the strength required to withstand internal pressure, while high chain entanglements give modern pipe materials their superior resistance to slow crack growth.

After polymerisation, the HDPE material is typically in a powder form, which is then compounded with the correct amount of additives, including carbon black, and pelletised so that it can be used by converters to produce pipe.

Additives, such as long term stabilisers and carbon black, are added to the material produced prior to pelletising so that pipes produced from PE100 material will be protected from UV and heat degradation in service.

PE100 materials that conform to the latest versions of the ISO/SANS 4427 and ISO/SANS 4437 Standards, have undergone stringent type testing and are supported by ongoing process verification testing (PVT) by the material manufacturers to ensure compliance.

The molecular tailoring of the material during polymerisation, compounding of the required additives, and good manufacturing practice during conversion into pipes ensure that hydrostatic strength is maintained for 50 years or more under arduous operating conditions.

POLYVINYL CHLORIDE

The main raw materials for the manufacture of PVC are ethylene and chlorine. Ethylene is derived from hydrocarbon feedstock (oil or natural gas), while chlorine is formed from the electrolysis of salt. The reaction of ethylene and chlorine results in ethylene dichloride (EDC). EDC is then thermally cracked, which leads to the formation of vinyl chloride monomer (VCM), the base monomer that is a pre-cursor to the polyvinyl chloride monomer (PVC).

The manufacturing process of PVC starts with the polymerisation of VCM in a polymerisation reactor. Polymerisation of VCM can take place by suspension, bulk, emulsion, and solution methods. The most commonly used polymerisation method is the suspension process, which produces resin suitable for the manufacture of pipe, cables, profiles, footwear, and various other applications. The suspension process involves the reaction of VCM in a reactor containing water and suspending agents, in the presence of an initiator. This leads to the

formation of PVC particles suspended in water, forming a slurry. The slurry discharged from the reactor is stripped of residual monomer and dried off, which leaves the PVC in dry powder form. The physical properties of the resulting resin are determined by the manufacturing additives and reactor conditions used.

Other polymerisation methods, though less commonly used, include emulsion process, normally used in paste or plastisol applications; bulk polymerisation whose higher purity is ideal for high clarity applications; and solution polymerisation, mainly used in PVC copolymers.

DIFFERENCES IN PRODUCTION BETWEEN PVC AND PE

Following the manufacture of PVC resin, additives must be added to the resin to stabilise it for conversion purposes (processing) and also to make it suitable for final product properties. The resin is sold as powder without additives, and the final producer sources the additives independently. PVC resin and these additives are formulated according to the requirements of the final product, in this case pipe. The addition of the additives to PVC resin and subsequent mixing is sometimes referred to as compounding, although this term is commonly used to include mixing and production of granules/pellets (or compound) on a compounding extruder.

PVC compounding at the convertor takes place in two forms. In the first, the convertor adds the additives, then uses a high speed mixer (similar to a coffee mixer) to obtain a homogenous mix consisting of PVC and these additives. The dry blend from the high speed mixer is then transferred to the extruder for extrusion of pipe. In the second form, in the case of a flexible, plasticised product such as PVC hoses, the convertor would, after the mixing process, convert the blend to granules or pellets, which are then used for cable extrusion. In this case, what goes into the extruder is the compound/granules/pellets. This would then be similar to HDPE granules/pellets.

The reason that many plasticised PVC applications have to go through the compounding step is that the powder resulting from the mixing process is normally oily, lumpy, and therefore not ideally suited to flow. This can cause bridging in the pipes, leading to serious process disruptions due to starvation of the extruder. Additionally, from a cost perspective for a PVC final product convertor, it is preferable to convert a dry blend without the intermediary step of compounding/pelletising/granulation. The compounding step involves a compounding extruder, which is a capital cost. Thus, unless compounding is required for the above reason, it makes sense for final product producers to only deal with dry blend. The simple rule of thumb is that plasticized or flexible PVC applications are normally compounded to pellets before final product manufacture, while rigid PVC products are produced from dry blend/powder. In both cases, additives are added at the convertor and not by the PVC resin manufacturer.

As additional information, there are businesses within the PVC industry which specialise in PVC compounding. They source PVC resin from the resin manufacturer, and additives from various suppliers, and then produce PVC compounds/granules or dry blend. This enables smaller businesses to produce final products without having to worry about sourcing additives and laying out compounding equipment.

The difference between HDPE and many other polymers, like PVC, is that the additives are added as part of the production process, followed by compounding, resulting in polymer granules or pellets. All of this takes place at the polymer manufacturing stage.

Note: HDPE is generally sourced by pipe converters in pelletised form, while PVC is mainly sourced from polymer suppliers in the form of a powder.

Note: In all pressure pipe applications for both PVC and PE, the materials have to be characterised according to the material's MRS value, as per ISO 9080.

CHARACTERISTICS OF THERMOPLASTICS

POLYETHYLENE

In order to predict the long-term strength behavior of polyethylene, various material characteristics need to be evaluated according to the relevant standards. In the case of polyethylene the most notable characteristics are as follows;

- Density and crystallinity
- Melt flow rate or viscosity, commonly referred to as the MFR
- Carbon content
- Oxidation Induction Time, or OIT

The density and crystallinity refers to the arrangement of the various monomer molecules in the polymer material, which are significant since this will influence the material's melting point, surface hardness, permeability, and water absorption. To determine the material's crystallinity, regular samples are observed under a microscope inside a laboratory to ensure that the material's properties comply with the prescribed standard.

The MFR and density are important because these will influence the long term strength properties of the pipe material. The MFR is determined by heating the material until it melts, while allowing the material to pass through an orifice with a certain diameter under a certain weight while applying pressure to pass the material through the orifice. The combination of the material's characteristics based on the density and the MFR test results are critical to ensuring the material's long-term strength. The MFR is dependent on the mean molecular weight, where well packed monomer molecules increase the materials' molecular weight. An increase in the molecular weight will result in a decrease in the MFR value, and greater strength. However, if the density of the material or the molecular weight become too high, the ease with which the material can be processed during pipe manufacture decreases, especially for larger diameter pipes, complicating the manufacturing process of pipes and other injection molding applications to produce pipe fittings.

The carbon content within polyethylene pipes affects the pipe's UV resistance properties, which are significant where polyethylene pipes are used in trenchless or above ground applications.

POLYVINYL CHLORIDE

Polyvinyl Chloride pipes are manufactured in a similar manner to polyethylene pipes, by means of extrusion, and can be manufactured with or without plasticisers. By adding plasticisers, the flexibility of PVC is increased, making it useful for various household articles like hose-pipes and floor tiles. However, adding some types of plasticisers can potentially reduce some favourable properties and material characteristics of PVC, since these plasticisers could migrate or escape over time causing the material to become brittle.

PVC containing no plasticisers is referred to as PVC-U – Un-plasticised PVC – and commonly known as rigid PVC. PVC-U is commonly used in the manufacture of water and sewer pipes. The service life of PVC pipes according to the regression curves from SANS ISO 9080 is 50 years, though PVC may last much longer if the correct engineering and design principles are followed. Since PVC-U contains no plasticisers, other additives are introduced in the manufacturing of PVC pipes in addition to the virgin polymer, to act as stabilisers. In the past there has been a great deal of controversy since many of these additives have been classified as cancer causing. Lead and other heavy metals were commonly used during the manufacturing process to produce PVC-U pipes in the past. In recent years, organic-based stabilisers have been developed to replace metallic stabilisers, but not all manufacturers have moved away from using heavy metal stabilisers to produce PVC pipes yet.

The molecular weight of PVC pipes is referred to as the K-value, different from PE, where it is referred to as the MFR. The K-value (molecular weight) for PVC can be determined in a variety of ways. One of the most common methods to determine the K-value of PVC in the past was the Fikentcher method. With this method a certain percentage of PVC is placed in cyclohexanone at ambient temperature.

A certain viscosity of the PVC is then determined. As with PE, a larger K-value denotes a greater molecular weight and strength, but also a decrease in the material's ability to be processed during extrusion.

Another significant test of PVC is the softening point test, referred to as the "Vicat Point". Generally this point should lie somewhere between 70˚C - 80˚C. The higher the Vicat Point, the greater the material's resistance to heat and, generally, the greater the overall strength of the material. In the past this has posed a problem when producing injection-moulded PVC fittings, since their shapes are more complicated than a pipe and require a higher viscosity, influencing the strength of the fittings. Recent developments in the production of PVC fittings, however, have increased the K-value for moulded fittings, for a Vicat Point up to 70˚C and above, rendering the fittings as strong as (and sometimes stronger than) the pipe itself.

FIGURE 3.12A: EXTRUSION OF AN HDPE GAS PIPE

FIGURE 3.12B: EXTRUSION OF AN HDPE PIPE

MANUFACTURE OF THERMOPLASTIC PIPES

Thermoplastic pipes (i.e. PE and PVC) are produced by an extrusion process where the virgin polymer material is melted at elevated temperatures before being extruded through a die specifically designed for the purpose of manufacturing a specific type of thermoplastic pipe. Manufacturing of thermoplastic pipes takes place on a continuous basis. Once the pipe has been extruded, satisfactorily and within the desired tolerances at the correct temperature, it is cooled in a water bath located at the end of the extrusion line of the pipe extrusion plant. Since the manufacturing of thermoplastic pipes takes place continuously, the length of the pipe is only limited by practical considerations, the client's needs, or the product's standard.

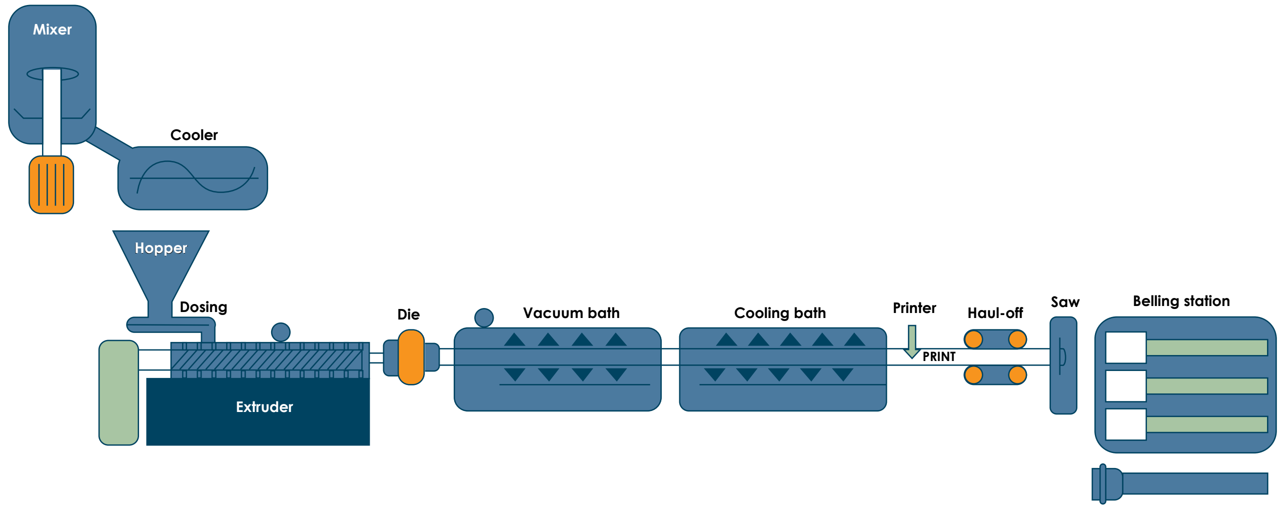


FIGURE 3.13: LAYOUT OF A PVC PIPE EXTRUSION PLANT

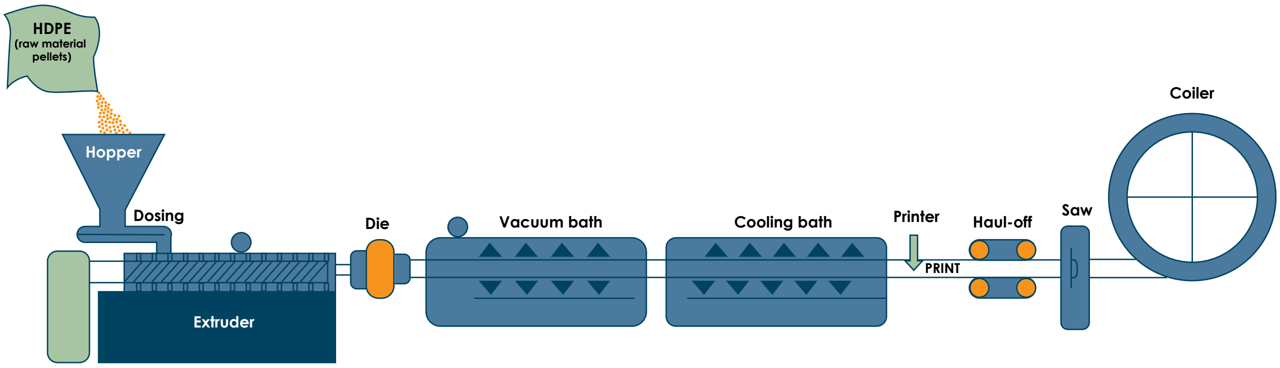


FIGURE 3.14: LAYOUT OF A HDPE PIPE EXTRUSION PLANT

STRESS, TIME, AND TEMPERATURE RELATIONSHIP

With plastic materials the relationship between stress and strain is time dependent. Hence, if the stress is kept constant the strain will increase with time. This is called the creep phenomenon. Since the strain in plastic is not proportional to the stress or the loading time, as in most elastic materials, Hooke's law cannot be applied directly to a viscoelastic material to determine its Elastic modulus. The tendency of plastic to creep is dependent on both the stress/time and the temperature, therefore the E-modulus in plastic is more commonly referred to as the creep modulus.

In practical terms this creep means that failure will occur after a certain loading period. As the time to burst is inversely proportional to stress, it is possible to determine a stress level at which the time to failure will exceed the pipeline's design life.

All plastics used for the manufacture of pipeline systems are classified, and their permissible stress limits determined, by long-term performance under hydrostatic pressure in accordance with SANS/ISO 9080.

Classification is achieved by testing pipe samples at different temperatures and internal pressures and recording the time to failure. The data is then extrapolated in accordance with SANS/ISO 9080 to predict the stress after 50 years. These results are plotted to give a regression curve. This classification system is based on the predicted minimum required strength (MRS) that would cause failure after 50 years.

The 97.5% lower confidence limit of the predicted stress is rounded down to give the MRS value for each manufacturer's material.

The values given assume an operating temperature of 20°C. The design stress value increases at lower temperatures and decreases with increasing temperature. The MRS value is therefore a constant value defined by the lower confidence limit of the pipe material strength.

By applying the relevant derating factors, the allowable design stress is adjusted for temperature, time, chemical de-rating, jointing, and application/ system design. When designing pipelines for use at temperatures above 20°C the appropriate design stress value must therefore be used.

Because regression curves are the basis for designing plastic piping, a detailed description of how they are constructed follows.

At a fixed temperature the pipe is put under a fixed hoop stress and the failure time "t" is measured. A range of hoop stresses (from 2 to 40 MPa, depending on the polymer and the temperature), are investigated, resulting in a range of failure times from 1 to 10 000 hours. The regression curve is calculated and presented as a log/log plot.

The long-term hydrostatic strength (SLTHS) is the predicted mean strength at a given temperature, calculable over time range from1 hour to 50 years. It is extrapolated from the 20/40/60/80 degree C curves (failure times measured from 1h to 10 000h = 416 days). To ascertain the reliability of the extrapolation, the lower prediction limit SLPL is calculated:

- SLTHS (MPa): Long Term Hydrostatic Stress = predicted mean stress at a temperature T and time t.
- SLCL (MPa): Lower Confidence Limit 97.5% = lower confidence limit of the interpolated hydrostatic stress at a temperature T and a time t.
- SLPL (MPa): Lower Prediction Limit 97.5% = lower prediction (extrapolation) limit of the predicted (extrapolated) hydrostatic stress for a single value at a temperature T and a time t.

The failure can be either ductile (which corresponds to creep rupture) or brittle (which corresponds to environmental stress cracking). Ductile failure occurs at "high" hoop stress and gives a short failure time.

Brittle failure occurs at "low" hoop stress and gives a long failure time. The two kinds of failure give rise to a linear curve made of two branches of different slope: almost horizontal for ductile failure (short failure time), and steep for brittle failure (long failure time). The transition point between the 2 modes of failure, which is represented by a change of slope on the regression curve, is called the "knee" of the regression curve.

PVC, and the latest grades of PE, do not display a "knee" on the curves. With SCG-PE resistant at between 60 and 80°C, it may be possible to observe the knee before 10,000 h, but at 20°C the knee should not be observed before 10,000 h (it can only be determined through extrapolation). As the behaviour of a resin cannot be known before starting its regression curve, the exact failure times cannot be predicted. In practice the creation of a regression could take 18 months or longer.

The permissible design stress is obtained by applying a service design coefficient (1.25 – 2.5) to the projected burst stress at 50 years. (MRS = minimum required stress)

TABLE 3.1: TYPICAL LONG-TERM DESIGN FACTORS FOR PROJECTED BURST STRESS AT 50 YEARS FOR NORMAL WATER APPLICATIONS

HDPE (PE100)	1.25 (all sizes)
PVC-U	≤ Ø90 mm = 2.5 ≥ Ø110 mm = 2.0
PVC-M	1.40 (all sizes)
PVC-O	1.60

Although HDPE (PE100) has a much lower strength than PVC-U, its toughness is much higher, hence the lower long-term safety factor. Another reason for the greater design factor of PVC pipe material is due to the variability in the permissible stress of PVC pipes from one pipe manufacturer to another, as opposed to HDPE pipes, which are manufactured purely from raw materials purchased from a raw material producer. Although PVC-M has the same 50 year strength as PVC-U, it is much tougher. PVC-O has a great combination of high long-term strength and a higher toughness than PVC-M and PVC-U.

Ductile failure is a creep-induced failure, or plastic deformation where the pipe stretches and deforms under pressure. Ductile failure resistance can be enhanced by increasing the crystallinity, and therefore the density of the polymer, the material is then stiffer. Brittle failure is the result of (age induced) environmental stress cracking (slow crack growth) through the disentanglement of the polymeric chains. It can be prevented by increasing the entanglement (higher molecular weight, chain branching).

In failure induced by creep, the failure time depends on the applied pressure. This means that a small change in pressure implies a large change in failure time. Conversely, environmental stress cracking / slow crack growth corresponds to an age induced degradation of the polymer. When the polymer becomes older, the polymeric chains disentangle themselves; micro cracks build and grow, so that the polymer loses its stress resistance.

It is accepted in pipe standards, and by water authorities around the world, that the 50 year design life depends as much on strength as it does on toughness. Tough materials fail by predictable ductile yielding, and hence allow the use of lower safety factors, while more brittle materials may suffer from 'unstable' (unpredictable) crack growth failure caused by stress concentration effects.

Short-term safety factors for short duration loads and surge pressures

It should be noted that the above design factors only apply to the long-term (50 years and above), and that the short-term factors for thermoplastic pipes are in fact much higher; up to 4 times higher than other pipe materials like metal pipes, since the short-term safety factors depend on the rate of loading or a sudden increase in pressure. In the case of plastic pipes the strength of elastic modules increases directly in proportion to the rate of short duration loading, since the material's molecular structure reacts internally to resist the stress, as with most viscoelastic materials.

Example of regression curve displaying a "knee".

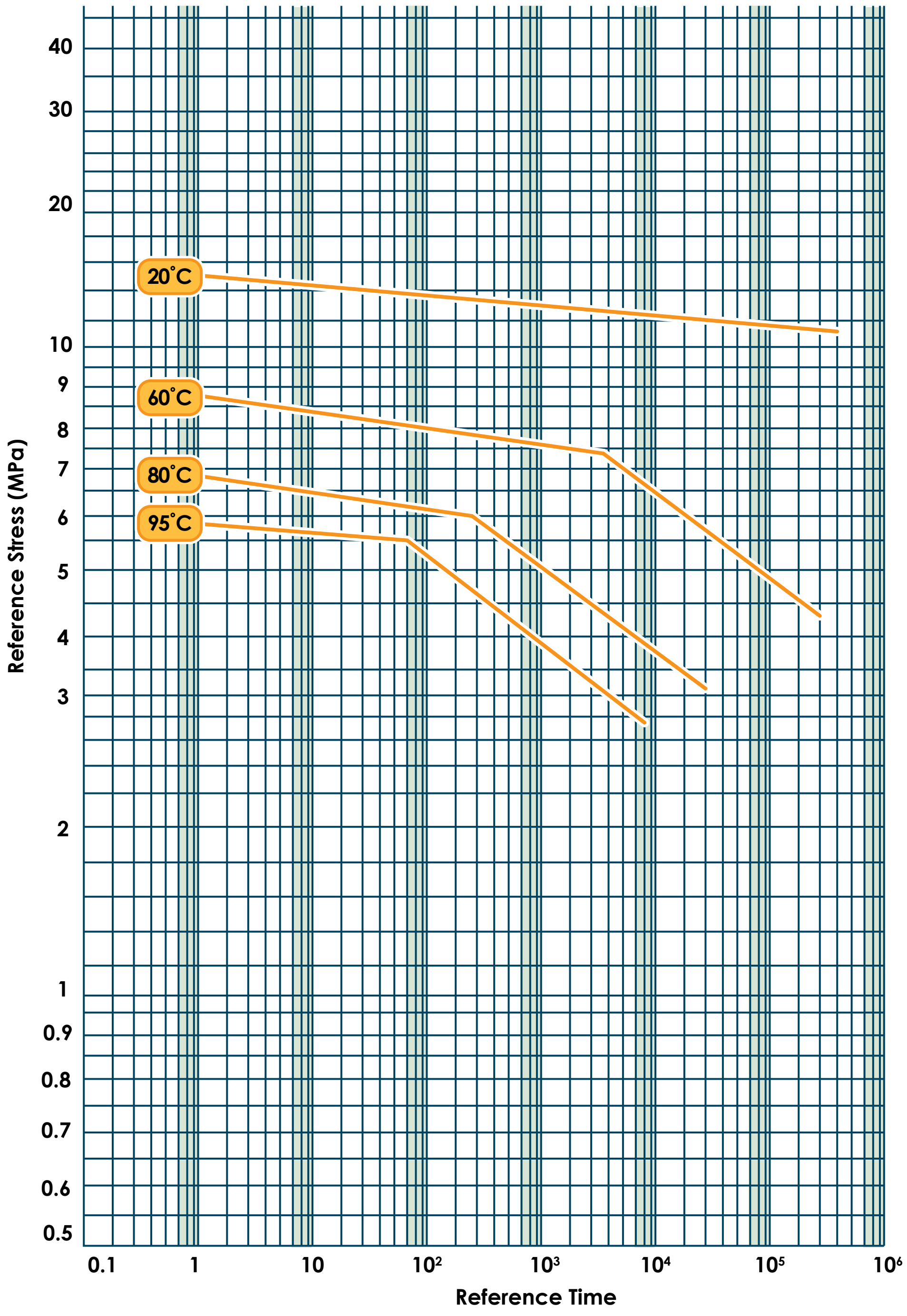


FIGURE 3.15: TYPICAL REGRESSION CURVE FOR HYDROSTATIC STRESS

TEMPERATURE DERATING OF PIPES

For buried pipes it can generally be assumed that the pipe's temperature will be equal to the temperature of the fluid it carries. Where a difference between the fluid and the external surroundings exists, the mean operating temperatures, as a general rule, can be taken as follows:

$$Tm = \frac{2Tw+Ts}{3} \qquad (46)$$

where; Tm = mean material temperature (over a 50 year period, design life period)
Temperature Tw = water
Temperature Ts = soil

Alternatively, a more accurate formula to determine the mean temperature along the pipe wall, which can also be used for exposed and trenchless pipe applications in or outside buildings, can be used. This formula is also useful where the temperature differences internally or externally can vary from less than 10˚C and up to 80˚C periodically:

$$Tm = T_1L_1 + T_2L_2 + \dots + T_nL_n \qquad (47)$$

where; Tm = mean material temperature (over a 50 year design life period)
Tn = average pipe material temperature for a proportion of the pipe life in ˚C
Ln = proportion of live spent at a given temperature Tn (i.e. over a 50 year design life period)

The following temperature derating factors should be applied together with the applicable factors of safety:

TABLE 3.2: TEMPERATURE ADJUSTMENT FACTORS FOR PVC PIPES

Working Temperature (°C)	Multiplication Factors
20	1.0
30	0.9
40	0.7
50	0.5
60	0.3

It should be noted that PVC-O pipes cannot be used at operating temperatures above 45°C.
It is not recommended that PVC-U or PVC-M pipes be used in applications exceeding 60˚C.

TABLE 3.3: TEMPERATURE ADJUSTMENT FACTORS FOR PE100 PIPES

Working Temperature (°C)	Multiplication Factors
20	1.0
25	0.9
30	0.8
35	0.7
40	0.6
45	0.5
50	0.4

It is not recommended that PE pipes be used in applications exceeding 50˚C.

For other types of Polyethylene pipes, refer to ISO 13761.

POISSON EFFECT

LONGITUDINAL STRAINS AND STRESSES IN PIPES

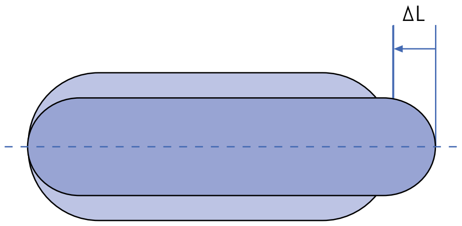
When a material is stretched, it usually contracts in the direction transverse to the direction of stretching (e.g. when a rubber band is stretched it becomes noticeably thinner). This phenomenon is called the **Poisson effect**. The ratio between these two quantities is known as **Poisson's ratio** (η).

When the liquid inside a pipe is pressurised it exerts a uniform force on the inside of the pipe, resulting in a radial stress within the pipe material. Due to Poisson's effect, this radial stress will cause the pipe to slightly increase in diameter and decrease in length as indicated by ΔL in the diagram below.

In PVC pipes joined with "spigot and socket" type joints, the decrease in length in each individual pipe is negligible, and not cumulative from pipe to pipe. Therefore, the Poisson effect is not critical in most PVC pipe systems.

However, in continuously jointed PE-HD pipes, the total decrease in length and the associated tensile force becomes significant. At unrestrained joints the pipes can fail by pulling out of the couplings. At restrained joints the pipes or the couplings may be prone to various forms of failure if the stresses are very high. Hence, the designs need to be analysed, detailed, and specified carefully.

The following formula can be used to quantify the Poisson effect in pipes:



$$\Delta L = \frac{P\ d\ L}{4\ t\ E}\ (1\text{-}2\eta) \qquad (48)$$

Where, Δ L = change in pipe length (mm)
P = internal pressure (kPa)
d = pipe diameter (mm)
L = original pipe length (m)
T = pipe wall thickness (mm)
E = Elastic modulus (MPa, i.e. 1200 MPa for PE 100)
η = Poisson's Ratio (i.e. 0.38 for PE 100)

STRAIN AND LONGITUDINAL STRESS

If a pipe is pressurised and restrained at both ends to prevent it from decreasing in length, the force required at each restraint can be calculated according to the following formula:

(Conversely, this is also the force required to "stretch" the pressurized pipe back to its original length)

$$F = \frac{E\ A_o\ \Delta L}{1000\ L_o} \qquad (49)$$

Where, F = force to resist change in length (kN)
E = elastic modulus (MPa)
A_o = cross sectional area of pipe (m2)
Δ L = change in pipe length (m)
L_o = original length of pipe (m)

THERMAL EXPANSION AND CONTRACTION

Longitudinal Strain

The expansion of pipes due to a temperature change depends on the start and final temperature (ΔT) of the pipe and the expansion coefficient of the piping material at the actual temperature. The general expansion formula for unrestrained pipe can be expressed as:

$$\Delta L = L_o\ .\ H.\ \Delta T \qquad (50)$$

Where, ΔL = change in pipe length (m)
L_O = original, unrestrained pipe length (m)
H = thermal expansion coefficient
(i.e. 120 x 10-6 m/m ˚C for PE 100)
ΔT = change in temperature (˚C)

Technical contributions received from Royal HaskoningDHV

RELATIONSHIP BETWEEN PRESSURE & STIFFNESS CLASSIFICATION OF PLASTIC PIPES

For a pipe of homogeneous material, such as thermoplastic, steel, or non-reinforced concrete, the structural properties can be determined from the pipe's dimensions and the material properties. For thermoplastics, the commonly used dimensional parameter is the SDR, which describes the relationship between diameter and wall thickness. With this ratio the pressure rating (PN) and the pipe stiffness (SN) can be determined.

For other materials this is referred to as the D/t ratio. In the case of pipes made from composite materials, such as GRP, reinforced concrete, or profiled wall PE pipes (where the stiffness is enhanced by adding reinforcement) the determination of the structural properties is more complex, as the quantities of the various materials and the dimensional ratios are adjusted to meet specific requirements.

For all pipe materials it is convenient to determine the actual structural performance by testing the pipes. These test results, together with the pipe/structure system properties plus design factors, can be used to model the installed conditions.

For thermoplastics such as PE, PP, and PVC, when the SDR and the material properties are given it is a simple process to switch from the pressure rating to the pipe stiffness. It is essential that the significance of this is understood, because the structural properties of a pipe required for a pressure pipeline and those required for a gravity pipeline are different. In addition to this, the installation method may require a different set of structural properties from those required during operation. With open trench installation the dominant loading during operation will far exceed that during installation; whereas with trenchless installations the pushing or pulling stresses developed during installation may exceed those during operation. With the latter situation the relationship between the structural properties and time also needs consideration.

The nominal pressure (PN) is the maximum continuous operating pressure to which a pipe can be subjected to at 20 ^{0}C, expressed in bars. The PN is obtained by rounding up the actual maximum operating pressure to a standard pressure class.

When dealing with internal pressure the structural parameter of significance is stress in the pipe wall, given in MPa. The relationship between pressure rating and the physical dimensions of a pipe given by Barlow's formula can be expressed in different forms:

$$t = \frac{PD}{2\delta + PD} \text{ (a)} \quad \text{or } \delta = \frac{P(D-t)}{2t} \text{ (b)} \quad \text{or } P = \frac{2\,\delta}{DR-1} \text{ (c)} \quad \textbf{(51)}$$

Where t is wall thickness in mm
P is internal pressure in MPa
D is mean outside diameter in mm
δ is hoop stress across pipe wall in MPa
DR is dimension ratio (note that
pipes are designated by their SDR)

PN is given in bar and relates to standard values of P and must be greater than or equal to P and is given by:

$$PN \geq \frac{2\delta}{SDR-1} \qquad \textbf{(52)}$$

Where P is internal pressure given in bar (note that
operating pressure is frequently given in MPa)
PN is nominal pressure given in bar

The dimension ratio (DR) defines a constant ratio between the outer diameter and the wall thickness of a pipe providing a convenient and simple way of expressing or specifying pipe dimensions so that the structural properties are constant regardless of the pipe diameter. The standard dimension ratios (SDR) are based on an established series of numbers, which are similar to, but not necessarily exactly equal to the DR numbers. It is hence more convenient to use SDR rather than DR when classifying pipes. The SDR together with the actual material properties is used to determine the structural properties of a pipe made from a given material.

The nominal stiffness (SN) is a convenient rounded number giving the minimum pipe ring stiffness (PRS) of a pipe or pipe fitting expressed in kN/m/m.

The PRS together with other parameters is used to determine what external load the pipe can handle. When dealing with external loads on flexible pipes the structural parameter of significance is strain, as distinct from stress. It is measured by pipe deflection under load which is dimensionless. The relationship between deflection, the physical properties of a pipe and the installed conditions is given by the Reclamation formula which can be expressed in different forms to give the vertical deflection of a flexible pipe:

$$\Delta y = \frac{\mathbf{T_f K_B \ y \ H}}{\mathbf{EI/R^3 + 0.061 \ F_d \ E'}} \qquad \text{(a)}$$

$$\Delta y = \frac{\mathbf{T_f KB \ y \ H}}{\mathbf{8EI/D^3 + 0.061 \ F_d}} \qquad \text{(b)}$$

$$\Delta y = \frac{\mathbf{T_f KB \ y \ H}}{\mathbf{8PRS + 0.061 \ F_d}} \qquad \text{(c)}$$

(53)

Where Δy is vertical deflection of pipe under load expressed as strain and is dimensionless

T_f is a dimensionless time lag factor, having a value between 1.5 and 3.0

K_B is bedding constant, having a value between 0.11 and 0.083

y is backfill density in kN/m^3

H is fill height over pipe in m

EI/R^3 is the pipe stiffness factor in kN/m/m

EI/D^3 is the pipe ring stiffness, PRS in kN/m/m

F_d is a dimensionless design factor having a value between 0.5 and 1.0

E' is the soil stiffness expressed in kN/m^2

Values of T_f, E', and F_d for various embedment materials and degrees of compaction are given in the Table below, condensed from Howard's publication and converted to metric units.

TABLE 3.4: GENERAL PROPERTIES OF EMBEDMENT MATERIALS

CLASSIFICATION OF EMBEDMENT	DEGREE OF EMBEDMENT COMPACTION			
	DUMPED	SLIGHT	MODERATE	HIGH
Compressible fine grained soils	There is no data available for soils with medium to high plasticity or significant organic content, and their use is not recommended			
Fine grained soils	E' = 0.35 Fd = 0.5 Tf * = 1.5	E' = 1.40 Fd = 0.5 Tf* = 2.0	E' = 2.80 Fd = 0.67 Tf* = 2.5	E' = 10.50 Fd = 0.75 Tf * = 2.5
Sandy or gravely fine grained soils	E' = 1.05 Fd = 0.5 Tf* = 1.5	E' = 2.80 Fd = 0.5 Tf * =2.0	E' = 7.00 Fd = 0.67 Tf * = 2.5	E' = 17.50 Fd = 0.75 Tf* = 2.5
Coarse - grained soils with fines	E' = 1.05 Fd = 0.5 Tf* = 1.5	E' = 2.80 Fd = 0.5 Tf * = 2.0	E' = 7.00 Fd = 0.67 Tf * = 2.5	E' = 17.50 Fd = 0.75 Tf * = 2.5
Clean coarse - grained soils	E' = 1.40 Fd = 0.67 Tf = 1.5	E' = 4.90 Fd = 0.67 Tf = 2.0	E' = 14.00 Fd = 0.75 Tf = 2.5	E' = 21.00 Fd = 1.0 Tf = 2.5
Crushed rock	E' = 7.00 Fd = 0.67 Tf = 2.0		E' = 21.00 Fd = 1.0 Tf = 3.0	

* This value should be doubled if this embedment can become saturated.

The degree of compaction is given in four categories that relate to percentage of standard Proctor, or relative density:

- Dumped – no compactive effort
- Slight – some effort, density < 85% standard Proctor, or < 40% relative density
- Moderate – intermediate effort, density ≥ 85% and < 95% standard Proctor, or ≥ 40% and < 70% relative density
- High –considerable effort, density ≥ 95% standard Proctor, or ≥ 70% relative density

It should be noted that the PRS used to designate the stiffness of the larger diameter pipes and pipe stiffness (PS) used to designate the stiffness of smaller diameter pipes, are not the same. Both are measures of pipe stiffness, but PRS is a calculated value whereas PS is a measured value given by subjecting a pipe to a parallel plate test. PRS is usually given in kN/m/m whereas PS is usually given in KPa. The relationship between PS and PRS is:

$$\mathbf{PS = 53.69\ PRS} \qquad \mathbf{(54)}$$

The relationship between PRS and SDR is:

$$\mathbf{PRS = \frac{EI}{D^2} = \frac{1000\ E}{12\ (SDR)^2}} \qquad \mathbf{(55)}$$

The symbols used are described above. Note that the PRS is given in kN/m/m, E (the modulus of elasticity) is given in MPa and SDR is dimensionless. The SN is obtained by rounding the PRS up to a standard value used to classify pipe stiffness.

The above indicates the usefulness of the SDR in obtaining both the PN and SN of a pipe so that the external load carrying capacity of a pressure pipeline and the allowable internal pressure of a gravity pipeline can be determined. As PN is a pressure in the pipe measured in bar and SN is a load on the pipe measured in kN/m/m, it is recommended that the conversion from the one to the other is preceded by first determining the SDR value of the pipe and then converting to the other.

PROPERTIES OF COMMONLY USED PLASTIC

TABLE 3.5: GENERAL PROPERTIES OF THERMOPLASTICS

Property	PE-HD	PP	PVC-U	PVC-M	PVC-O
GENERAL PROPERTIES					
Surface feel	Waxy	Waxy	Smooth	Smooth	Smooth
Usual colours	Black, Orange (Striped and/or co-extruded)	Ivory white, blue, green brown, terra cotta, grey	Blue, Sand, White	Blue, Sand, White Blue, Sand, White	
Sound when dropped	Clatter	Clatter	High clatter	High clatter	High clatter
Combustibility	Bright flame: Drips continue to burn while falling	Bright flame: Drips continue to burn while falling	Self Extinguishing	Self Extinguishing	Self Extinguishing
Odour of smoke after flame is extinguished	Like candles	Like resin	Pungent like hydrochloric acid	Pungent like hydrochloric acid	Pungent like hydrochloric acid
Nail test impression	Impression possible	Very slight impression possible	Impression not possible	Impression not possible	Impression not possible
Floats on water	Yes	Yes	No	No	No
Notch sensitivity	No	No	Yes	No	No
Method of joining	Thermal or mechanical welding and/or spigot or socket	Thermal or mechanical welding and/or spigot or socket	Solvent cement and/or thermal, chemical or mechanical welding and/or spigot or socket	Solvent cement and/or thermal, chemical or mechanical welding and/or spigot or socket	Solvent cement and/or thermal, chemical or mechanical welding and/or spigot or socket
PHYSICAL PROPERTIES					
Linear expansion mm/m/°C	0.2	0.15	0.07	0.07	0.07
Specific weight - kg/m^3	0.96 x 10^3	0.91 x 10^3	1.45 x 10^3	1.45 x 10^3	1.45 x 10^3
Specific heat - kcal/mh°C	0.4	0.42	0.23	0.23	0.23

Property	PE-HD	PP	PVC-U	PVC-M	PVC-O
Thermal conductivity - kcal/mh°C	0.40	0.19	0.14	0.14	0.14
Softening point ˚C	67	130-170	78-81	78-81	78-81
MECHANICAL PROPERTIES					
Young's modulus at 20°C - MPa (Short Term)	800 - 1100	800 - 1800	3300	3000	4000
Young's modulus at 20˚C - MPa (Long Term 50 years)	200-275	-	1500	1400	1800
Tensile yield at 20°C - MPa (Short Term)	23-26	23-31	52	48	75
Tensile yield at 20˚C - MPa (50 years extrapolated)	23-26	-	26	26	50
Elongation at break %	150	-	50	75	75
Poisson Ration	0.4	0.45	0.4	0.4	0.4

Note: The designer should check with the pipe supplier about the product and its properties.

CHAPTER 4:

MOST POPULAR PLASTIC PIPE MATERIALS

HIGH DENSITY POLYETHYLENE (PE-HD)

BASIC DESCRIPTION

POLYMERS

In the first generation of PE, the curve at 60°C and 80°C showed a knee before 10 000h, making it possible to calculate the co-ordinates of the knee at 20°C by extrapolation. They were generally stiff polymers of high density, but unsatisfactory slow crack growth resistance at 80°C. With the second (PE 80-1980) and third (PE 100-1990) generations of PE there is no longer a knee at 60°C and even at 80°C, with hardly any brittle failure before 10 000h.

Second generation polymer development resulted in improvements to the slow crack growth mechanism by increasing the chain branch content of the polymer. This resulted in a MDPE PE 80 pipe resin which had the added beneficial characteristic of flexibility, allowing long lengths of pipe to be coiled. This made it suitable for low cost installation.

The third generation resins were formed by new production technologies, in particular the manufacture of bi-modal polyethylene resins. The science of molecular design recognised that the placement of the co-monomer branches in a specific part of the molecular weight distribution could significantly retard the slow crack growth properties of a PE resin, without affecting the creep resistance performance. The increased strength and toughness of these resins allowed a new classification of PE resins to be developed: PE 100.

TABLE 4.1: SCR POLYMER CLASSIFICATION (MRS = MINIMUM REQUIRED STRENGTH)

Designation	Classification MRS (MPa)	Design Stress (MPa) Water
PE 100	10.0	8.0
PE 80	8.0	6.3

BENEFITS OF PE

- High impact strength
- Excellent corrosion resistance
- Very good chemical resistance
- Excellent abrasion resistance
- Chemically inert and unaffected by acidic soil conditions
- Biologically inert against micro organisms
- Can be fusion welded, ensuring absolutely leak free joints
- Very smooth bore and low friction loss and maintaining this smoothness throughout its useful life
- Low mass (about 1/8 of steel) and ease of handling
- High flexibility, enabling long lengths to be coiled
- Inherent resistance to effects of ground movement
- Non toxic and safe for drinking water
- Low installation cost and maintenance free
- Large range of sizes, from 16 – 2 000 mm
- Very suitable for rehabilitation of old pipelines through trenchless technologies

BENEFITS OF PE 100 VS PE 80

In the early 1990s, a new type of PE material was developed in Europe with higher hoop strength, giving rise to the PE 100 classification. These materials are sometimes termed bimodal or 3rd generation because of the two stage polymerisation process used to produce them. PE 100 materials produce stronger pipes, which are used for higher pressure operation in gas and water distribution systems.

A comparison of a 200 mm OD Pipe with water as fluid at 10 bar operating pressure is given in table 4.2.

TABLE 4.2: PE 100 VS PE 80 COMPARATIVE MATERIAL SAVING

Heading	Wall thickness	Mass (kg/m)	ID (mm)	Cross Sectional area (cm ^{2})
PE 80	14.7	8.63	169.6	226
PE 100	11.9	7.10	175.5	242

Comparative saving in mass 18% and increase in cross sectional area 7%.

A comparison of the installation costs of PE and steel are given in table 4.3.

TABLE 4.3: TYPICAL INSTALLED COST RATIO BETWEEN STEEL AND PE-HD (HIGH DENSITY POLYETHYLENE) PIPES IN RURAL AREAS

PE-HD Pipes

Diameter (mm)	80	100	150	200
Material	1.1	1.0	0.9	0.7
Laying	1.3	1.4	1.7	1.8
Trenching/ Finishing	1.2	1.2	1.2	1.2
Overall	1.21	1.21	1.22	1.14

Steel Pipes

Diameter (mm)	80	100	150	200
Material	1.1	1.0	0.9	0.7
Laying	1.3	1.4	1.7	1.8
Trenching/ Finishing	1.3	1.3	1.3	1.3
Overall	1.29	1.28	1.3	1.22

TABLE 4.4: COMPARISON OF 110 MM OD PIPE MADE WITH PE 80 AND PE 100

Polymer Grading	MRS MPa 50 yr 20° C	Design Coeff. For water 20° C	Max design stress MPa	Test stress MPa 165 hrs 80° C	Test stress MPa 20° C 100 hrs	Test stress MPa 80° C 1000 hrs	Notched hoop stress bar 80° C 500 hr	Minimum Wall Thickness mm *	PN Nominal Pressure Bar	SDR	Pipe series
PE 100	10	1.25	8.0	5.4	12.4	5.0	9.2	10.0	16	11	5
								8.1	12.5	13.6	6.3
								6.6	10	17	8
PE 80	8	1.25	6.3	4.5	10.0	4.0	8.0	10.0	12.5	11	5
								8.1	10	13.6	6.3
								6.6	8	17	8

COMMON APPLICATIONS

PE-HD for pressure pipe applications

Polyethylene was discovered by ICI in 1933 and its commercial relevance quickly recognised. Low Density Polyethylene (LDPE) started to be used for pipe applications in the early 1950s, but stress crack resistance was poor and thick walled pipe was required due to the relatively low strength of this material, equivalent to an MRS (Minimum Required Strength) of 3.2MPA, otherwise known as PE 32 resin.

In 1953, Karl Ziegler and Guilio Natta invented High Density Polyethylene. For their invention, they were jointly awarded the Nobel Peace Prize for Chemistry in 1963. PE-HD was first used as pipe material in 1955 and some of the first pipes ever produced and put on test in 1955 are still under pressure on LyondellBasell's test rig in Frankfurt, Germany. The first PE-HD resins were classified as PE 50 and PE 63.

PE-HD materials are characterized by higher hoop strength and stiffness when compared to LDPE.

However, these 1st generation PE-HD materials were prone to Slow Crack Growth (SCG) and were improved in the 1970s with the introduction of 2nd

generation PE-HD materials. Some of these materials were classified as PE 80 but were generally inferior in resistance to Slow Crack Growth and Rapid Crack Propagation (RCP). Most manufacturers are now phasing out these PE 80 PE-HD resins since there is no significant cost saving in manufacturing lower quality polymers, due to the natural progressing of manufacturing plants and modern technology.
Note: Resistance to RCP is an additional requirement for gas-pipes (not water pipes).

In the 1990s, a newer generation of materials was developed, with higher hoop strength and much improved resistance to RCP. These 3rd generation materials, referred to as PE 100 resins due to their MRS of 10MPa, are sometimes called bi-modal resins, since a two-stage polymerisation process is used to produce them.

Table 4.5 shows, in chronological order, how the hoop strength and subsequent classification of resins has improved since 1950.

TABLE 4.5

Date	Type	Classification
1950s	LDPE	PE 32/40
1955	PE-HD 1st generation	PE 50/63
1970s	PE-HD 2nd generation	PE 80
1990s	PE-HD 3rd generation	PE 100

Many manufacturers are now phasing out PE 80 PE-HD resins in favour of the newer PE 100 resins. Because of the higher hoop strength of PE 100 resin when compared to PE 80 resins, it is possible to produce pipes with a higher pressure rating or to reduce the wall thickness for any given pressure rating.

The examples in table 4.6 are for pipe with a pressure rating of 16 bar.

TABLE 4.6

Pipe diameter	Wall thickness with PE 80 resin (mm)	Wall thickness with PE 100 resin (mm)	Material saving
25mm	3.2	2.5	19%
110mm	13	10.5	17%
630mm	73.9	60.1	17%

The latest ISO4427 and ISO4437 standards, released in 2007, are the benchmark documents which effectively outline best practise for pipe resin characteristics and pipe manufacture. The new PE 100 resins have now effectively removed the risk of RCP, making them ideal for use in water and gas applications.

Some typical applications of PE pipes are listed below:

Water supply

PE pipes offer distinct advantages over other materials (e.g. steel, fibre cement, concrete, etc.) especially when used for water supply and in areas with a high water table, in which their installation is simplified by jointing outside the trench.

Some examples:

- Potable water reticulation
- Sewage works
- Water Works & Water Treatment Plants
- Slurry Pipe Systems

Furthermore, because of their flexibility and low weight, they are ideal for use in underwater environments in various applications, such as marine outfall sewers.

Mining (Surface and Underground)

PE pipes have yielded excellent results when used in mining applications. Owing to their high abrasion and corrosion resistance, UV stability, ease of handling and installation, and their high mechanical strength, they are ideal for:

- Tailings (slurries and effluents)
- Irrigating leaching piles
- Acid and alkaline solutions
- Concentrate pipelines (Reduction works and Drainage)
- Fire fighting installations below ground
- Drinking water pipelines
- Chilled water pipelines
- Compressed air pipelines
- Vacuum lines (Drum filter)

Agriculture/Irrigation

PE pipes have various uses in agriculture as non-permanent couplings allow rapid coupling and uncoupling. Because it is flexible, it can be coiled, which facilitates transport (50m, 100m or longer coils).

Some applications are:

- Spray irrigation (Acids, Ammonia, Brine, Carbon Dioxide, Sugar solutions, Syrups, Fertilizers, etc.)
- Water pipes

Fishing Industries

In the fishing industry, the use of PE pipes is increasing. Because of their light weight and ease of handling, toughness, UV stability, resistance to salt water and attack by marine organisms, they are ideal for these applications, amongst others:

- Salmon breeding cages
- Maritime discharge and suction (Abalone farms)
- Salt water

Chemical/Steel/Refineries

In the chemical industry, PE pipes have produced excellent results. Owing to their high resistance to corrosion, chemicals and abrasion, they are ideal for:

- Conveying acid and alkaline solutions
- Conveying chemical products (Bleach, Peroxides, Dye Liquors, Sulphide Water, Hot effluent)
- Conveying water under pressure
- Fire-fighting systems

General

PE pipe systems have been used successfully in many applications, both general as well as highly specialised, in industrial and civil sectors.
The most common applications are the following:

- Compressed air and air ventilation
- Protection of electrical and telephone cables
- High temperature liquids and gases
- Gas, petroleum and its derivatives
- Corrosive waste water, hot effluents
- Potable Water
- Pneumatic transport
- Drainage and Sub-Soil Drainage
- Dewatering

PE in Gas Distribution

The high replacement cost of corroded iron and steel mains led to the focus being shifted to Plastics in the 50s. Many types of plastics were considered and tested for gas distribution, and by the end of the 60s it was concluded that polyethylene offered the best answers to the important aspects of:

- SANS/ISO 4437 4p to 10 bar
- Ductility
- Injection moulded fittings
- Jointing by fusion
- Environmental stress crack resistance
- Resistance to Rapid crack propagation (RCP)

Gas pipe operating pressures are classified as follows:

- Low pressure up to 100 mbar
- Medium pressure up to 4 bar
- Intermediate pressure 5 to 19 bar
- High pressure 50 to 70 bar

High pressure lines make use of polyethylene coated steel pipes with cathodic protection. For distribution systems up to 10 bar, polyethylene is the most suitable material, technically as well as economically. Even for 200mm pipes polyethylene represents a 15% cost saving on the installed system (European basis). Over 90% of the pipe installed for natural gas distribution in the U.S. and Canada is plastic, and of that 99% is polyethylene. For this application PE is the material of choice worldwide.

TABLE 4.7: PE 100 (ORANGE) PIPE, SANS/ISO 4437 FOR SUPPLY OF GASEOUS FUELS

Nominal Outside diameter D (mm)	Permitted Ovality[c]		Standard Dimension Ratio[a]																				
			SDR 9			SDR 11[b]			SDR 13.6			SDR 17[b]			SDR 17.6[c]			SDR 21			SDR 26		
			PN - Nominal Pressure (Bar)[b]																				
			PN 12,5			PN 10			PN 8			PN 6,3			PN 6			PN 5			PN 4		
	Straight	Coiled	e[e]	ID	kg/m	e[e]	ID	kg/m	e[e]	ID	kg/m	e[e]	ID	kg/m	e[e]	ID	kg/m	e[e]	ID	kg/m	e[e]	ID	kg/m
16	1.2	1.2	3.0	9.8	0.1	2.3[d]	11.2	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	1.2	1.2	3.0	13.8	0.2	2.3[d]	15.2	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	1.2	1.5	3.0	18.8	0.2	2.3[d]	20.2	0.2	2.3[d]	20.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-
32	1.3	2	3.6	24.6	0.3	3.0	25.8	0.3	2.4[d]	27.0	0.2	2.3[d]	27.2	0.2	2.3[d]	27.2	0.2	-	-	-	-	-	-
40	1.4	2.4	4.5	30.7	0.5	3.7	32.4	0.4	3.0	33.8	0.3	2.4[d]	35.0	0.3	2.3[d]	35.2	0.3	2.3[d]	35.2	0.3	-	-	-
50	1.4	3	5.6	38.5	0.8	4.6	40.5	0.6	3.7	42.4	0.5	3.0	43.8	0.4	2.9[d]	44.0	0.4	2.4[d]	45.0	0.4	2.3[d]	45.2	0.3
63	1.5	3.8	7.1	48.4	1.2	5.8	51.1	1.0	4.7	53.3	0.8	3.8	55.2	0.7	3.6	55.6	0.7	3.0	56.8	0.6	2.5[d]	57.8	0.5
75	1.6	4.4	8.4	57.7	1.7	6.8	61.0	1.4	5.6	63.5	1.2	4.5	65.7	1.0	4.3	66.1	0.9	3.6	67.6	0.8	2.9[d]	69.0	0.7
90	1.8	5	10.1	69.2	2.5	8.2	73.1	2.1	6.7	76.2	1.7	5.4	78.9	1.4	5.2	79.3	1.4	4.3	81.1	1.1	3.5	82.8	0.9
110	2.2	6	12.3	84.7	3.7	10.0	89.5	3.1	8.1	93.3	2.6	6.6	96.4	2.1	6.3	97.0	2.0	5.3	99.1	1.7	4.2	101.3	1.4
125	2.5	-	14.0	96.3	4.8	11.4	101.6	4.0	9.2	106.1	3.3	7.4	109.8	2.7	7.1	110.4	2.6	6.0	112.7	2.2	4.8	115.1	1.8
140	2.8	-	15.7	107.8	6.0	12.7	113.9	5.0	10.3	118.8	4.1	8.3	122.9	3.4	8.0	123.6	3.3	6.7	126.2	2.8	5.4	128.9	2.3
160	3.2	-	17.9	123.3	7.8	14.6	130.0	6.5	11.8	135.8	5.4	9.5	140.5	4.4	9.1	141.3	4.2	7.7	144.2	3.6	6.2	147.2	3.0
180	3.6	-	20.1	138.7	9.9	16.4	146.3	8.3	13.3	152.7	6.8	10.7	158.0	5.6	10.3	158.8	5.4	8.6	162.3	4.6	6.9	165.8	3.7
200	4	-	22.4	154.0	12.3	18.2	162.6	10.2	14.7	169.8	8.4	11.9	175.6	6.9	11.4	176.6	6.6	9.6	180.3	5.7	7.7	184.2	4.6
225	4.5	-	25.2	173.3	15.5	20.5	182.9	12.9	16.6	190.9	10.7	13.4	197.5	8.8	12.8	198.7	8.4	10.8	202.8	7.1	8.6	207.3	5.8
250	5	-	27.9	192.8	19.1	22.7	203.4	15.9	18.4	212.2	13.1	14.8	219.6	10.7	14.2	220.8	10.3	11.9	225.6	8.7	9.6	230.3	7.1
280	9.8	-	31.3	215.8	24.0	25.4	227.9	19.9	20.6	237.7	16.5	16.6	245.9	13.5	15.9	247.4	13.0	13.4	252.5	11.0	10.7	258.0	8.9
315	11.1	-	35.2	242.8	30.3	28.6	256.3	25.2	23.2	267.4	20.9	18.7	276.6	17.1	17.9	278.3	16.4	15.0	284.2	13.9	12.1	290.1	11.3
355	12.5	-	39.7	273.6	38.5	32.2	288.9	32.0	26.1	301.4	26.5	21.1	311.7	21.7	20.2	313.5	20.9	16.9	320.3	17.6	13.6	327.1	14.3
400	14	-	44.7	308.3	48.9	36.4	325.3	40.8	29.4	339.7	33.6	23.7	351.4	27.5	22.8	353.2	26.5	19.1	360.8	22.5	15.3	368.6	18.2
450	15.6	-	50.3	346.8	61.9	40.9	366.1	51.5	33.1	382.1	42.5	26.7	395.2	34.8	25.6	397.5	33.5	21.5	405.9	28.4	17.2	414.7	23.0
500	17.5	-	55.8	385.6	76.3	45.5	406.7	63.7	36.8	424.5	52.5	29.7	439.1	43.1	28.4	441.7	41.3	23.9	451.0	35.1	19.1	460.8	28.4
560	19.6	-	-	-	-	50.9	455.6	79.8	41.2	475.5	65.9	33.2	491.9	53.9	31.9	494.6	51.9	26.7	505.2	43.9	21.4	516.1	35.6
630	22.1	-	-	-	-	57.3	512.5	101.0	46.3	535.0	83.3	37.4	553.3	68.3	35.8	556.6	65.6	30.0	568.5	55.5	24.1	580.5	45.1

NOTES:

a) The standard dimensions ration SDR corresponds to the quotient between the outside diameter and the wall thickness of the pipe. It is non-dimensional

b) The nominal pressure PN corresponds to the maximum permissible operating pressure of the pipe at 20°C in bar.

c) Measurement of out-of-roundness shall be made at the point of manufacturing. If other values for the out-of-roundness than those given in Table 4.7 are necessary (e.g. coiled pipes), they shall be agreed between the manufacturer and the end-user. Out of Roundness permitted as per SANS/ISO 11922-1. This table is based on the standards SANS/ISO 4437 and SANS/ISO 4065/SANS/ISO 161/1

d) Minimum wall thickness values greater than limits of 2.3 mm, 2.4 mm, 2.5 mm, and 2.9 mm can be imposed for practical reasons in accordance with national requirements. See manufacturer's technical files or national specifications for advice.

e) e = Minimum Wall Thickness in mm. The weights are calculated on the base of average diameter and thickness values, according to tolerance specified in the standard SANS/ISO 11922-1 and P=0.958g/cm3.

PROPERTIES OF PE 100

TABLE 4.8A: TYPICAL PHYSICAL PROPERTIES OF PE 100 (UNPROCESSED)

Physical Properties	Test method	Values	Unit
Density	ISO 1183	0.952	g/cm^3
Melt Flow Index (190°C/5Kg)	ISO 1133	0.30	g/10 min.
Vicat Softening Point (5Kg)	ISO 306	67	°C
Crystalline Melting Range	ISO 3146-85	130-133	°C

TABLE 4.8B: TYPICAL MECHANICAL PROPERTIES OF PE 100

Mechanical Properties	Test Method	Values	Unit
Shore D, Hardness	ISO 868	61	-
Tensile Yield	ISO 527	23-26	MPa
Ultimate Tensile	ISO 527	35	MPa
Ultimate Elongation	ISO 527	>600	%
Elastic Modulus	ISO 527	800-1100	MPa
Flexural Stress (3.5% Deflection)	ISO 178	19	MPa
Notched Impact (Charpy) acN 23°C	ISO 179	20	KJ/m^2
Notched Impact (Charpy) acN - 30°C	ISO 179	6	KJ/m^2
Thermal Stability 200°C	ISO 10837	>60	min.
Carbon Black Content	ASTM D 1603	2.0-2.5	%
Slow Crack Growth	ISO	>500	hrs

NOTE: It is important that designers and specifiers of plastic pipe are aware that the use of PE 80 polymers to manufacture plastic pipe has been discontinued. The information in this manual with regards to PE 80 pipe should only be used for reference and comparison purposes.

PE 80 pipe should not be specified. It is also important that designers are aware that there are some old generation PE 80 pipes which are still in operation even though the polymer of PE 80 pipe has been discontinued for this purpose by polymer suppliers.

PE 100 should be specified explicitly: no external regrind should under any circumstances be used by manufacturers of plastic pipe (which forms part of the SAPPMA membership requirements). It is important to only buy PE products from trustworthy manufacturers (preferably SAPPMA members) in order to avoid the possibility of introducing substandard quality pipes from manufacturers. There is always the possibility of manufacturers using old recycled PE 80 pipe to produce a new pipe which visually resembles a PE 100 pipe, but is in fact regrind PE 80 material. To avoid this possibility and discourage the production of sub-standard pipes, the designer should ensure that PE 100 pipe is specified explicitly and reference is made to the relevant SANS standard.

TABLE 4.9: SIGNIFICANCE OF MATERIAL PROPERTIES

Property	Effect
Ductility	Impact resistance; Resistance to rapid crack propagation (RCP)
Strength	Resistance to internal pressure
Stiffness	Resistance to loading
Flexibility	Deformation under stress
Chemical resistance (ESCR)	Resistance to slow crack growth

Abrasion Resistance of PE Materials

A number of tests have been devised to measure the abrasion resistance of different pipe materials. One of the most important was developed by Dr. Kirschmer, known as the Darmstadt Test (Kirschmer, 1966). The test specimen is a one metre length of pipe which is tilted back and forth with a frequency of 21.6 cycles per minute while containing an abrasive mixture of 46% by volume of quartz sand (with a particle size of 0-30 mm) in water. The resultant flow rate over the surface of the pipe is 0.36 m/s. As shown in Figure 4.1, abrasion can then be plotted for different materials as a function of the number of cycles. On the basis of these results, PE and PP pipe perform better than clay or GRP, and much better that concrete pipes.

While the Darmstadt Test provides a quick and easy comparison between different pipe materials, the conditions of these tests are a long way from the actual conditions for the transportation of mining slurries, where the velocities are much higher and in a single direction. Meldt reported on a series of tests carried out under much more realistic conditions which compared the abrasion performance of steel and PE pipes and bends (Meldt, 1982).

The 50mm pipes and bends were built into a pipeline, and a medium comprising of a mixture of quartz sand and water was circulated through the network at a velocity of 7 metres per second. The water/sand mixtures at 7 and 14% concentration were circulated continuously until the first hole appeared in the pipeline, and the results used to calculate an average wear rate. The results shown in Table 4.10 indicate that the abrasion rate of the steel pipes was approximately four times that of PE pipes. The greatest frictional wear took place at the bends, and the shallower the bend radius the longer the life of the system.

Practical experience in mining operations confirms these laboratory results, and in many mining operations many kilometres of PE pipe are used to transport slurries around the site. For higher pressure systems, lining the steel pipelines to extend the life of the system is becoming increasingly more popular.

Examples of test methods: The Darmstadt Test Method/Result

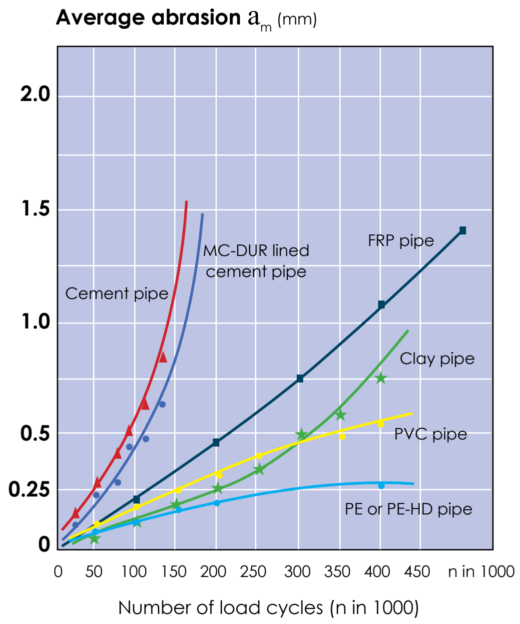


FIGURE 4.1: WEAR RATES FOR DIFFERENT PIPE MATERIALS AS MEASURED IN THE DARMSTADT TEST

TABLE 4.10: ABRASION RATES OF STEEL AND PE PIPES

Pipe Type	PE pipes		Steel pipes	
Sand (% by volume)	7	14	7	14
Abrasion rate (βm/h)	0.38	0.58	1.5	2.3

Note: 1 ßm = 0.001 mm

Mechanical Couplings In PE-HD Pipes

Mechanical couplings provide a non-permanent method of joining PE-HD pipes at pipe closures or repairs, where jointing by means of butt welding or electro fusion is not possible or practical. Mechanical joints must be of the tension resisting type (for reasons described below). Generally, mechanical joints can be dismantled or adjusted without completely destroying the pipe, although significant deformation of the pipe surface can occur which would require the damaged pieces of pipe to be cut off before attempting to remake the joint.

When PE-HD pipes are pressurised they expand radially but shorten axially (longitudinally) due to the Poisson Effect (as described in Chapter 3). The effect is compounded when the pipe shortens due to thermal contraction. The resulting changes in length and induced stresses in long, continuously welded PE-HD pipes can be significant, especially when there is little or no soil restraint, such as in pipe sleeves or in cracked pipes when "trenchless technology" is used to replace pipes.

If unrestrained mechanical joints are used (eg "VJ" and "long VJ" type couplings), cyclical changes in the pipe length can easily cause the rubber seals to become damaged or contaminated, and the joint will eventually leak and fail even if the pipe has passed the prescribed pressure tests. In extreme cases the pipes can pull out from the coupling completely.

Unless properly designed external restraints are used to provide positive anchorage for the pipes to be joined, specialist suppliers of pipes and fittings should be consulted for suitable jointing solutions.

SPECIFIC DESIGN CONSIDERATIONS

DESIGN FEATURES

PE 100 polymer pipe therefore provides the opportunity to choose either:

- Higher operating working pressure
- Thinner walls and therefore less material
- Higher safety margin
- Bigger cross sectional area and improved flow
- Good resistance to fatigue

Design Stress and Safety Factor (service coefficient)

Safety factors take into account handling conditions, service conditions, and other circumstances not directly considered in the design.

In terms of SANS/ISO 4427 the minimum safety factor for water is 1.25. This factor, when applied to the Minimum Required Strength (MRS), for the particular material classification (e.g. PE 80, PE 100), gives the maximum allowable hydrostatic design stress for the designated material as shown in table 4.1.

The relationship between the design stress dimmentions and pressure is given by Barlow's equation.

$$e = \frac{PD}{2\sigma + P}$$

or

$$\sigma_s = \frac{P\,(D-e)}{2e} \qquad (56)$$

Where: e - minimum wall thickness (mm)
P - internal pressure (MPa)
D - outside diameter (mm)
σ_s - design stress (MPa)

For example the minimum wall thickness for a 250 mm Class 10 PE pipe made from PE 80 material is:

$$e \;-\; 1.0 \times 250 \,/\, \{(2 \times 6.3) + 1.0\}$$

$$-\; 18.38\ \text{mm} \qquad (57)$$

Round up to 18.4 mm for manufacture and/or the appropriate SDR (Standard Dimenion Ratio = OD/e) for the Class and Material designation.

Minimum Required Strength (MRS) and Design Stress

The MRS (minimum required strength) classification of pipe is based on a 50 year life. This does not mean that the pipe will fail at 50 years, because the design stress is calculated using the 97.5% lower confidence limit of the predicted stress, coupled with a minimum safety factor of 1.25 (for water). Consequently when in service, the pipe is operating well below the stress that would cause a failure at 50 years and the actual failure time due to creep is likely to be only after hundreds of years.

SANS/ISO 4427-1 Table A1

For derating calculations, the average annual operating temperature, not the peak temperature, must be used.

MRS values usually assume an operating temperature of 20°C. The MRS value increases at lower temperatures and decreases at higher ones. Therefore, when designing pipelines for use at temperatures above 20°C, the correct MRS value must be used for the given operating temperature.

The design stress used to calculate standard pipe dimensions for a given pressure duty is obtained by dividing the MRS by a safety factor C (or design coefficient). The safety factor adopted by ISO from field experience is a minimum of 1,25 for water and 2,0 for gas.

The main criteria to select a good pipe material are:

- Strength
- Stiffness (or flexibility)
- Ductility (in toughness)
- Chemical resistance
- Resistance to fatigue
- Joint ability
- Suitability at the service temperature
- Resistance to thermo oxidative uv exposure
- Environmental stress crack resistance

All these properties are time-dependent, and therefore a compromise must be made on the basis of both short-term and long-term properties for a particular application as indicated hereafter:

The choice of polymer should be based upon the optimal balance of those properties.

External or internal pressures occurring at elevated temperatures can cause environmental stress cracking in polyethylene. This is essentially slow rate crack growth, and can be accelerated by a chemical environment other than air or water.

Environments that can accelerate crack growth are agents such as:

- Detergents
- Alcohols
- Silicone products

The Stress Regression Line

The traditional method of portraying the long term tensile strength is by means of a graph of log stress vs log time to failure. This is known as the stress regression line. It is a plot of the circumferential hoop stress in the wall of the pipe (from internal pressure) against time to failure.

Numerous test results are needed to determine both the classification of the resin and to ensure that no ductile- brittle "knee" is observed before 50 years at 20°C. Testing is performed over a range of pipe pressures and temperatures (typically 20°C, 60°C 80°C) with a minimum of 30 hoop stress results being obtained at each temperature. There must be at least four pipes that do not fail before 7 000 hours, and one that does not fail until after 9 000 hours.

The data produced can then be used to define the linear regression with the line extrapolated to 50 years at 20°C thus allowing the material classification to be determined (refer ISO 9080 & SANS/ISO 4437). ISO 4427 requires no brittle failure ("knee") before 5000 hours at 80°C.

The hoop stress is derived from Barlow's formula and is as follows:

$$e = \frac{PD}{2\sigma + P}$$

or

$$\sigma_s = \frac{P\,(D-e)}{2e} \qquad (58)$$

where: P - internal pressure (MPa)
e - minimum wall thickness (mm)
D - outside diameter (mm)
σ_s - circumferential hoop stress in wall of pipe (MPa)

The Stress Regression Line for PE is given below.

Refer to general explanation of regression lines - Fig 3.15 on page 61.

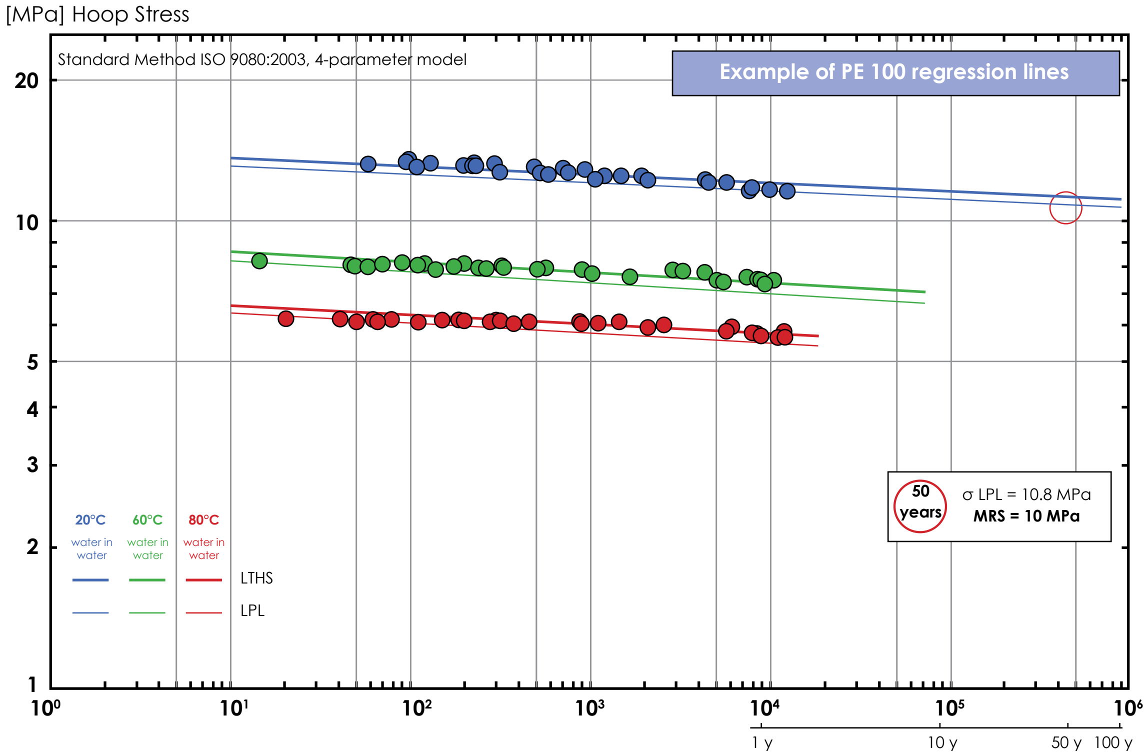


FIGURE 4.2: REGRESSION CURVE OF A MODERN PE 100 MATERIAL

Bending Limit

The minimum bending radius permitted for a pipe depends on its pressure class, the elastic modulus of the material, and its permissible stress, which in turn vary as a function of the applied load and the temperature.

The following table lists the values suggested for the minimum bending radii of Polyolefin pipes.

TABLE 4.11: BENDING RADII

SDR	Min. bending radius - PE
33	30D
26	25D
17	20D
11	20D
D = outside diameter of pipe	

JOINTING OF PIPES

Dimensions

In table 4.17 (page 87) it can be seen that SANS/ISO 4427 have grouped together the different pressure classes, produced from different material designations, under a common heading known as the Standard Diameter (Dimension) Ratio or SDR. The minimum wall thicknesses specified are not exactly that which would be derived from a calculation using Barlow's formula or SDR, but are the rounded up values of the highest minimum wall thickness calculated for any size and class in the SDR group.

Polyethylene Welding Processes

Butt Welding

There are five stages in the welding process, namely

- bead-forming (also known as adapting),
- heating (also known as soaking or pre-heating),
- changeover (also known as conversion),
- joining
- cooling.

These stages are represented in figure 4.3.

To ensure that the pipe walls remain at a constant ambient temperature, the open ends of the pipes may be closed off before welding to prevent airflow through the pipe, which could cause uneven temperatures and too rapid cooling of the weld.

Bead-forming

The heated tool, heated to the predetermined temperature, is inserted between the joint faces to be joined, and the joint faces are pressed against the heated tool under the force or pressure setting for bead-forming. The force or pressure is maintained until the full joint faces of the pipes are in contact with the heated tool and a bead is formed around the circumference of both pipe components at the contact face (see column 2 of table 4.12).

Heating or soaking

The welding pressure setting for heating is reduced to 0,01 N/mm2 during the heating or soaking period.

Changeover

After the heating or soaking time has expired, the joint faces are withdrawn from the heating tool, which is either swung out of the way or removed and placed in a holding bin. The heating plate shall be removed without damage to, or contamination of, the joint faces. The joint faces are then immediately pressed together. (See table 4.12 for changeover times, which must be kept to a minimum to prevent cooling of the molten plastics.)

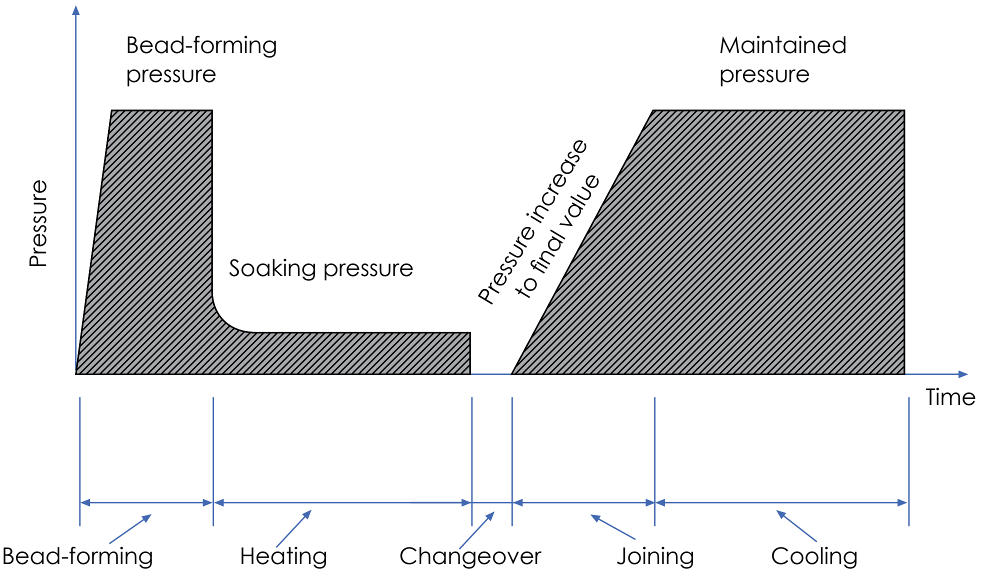


FIGURE 4.3: PRESSURE/TIME DIAGRAM AS PER SANS/ISO 10268-1- EDITION 1.3

TABLE 4.12: RECOMMENDED VALUES FOR THE HEATED-TOOL WELDING OF HIGH-DENSITY POLYETHYLENE (PE-HD), DETERMINED AT AN AMBIENT TEMPERATURE OF 20 °C AND AT MODERATE AIRFLOW

1	2	3	4	5	6
Nominal wall thickness mm	**Bead-forming $\rho = 0,15\ N/mm^2$ Height of bead prior to heating period (min. values) mm**	**Heating $\rho < 0,02\ N/mm^2$ Heating time s**	**Changeover**	**Joining $\rho = 0,15$ to $0,20\ N/mm^2$**	
			Maximum time s	**Time to complete pressure build-up s**	**Total cooling time while under joining pressure min**
Up to 4.5	0.5	45	5	5	6
4.5 to 7	1.0	45 to 70	5 to 6	5 to 6	6 to 10
7 to 12	1.5	70 to 120	6 to 8	6 to 8	10 to 16
12 to 19	2.0	120 to 190	8 to 10	8 to 11	16 to 24
19 to 26	2.5	190 to 260	10 to 12	11 to 14	24 to 32
26 to 37	3.0	260 to 370	12 to 16	14 to 19	32 to 45
37 to 50	3.5	370 to 500	16 to 20	19 to 25	45 to 60
50 to 70	4.0	500 to 700	20 to 25	20 to 35	60 to 80

For PE-HD, the heating time, in seconds, is approximately 10 times the wall thickness, in millimetres. NOTE Less than wall thickness 4.5 mm will result in an increase in the risk factor for weld failure and care should be taken with regard to the substance being carried by the completed installation. If the installation is to carry dangerous substances, other welding methods should be considered.

Reference: SANS 10268-1

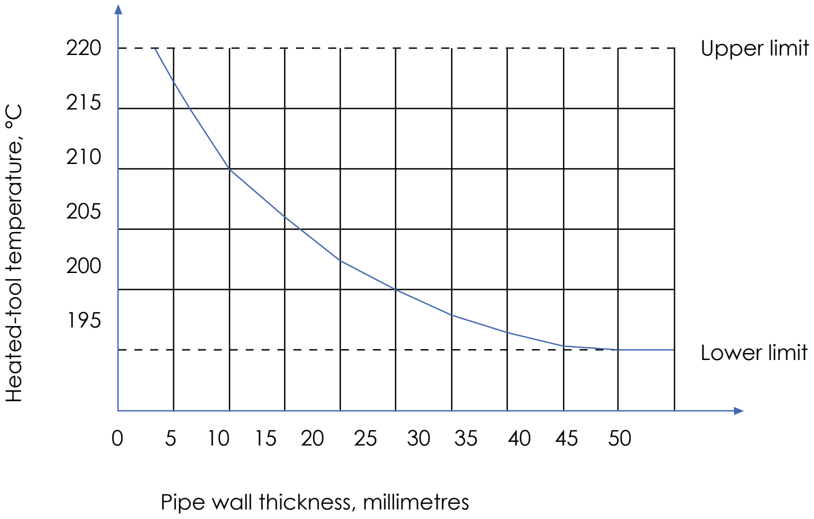


FIGURE 4.4: HEATED-TOOL TEMPERATURE AS A FUNCTION OF PIPE WALL THICKNESS FOR POLYETHYLENE (PE-HD)

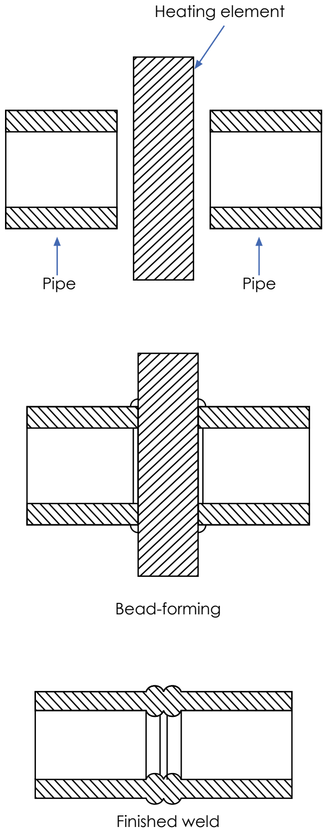


FIGURE 4.5: PRINCIPLE OF HEATED-TOOL BUTT WELDING AS PER SANS/ISO 10268-1 - EDITION 1.3

Joining

When the components to be welded have been brought into contact with each other, the joining force or pressure shall be continuously and evenly increased from zero to the final value indicated in table 4.12. This increase shall occur within the time frame indicated in the table that is used, and the final pressure shall be maintained until the weld has cooled. The bead will attain its final shape during this time. Fast cooling or the use of coolants will severely affect the weld quality, and are therefore forbidden. A uniform bead shall be present inside and outside the pipe at the joint as indicated in figure 4.5. In the case of larger pipes (wall thickness 20 mm or more), covering the weld zone during cooling to slow the cooling process will have a beneficial effect on the weld quality. Uneven bead formation might be caused by uneven flow behaviour of the materials being joined. The established height K (see figure 4.6) of the bead shall always exceed zero.

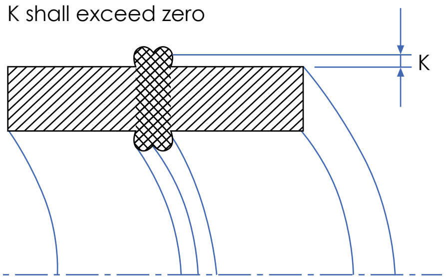


FIGURE 4.6 — BEAD FORMATION AS PER SANS/ ISO 10268-1 - EDITION 1.3

Testing and approval

For testing of the finished welds, see SANS/ISO 6269.
For approval of welders, see SANS/ISO 10269.
For approval of welding procedures, see SANS/ISO 10270.

ISO 21307 specifies a dual pressure and high pressure method.

Heated-Tool Socket Welding

Principle

Heated-tool socket welding is a variant of heated-tool butt welding, except that the heating tool is made up of a socket on one side and a spigot on the other. The pipe to be welded is inserted into the socket while the fitting is placed over the spigot. When heating has been completed, the heating tool is withdrawn and the two components are pushed one into the other and held under pressure until cool. This method of joining is used for semi-crystalline materials such as polyvinylidene fluoride (PVDF), polyethylene (PE), and polypropylene (PP). Manual welding may be undertaken with pipes of diameter up to and including 50 mm, but above this diameter a welding machine is required to obtain the necessary pressure to ensure a good joint. When large numbers of joints in the smaller diameters are required, production efficiency is increased if a welding machine is used. In heated-tool socket welding, the welding temperature is much higher than in heated-tool butt welding (between 250 °C and 270 °C), since no pre-heating takes place. The heating tool has to be treated with a non-stick coating such as PTFE to prevent adhesion to the molten plastics components. See ISO 8085-1 and ISO 8085-2 for the pipe-fitting specifications. Figure 4.6 illustrates the principle of heated-tool socket welding.

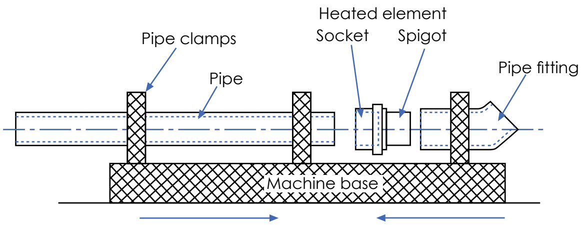


FIGURE 4.7: PRINCIPLE OF HEATED-TOOL SOCKET WELDING AS PER SANS/ISO 10268-1 - EDITION 1.3

The pipe components to be joined and the heating tool are first axially aligned, after which the pipe and the fitting are moved into and onto the heated tool and held there for the specified time in accordance with table 4.14 and 4.15 (depending on the material being welded). They are then withdrawn from the tool, which is rapidly moved out of the way. The pipe and fitting are then brought together and held under pressure for the specified time in accordance with table 4.14 and 4.15.

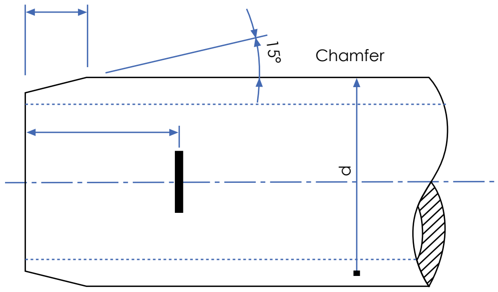


FIGURE 4.8: PIPE CHAMFERING AS PER SANS/ISO 10268-1 - EDITION 1.3

TABLE 4.13

Dimensions in millimetres

1	2	3	4
Pipe diameter d	**Pipe peeling diameter**	**Insertion depth l**	**Pipe chamfer b**
16	15.90 ± 0.05	13	2
20	19.90 ± 0.05	14	2
25	24.90 ± 0.05	15	2
32	31.90 ± 0.05	17	2
40	39.85 ± 0.10	18	2
50	49.85 ± 0.10	20	2
63	62.80 ± 0.15	26	3
75	74.80 ± 0.15	29	3
90	89.80 ± 0.15	32	3
110	109.75 ± 0.20	35	3

Execution of the Weld

Manual welding

The fitting is pushed onto the heated spigot and the pipe is inserted into the heated socket up to a mark previously made. The components are retained on the heating tool for the heating time specified in table 17 and 18 (depending on the material being welded).

After expiration of the heating time, the components are sharply withdrawn from the heating tool and, without any twisting motion, are pushed together up to the mark on the pipe. Table 4.14 and 4.15 (depending on the material being welded) give the maximum permissible changeover periods. The components shall be held in this position without any movement for the period indicated in table 4.14 and 4.15 (depending on the material being welded) to allow the joint to cool before stress loads can be applied. The end of the pipe shall not touch the shoulder inside the socket. A weld upset or bead shall be present over the entire circumference of the joint. If the bead is not present, the weld is not acceptable.

After every weld has been completed, the heating tool shall be allowed to cool to a safe temperature and shall be cleaned with cleaning solvent and lint-free paper.

Welding with a welding machine

The basic principles are the same as for manual welding, except that the components are held in clamping devices that can be moved in a horizontal direction to bring the components up to the heating tool, to withdraw them from the heating tool (which is then swung out of the way), and to press the pipe into the fitting once fusion temperature has been reached. Before welding starts, the axial alignment of the clamping devices shall be checked, and the movement stops that are set up to control the insertion depth of the pipe into the fitting shall also be checked. All other details concerning welding temperature, heating, changeover and cooling times are contained in table 4.14 and 4.15 (depending on the material being welded).

TABLE 4.14: RECOMMENDED VALUES FOR HEATED TOOL SOCKET WELDING POLYPROPYLENE PIPES AS PER SANS/ISO 10268-1 - EDITION 1.3

1	2	3	4	5
Outside Pipe Diameter mm	Minimum pipe wall thickness mm	Heating time s	Changeover time (maximum) s	Cooling Time min.
15	2.0	5	4	2
20	2.5	5	4	2
25	2.7	7	4	2
32	3.0	8	6	4
40	3.7	12	6	4
50	4.6	18	6	4
63	3.6	24	8	6
75	4.3	30	8	6
90	5.1	40	8	6
110	6.3	50	10	8

TABLE 4.15: RECOMMENDED VALUES FOR HEATED TOOL SOCKET WELDING HIGH-DENSITY POLYETHYLENE (PE-HD)

1	2		3	5	6
Outside pipe diameter mm	Heating time s		Changeover time (maximum) s	Joining and Cooling Times	
	For PN10 SDR 11[a]	For PN 6 SDR 17,666[a]		Joining s	Cooling Time mm
16	5	–	4	6	2
20	5	–	4	6	2
25	7	[b]	4	10	2
32	8	[b]	6	10	4
40	12	[b]	6	20	4
50	12	[b]	6	20	4
63	24	[b]	8	30	6
75	30	15	8	30	6
90	40	22	8	40	6
110	50	30	10	50	8
125	60	35	10	60	8

[a] Standard dimension ratio of nominal diameter to wall thickness.
[b] Not recommended because of insufficient wall thickness.

Destructive Test

Procedure

Unless otherwise agreed upon or specified in the terms of delivery for the product to be tested, the test shall be carried out at an ambient temperature of 23°C ± 2 °C. The test specimen and testing equipment shall be set up as shown in figure 4.9.

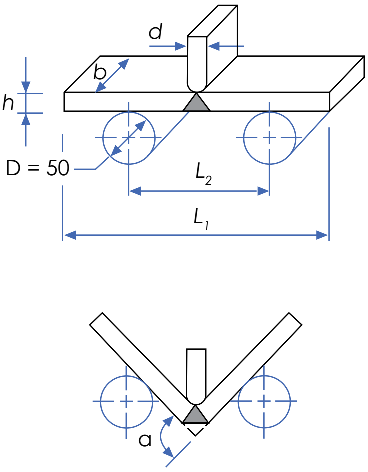


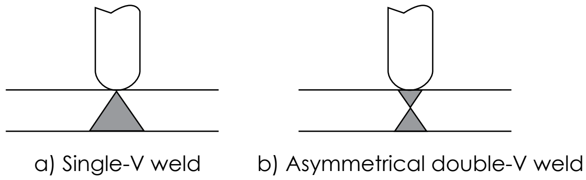
FIGURE 4.9: DIAGRAM OF THE MECHANICAL TEST

The speed of testing shall be in accordance with table 4.16.

TABLE 4.16: BENDING TEST SPEEDS FOR RELEVANT THERMOPLASTICS

1	2
Material	**Test speed mm/min**
PE-HD	50
PP, PVDF	20
PVC	10

The bending beam shall be applied at the centre of the weld. In the case of hot-gas welded single-V welds, the bending beam shall be applied to the weld root, whereas, in the case of asymmetrical double-V welds, the bending beam shall be applied to the shallower side of the weld (see figure 4.10).



a) Single-V weld

b) Asymmetrical double-V weld

FIGURE 4.10: BENDING BEAM POSITION

Start the bending process at the required test speed until fracture or crack initiation occurs, or up to an angle of 160°. Measure the bending angle as shown in figure 18, with the test piece under load.

The complete pressing-through of the test specimen between the supports corresponds to a bending angle of approximately 160°. If this is achieved without crack initiation, record the result as "≥ 160°".

NOTE If a better indication of the onset of cracking is required, a force-displacement curve may be recorded and evaluated.

If a maximum of two test specimens from a batch of five fail the test, two new substitute test specimens from the same test sample may be tested. No value shall then lie below the required minimum.

Reference to be made to SANS/ISO 10268 -1 Welding of thermoplastics - Welding Process Part1: Heated-tool welding.

Note: Plastics-SA can perform various bend tests on thermoplastic pipes to the clients on dedicated equipment supplied by SAPPMA.

Welder Training and Qualifications

Welders need to be trained by a recognised institution in one of the following welding processes:

Butt-welding (HS), socket fusion welding (HS), electro fusion welding (HM), hot-gas extrusion welding (WE).

Ensure the welder is trained for the process being specified. PlasticsSA (PSA)'s training courses are currently the only nationally recognised thermal welder training courses, and are registered through Merseta.

On successful completion of the training course the welder is tested in accordance with SANS/ISO 10269 – Testing and approval of welders. A typical certificate in figure 4.11 is issued, indicating the welding process the welder is found to be competent in. Welders that do not achieve a min. of 70% in the theoretical exam may only weld under supervision of a fully qualified welder. Beware that there are dubious characters out there who will fraudulently manipulate certificates; please check their legitimacy with PSA. IFPA members only make use of certified welders that have gained appropriate experience.

PLASTICS SA

Certificate

Accreditation Number 17-QA/ACC/0109/07

In compliance with the MERSETA Education and Training Quality Assurance

Justice Resmat Baloyi

ID Number 810405 6223 08 6

was found competent in the
outcomes of the following programme

Thermoplastic Welding
Hot Air Extrusion Welding (WE)

May weld under supervision only

Valid until 31 July 2011

which is aligned to specific unit standards of the
National Certificate in Thermoplastic Fabrication NQF Level 2 [24215]
with a total of 13 credits

Training Director – A N Hanekom

Learner No. PFSA103872

Regional Training Manager – M Subiah

July 2010

FIGURE 4.11: EXAMPLE OF WELDING CERTIFICATE

TABULATION OF DIMENSIONS

TABLE 4.17: PE-HD DIMENSIONS AND CLASSIFICATION

	Pipe series											
	SDR 6		SDR 7.4		SDR 9		SDR 11		SDR13,6		SDR 17	
	S 2.5		S 3.2		S 4		S 5		S 6.3		S 8	
	Nominal pressure (PN) [a] bar											
PE 80	PN 25		PN 20		PN 16		PN 12.5		PN 10		PN 8	
PE 100	-		PN 25		PN 20		PN 16		PN 12.5		PN 10	
Wall Thicknesses [b] mm												
Nominal size	^{e}min	^{e}max	^{e}min	^{e}max	^{e}min	^{e}max	^{e}min	^{e}max	^{e}min	^{e}max	^{e}min	^{e}max
16	3.0	3.4	2.3 [c]	2.7	2.0 [c]	2.3	-	-	-	-	-	-
20	3.4	3.9	3.0	3.4	2.3 [c]	2.7	2.0 [c]	2.3	-	-	-	-
25	4.2	6.0	3,5	4.0	3.0	3.4	2.3 [c]	2.7	2.0 [c]	2.3	-	-
32	5.4	6.1	4.4	5.0	3.6	4.1	3.0	3.4	2.4	2.8	2.0	2.3
40	6.7	7.5	5.5	6.2	4.5	5.1	3.7	4.2	3.0	3.5	2.4	2.8
50	8.3	9.3	6.9	7.7	5.6	6.3	4.6	5.2	3.7	4.2	3.0	3.4
63	10.5	11.7	8.6	9.6	7.1	8.0	5.8	6.5	4.7	5.3	3.8	4.3
75	12.5	13.9	10.3	11.5	8.4	9.4	6,8	7.6	5.6	6.3	4.5	5.1
90	15.0	16.7	12.3	13.7	10.1	11.3	8,2	9.2	6.7	7.5	5.4	6.1
110	18.3	20.3	15.1	16.8	12.3	13.7	10.0	11.1	8.1	9.1	6.6	7.4
125	20.8	23.0	17.1	19.0	14.0	15.1	11.4	12.7	9.2	10.3	7.4	8.3
140	23.3	25.8	19.2	21.3	15.7	17.4	12.7	14.1	10.3	11.5	8.3	9.3
160	26.6	29.4	21.9	24.2	17.9	19.8	14.6	16.2	11.8	13.1	9.5	10.6
180	29.9	33.0	24.6	27.2	20.1	22.3	16.4	18.2	13.3	14.8	10.7	11.9
200	33.2	36.7	27.4	30.3	22.4	24.8	18.2	20.2	14.7	16.3	11.9	13.2
225	37.4	41.3	30.8	34.0	25.2	27.9	20.5	22.7	16.6	18.4	13.4	14.9
250	41.5	45.8	34.2	37.8	27.9	30.8	22.7	25.1	18.4	20.4	14.8	16.4
280	46.5	51.3	38.3	42.3	31.3	34.6	25.4	28.1	20.6	22.8	16.6	18.4
315	52.3	57.7	43.1	47.6	35.2	38.9	28.6	31.6	23.2	25.7	18.7	20.7
355	59.0	65.0	48.5	53.5	39.7	43.8	32.2	35.6	26.1	28.9	21.1	23.4
400	-	-	54.7	60.3	44.7	49.3	36.3	40.1	29.4	32.5	23.7	26.2
450	-	-	61.5	67.8	50.3	55.5	40.9	45.1	33.1	36.6	26.7	29.5
500	-	-	-	-	55.8	61.5	45.4	50.1	36.8	40.6	29.7	32.8
560	-	-	-	-	62.5	68.9	50.8	56.0	41.2	45.5	33.2	36.7
630	-	-	-	-	70.3	77.5	57.2	63.1	46.3	51.1	37.4	41.3
710	-	-	-	-	79.3	87.4	64.5	71.1	52.2	57.6	42.1	46.6
800	-	-	-	-	89.3	98.4	72.6	80.0	58.8	64.8	47.4	52.3
900	-	-	-	-	-	-	81.7	90.0	66.2	73.0	53.3	58.8
1000	-	-	-	-	-	-	90.2	99.4	72.5	79.9	59.3	65.4
1200												

TABLE 4.17: PE-HD DIMENSIONS AND CLASSIFICATION CONTINUED

	Pipe series							
	SDR 21		SDR 26		SDR 33		SDR 41	
	S 10		S 12.5		S 16		S 20	
	Nominal pressure (PN) [a] bar							
PE 80	PN 6 [d]		PN 5		PN 4		PN 3,2	
PE 100	PN 8		PN 6 [c]		PN 5		PN 4	
Wall Thickness [b] mm								
Nominal size	^{e}min	^{e}max	^{e}min	^{e}max	^{e}min	^{e}max	^{e}min	^{e}max
16	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	_	-
25	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-
40	2.0 [c]	2.3	-	-	-	-	-	-
50	2.4	2.8	2.0	2.3	-	-	-	-
63	3.0	3.4	2.5	2.9	-	-	-	-
75	3.6	4.1	2.9	3.3	-	-	-	-
90	4.3	4.9	3.5	4.0	-	-	-	-
110	5.3	6.0	4.2	4.8	-	-	-	-
125	6.0	6.7	4.8	5.4	-	-	-	-
140	6.7	7.5	5.4	6.1	-	-	-	-
160	7.7	8.6	6.2	7.0	-	-	-	-
180	8.6	9.6	6.9	7.7	-	-	-	-
200	9.6	10.7	7.7	8.6	-	-	-	-
225	10.8	12.0	8.6	9.6	-	-	-	-
250	11.9	13.2	9.6	10.7	-	-	-	-
280	13.4	14.9	10.7	11.9	-	-	-	-
315	15.0	16.6	12.1	13.5	9.7	10.8	7.7	8.6
355	16.9	18.7	13.6	15.1	10.9	12.1	8.7	9.7
400	19.1	21.2	15.3	17.0	12.3	13.7	9.8	10.9
450	21.5	23.8	17.2	19.1	13.8	15.3	11.0	12.2
500	23.9	26.4	19.1	21.2	15.3	17.0	12.3	13.7
560	26.7	29.5	21.4	23.7	17.2	19.1	13.7	15.2
630	30.0	33.1	24.1	26.7	19.3	21.4	15.4	17.1
710	33.9	37.4	27.2	30.1	21.8	24.1	17.4	19.3
800	38.1	42.1	30.6	33.8	24.5	27.1	19.6	21.7
900	42.9	47.3	34.4	38.3	27.6	30.5	22.0	24.3
1000	47.7	52.6	38.2	42.2	30.6	33.5	24.5	27.1
1200	57.2	63.1	45.9	50.6	36.7	40.5	29.4	32.5

NOTE: 1 bar = 0,1 MPa = 105 Pa; 1 MPa = 1 N/mm^2

a PN is based on MRS divided by C (1.25)

b Tolerances in accordance with SANS/ISO 11922-1:1997, grade V, calculated form (0.1emin+0.1)mm rounded up to the next 0.1mm. For certain applications for e > 30 mm, ISO 11922-1:1997, grade T, tolerances may be used calculated from 0.15^{e}min rounded up to the next 0.1 mm.

c The calculated value of ^{e}min according to ISO 4065 is rounded up to the nearest value of either 2.0, 2.3 or 3.0. This is to satisfy certain national requirements. For practical reasons, a minimum wall thickness of 3.0 mm is recommended for electrofusion jointing and lining applications.

d Actual calculated values are 6.4 bar for PE 100 and 6.3 bar for PE 80.

e OD and ovality tolerance refer SANS/ISO 4427-2 Table 1.

TABULATION OF PIPE FITTINGS

Moulded vs Fabricated PE-HD Fittings

Fabricated or mitred and welded fittings are not as strong as moulded fittings, and have to be de-rated as such. The maximum allowable operating pressure of a pipeline must accordingly be derated if fabricated fittings are used, with de-rating factors varying between 0.6 to 0.9, depending on the type and geometry of the fitting and the welding process used.

Tee-junctions and elbows should ideally be injection or compression moulded, albeit moulded fittings are generally only available for diameters ranging between *DN 25 and DN 225.
**dependent on manufacturer*

Quality Control for Electrofusion Fittings on PE-HD Pipes

Electrofusion fittings are generally used in PE-HD pipes to produce convenient, strong and homogeneous joints at closures, repairs etc. Whilst it is easy to make successful joints, electrofusion fittings can easily fail unless excellent quality control and cleanliness is maintained throughout the jointing process. The following points address only the most common problems encountered with electrofusion fittings.

- Preparation and maintaining cleanliness of the surfaces to be joined is critical. Equipment must be calibrated, and preferably computer controlled, to ensure the correct fusion and cooling down periods for the particular class of pipe. If a print-out is provided, the record must be kept for QA purposes.
- The contact surfaces of the pipes must be visually inspected for defects, and the ends of the pipes to be joined must be cut square using proper pipe cutters.
- The surface of the pipe must be scraped (reamed) with a purpose-specific tool to remove surface oxidation.
- The fitting must only be removed from its plastic wrapping when it is ready to be fitted onto the prepared pipe ends so as to avoid contamination during handling outside and inside the trench.
- The reamed pipe ends and the inside surfaces of the fitting must not be touched to prevent contamination by oils, salts and acids that may be present on the skin. If necessary, a new pair of latex gloves should be worn for each installation to avoid contamination.

Before fusion commences, the pipe and the coupling must:

- provide a snug fit between pipe and fitting to ensure the required welding pressure is developed between the two components (if the fit is loose the melt pool will not form properly)
- be collinear, concentric, and not under any strain (e.g. at a bend)
- be free of all dust, dirt and oils, noting that no lubricants may be used even if the fit is tight
- be wiped with clean rags and an approved solvent such as isopropyl alcohol to remove any remaining traces of air-borne moisture, dirt, oil or salts
- be kept perfectly immobile until the melt pool has cooled and fusion is complete

MINIMAL DIMENSIONAL REQUIREMENTS FOR FITTINGS

These requirements are given on pages 94 - 102 that follows

FIGURE 4.12: STUB FLANGES

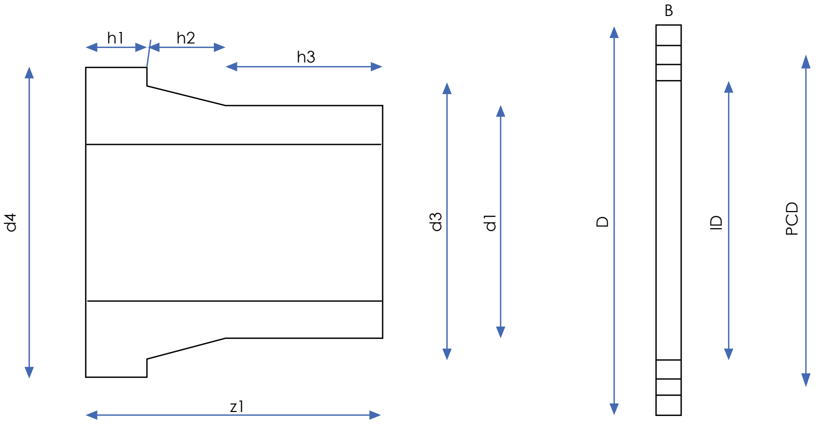


TABLE 4.18: STUB FLANGE DIMENSIONS

Pipe outside diameter d1	d3	d4	h1	h2	h3	z1	D
20	27	45	7	13	30	50	95
25*	33	56	9	13	28	50	105
32*	40	65	10	13	27	50	15
40*	50	73	11	15	24	50	140
50*	61	82	12	15	23	50	50
63*	75	98	14	20	16	50	165
75	89	110	16	20	14	50	185
90*	105	129	17	20	43	80	200
110	125	158	18	25	37	80	220
125	132	158	25	20	35	80	220
140	155	188	25	28	27	80	250
160	175	212	25	28	27	80	285
180	180	212	30	30	20	80	285
200	232	268	32	40	28	100	340
225	235	268	32	30	38	100	340
250	285	320	35	40	25	100	395
280	291	320	35	30	35	100	395
315	335	370	35	40	25	100	445
355	373	430	40	40	40	120	505
400	427	482	46	45	29	120	565
450*	514	540	60	60	10	120	670
500	530	585	60	50	10	120	670
560*	615	645	60	60	10	120	780
630	642	685	60	40	20	120	780
710	737	800	50	50	20	120	895
800	840	905	52	50	18	120	1015
900	944	1005	55	50	15	120	1115
1000	1047	1110	60	70	10	140	1230
1200	1245	1330	60	70	10	140	1455

**Note: On Stub Flanges sizes 25; 32; 40; 50; 63; 90; 450 & 560 OD dimension d4 is reduced to accommodate SANS/ ISO 1123 1000/3; 1600/3; BS10 Table D and ASA 150 Flanges.*

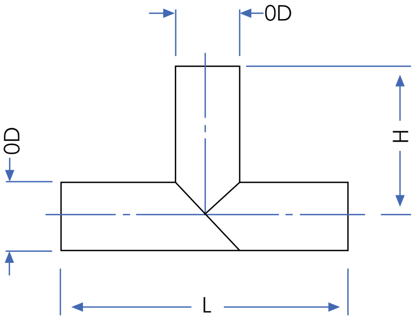
TABLE 4.19: DIMENSIONS OF STEEL FLANGES

BS4504 10/3 SANS/ISO 1123 1000/3						BS4504 16/3 SANS/ISO 1123 1600/3							
Dimensions						**Dimensions**					**No of bolts**	**Plastic to plastic**	**Plastic to steel**
OD	D	ID	B	PCD	No of Bolts	D	ID	B	PCD	No of Bolts	Bolt Size	SDR11 - SDR7.4	SDR11 - SDR7.4
20	95	30	10	65	4	95	30	10	65	4	M12	75	65
25	105	38	10	75	4	105	38	10	75	4	M12	75	65
32	115	45	10	85	4	115	45	10	85	4	M12	75	65
40	140	52	12	100	4	140	52	12	100	4	M16	100	75
50	150	63	12	110	4	150	63	12	110	4	M16	100	75
63	165	74	12	125	4	165	74	12	125	4	M16	100	75
75	185	86	12	145	4	185	86	12	145	4	M16	100	75
90	200	103	12	160	8	200	103	12	160	8	M16	100	75
110	220	136	15	180	8	220	136	15	180	8	M16	125	90
125	220	136	15	180	8	220	136	15	180	8	M16	125	90
140	250	158	15	210	8	260	158	16	210	8	M16	125	90
160	285	190	20	240	8	285	190	20	240	8	M16	180	125
180	285	190	20	240	8	285	190	20	240	8	M20	180	125
200	340	237	20	295	8	340	237	20	295	12	M20	180	125
225	340	237	20	295	8	340	237	20	295	12	M20	180	140
250	395	279	25	350	12	405	279	25	355	12	M20	230	165
280	395	292	25	350	12	405	292	25	355	12	M20	255	165
315	445	330	25	400	12	460	330	25	410	12	M20	255	164
355	505	376	25	460	16	520	376	25	470	16	M24	230	165
400	565	430	27	515	16	580	430	27	525	16	M24	255	165
450	615	476	30	565	20	640	476	30	585	20	M24/ M30*	255	180
500	670	533	30	620	20					20	M24/ M30*	230	180
560	730	592	36	675	20					20	M24/ M30*	230	180
630	835	662	36	780	20					20	M24/ M30*	230	200
710	895	737	40	840						24	M24	250	180
800	1.015	840	45	950						24	M30	280	210
900	1.115	942	50	1.050						28	M30	310	240
1000	1.230	1.045	55	1.060						28	M30	340	250

Fabricated Fittings (PE-HD & PP)

Pipe fittings such as segmented T-pieces, laterals and seamless bends can be manufactured from pipe in a wide variety of sizes and pressure classes, but mostly from 75 mm OD upwards and Class 6 or higher. Permissible working pressure is 50% of class of pipe used to fabricate fitting, e.g. 1000 kPa produces a 500 kPa fabricated fitting.

FIGURE 4.13: SEGMENTED T-PIECES



SANS/ISO 4427 - Pant 3 Fittings

TABLE 4.20: DIMENSIONS FOR SEGMENTED T-PIECES

OD	H	L
50	150	300
63	150	300
75	400	800
90	400	800
110	400	800
125	400	800
140	400	800
160	400	800
200	450	900
225	450	900
250	450	900
280	450	900
315	650	1300
355	650	1300
400	650	1300
450	850	1700
500	850	1700
560	900	1800
630	900	1800
710	1150	2300
800	1150	2300
900	1150	2300
1000	1150	2300

FIGURE 4.14: SEGMENTED LATERALS

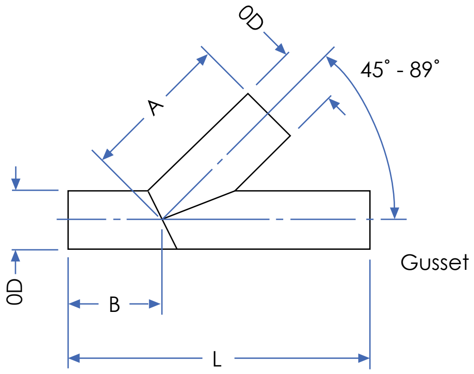


TABLE 4.21: DIMENSIONS FOR SEGMENTED LATERALS

OD	A	B	L
50	200	150	400
63	200	150	400
75	475	370	950
90	475	370	950
110	475	370	950
125	475	370	950
140	475	370	950
160	475	370	950
180	875	530	1350
200	875	530	1350
225	875	530	1350
250	875	530	1350
280	900	700	1800
315	900	700	1800
355	900	700	1800
400	900	700	1800
450	1100	870	2200
500	1100	870	2200
560	1200	950	2400
630	1200	950	2400
710	1500	1200	3000
800	1500	1200	3000
900	2000	1600	4000
1000	2000	1600	4000

Add permissible working pressure

FIGURE 4.15: SEGMENTED BENDS

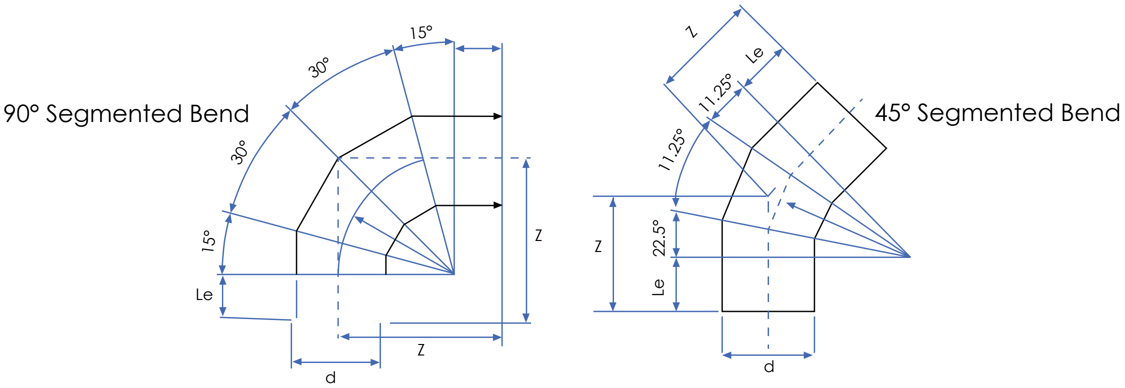


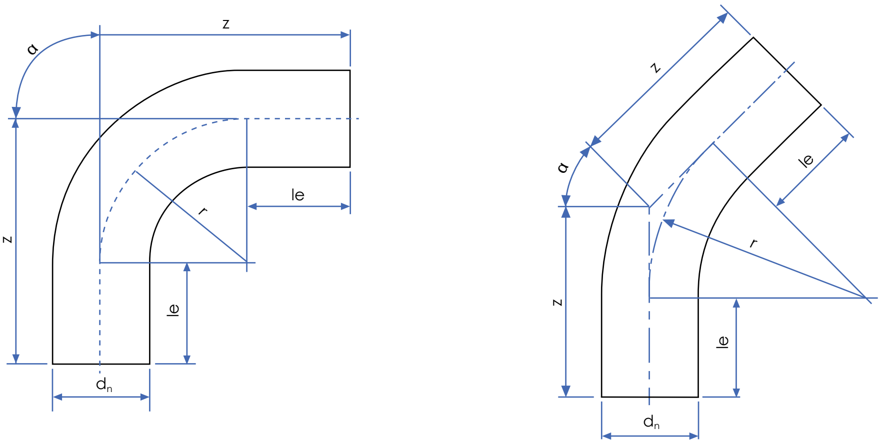
TABLE 4.22: DIMENSIONS FOR SEGMENTED BENDS

		PLAIN ENDED	
diameter (d)	**radius (r)**	**90°**	**45°**
		Z	Z
50	75	220	220
63	95	280	280
75	113	330	330
90	135	400	400
110	165	370	370
125	188	400	400
140	210	430	430
160	240	470	470
180	270	510	510
200	300	550	550
225	338	600	600
250	375	650	650
280	420	710	710
315	472	620	620
355	532	680	680
400	600	760	760
450	675	1300	900
500	750	1400	900
560	840	1150	950
630	945	1300	1100
710	1065	1450	1250
800	1200	1500	1300
900	1350	1700	1500
1000	1500	1800	1600

TABLE 4.23: DERATING FACTORS FOR SEGMENTED BENDS

Cut angle β	**Derating factor** f_B
$\leq 7.5^\circ$	1.0
$7.5^\circ < \beta \leq 15^\circ$	0.8

FIGURE 4.16: SEAMLESS BENDS



Fabricated fitting dimensions

TABLE 4.24: DIMENSIONS FOR SEAMLESS BENDS

Dimensions in millimetres

Nominal outside diameter d_n	Minimal tubular length of fitting $l_{e, min}$	Nominal bend radius r	Nominal branch length z	Nominal angle of fitting $α$
90	150	Declared by the fitting manufacturer e.g 1,5 x *d* 2 x *d* 2.5 x *d* 3 x *d*	Declared by the fitting manufacturer	Declared by the fitting manufacturer With a tolerance of +- 2° The maximum tolerance for pipe bends shall be +- 5°
110	150			
125	150			
140	150			
160	150			
180	150			
200	150			
225	150			
250	250			
280	250			
315	300			
355	300			
400	300			
450	300			
500	350			
560	350			
630	350			
710	350			
800	350			
900	400			

FIGURE 4.17: SEAMLESS LONG RADIUS BENDS PLAIN ENDED

RADIUS: 3 X OD OF PIPE

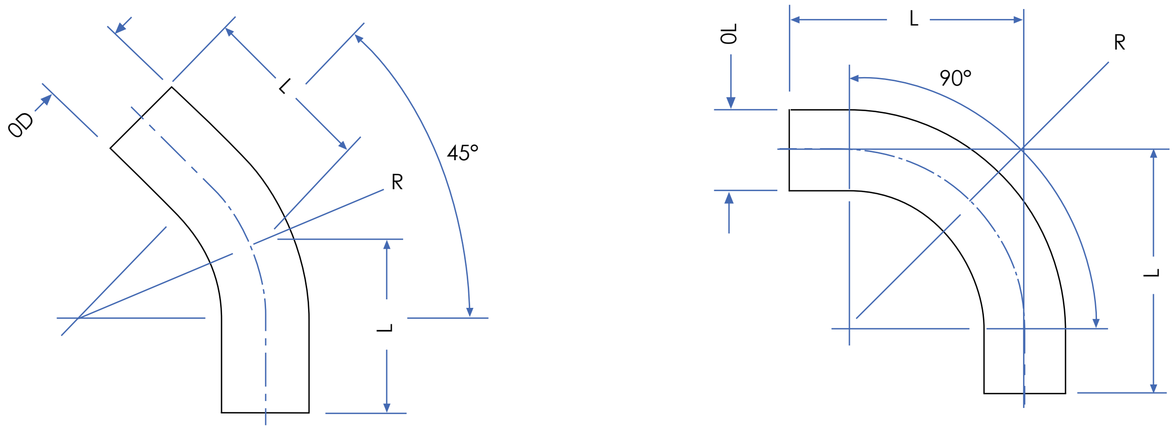


TABLE 4.25: DIMENSIONS FOR SEAMLESS LONG RADIUS BENDS PLAIN ENDED

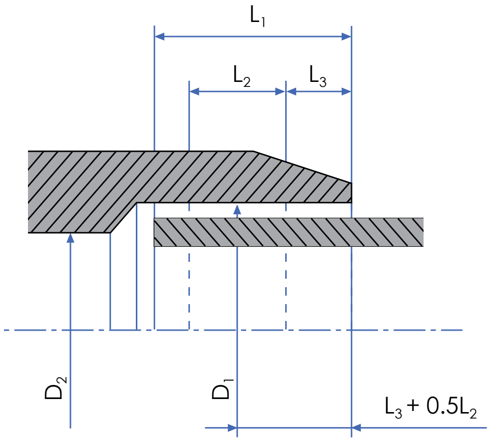
OD	**Radius**	**45˚** *L*	**90˚** *L*
110	330	345	535
125	375	360	580
140	420	380	625
160	480	405	685
180	540	430	745
200	600	455	805
225	675	485	880
250	750	515	955
280	840	555	1045
315	945	585	1150
355	1065	645	1270
400	1200	705	1405
450	1350	765	1555
500	1500	830	1705

The minimum wall thickness of the pipe bend after bending shall be in accordance with ISO 4427-2.

Destructive techniques may be used to demonstarte consistency of the manufacturing process.

For bends fabricated out of pipes, usually no derating factor applies.

FIGURE 4.18: ELECTROFUSION SOCKET DIMENSIONS



Key

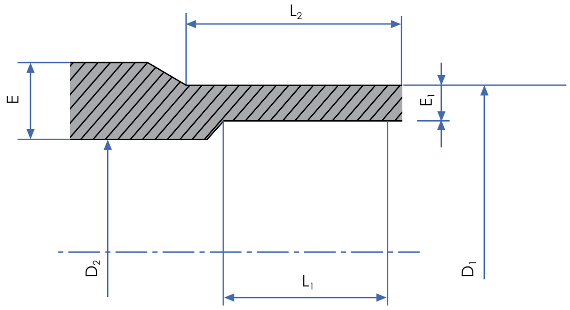
D_1	mean inside diameter in fusion zone [a]
D_2	bore that is minimum diameter of flow channel through body of fitting [b]
L_1	depth of penetration of pipe or male end of spigot fitting [c]
L_2	heated length within socket [d]
L_3	distance between mouth of fitting and start of fusion zone [e]
a	D_1 is measured in a plane parallel to the plane of the mouth at a distance of $L_3 + 0{,}5L_2$.
b	$D_2 > (d_n - 2e_{min})$.
c	In the case of a coupling without a stop, it is not greater than half the total length of the fitting.
d	As declared by the manufacturer to be the nominal length of the fusion zone.
e	As declared by the manufacturer to be the nominal unheated entrance length of the fitting. L_3 shall be > 5 mm.

TABLE 4.26: ELECTROFUSION SOCKET DIMENSIONS

Dimensions in millimetres

Nominal diameter of the fitting d_n	Depth of penetration			Fusion zone $l_{2.\,\min}$
	$l_{1.\,\min}$		$l_{1.\,\max}$	
	Intensity regulation	Voltage regulation		
20	20	25	41	10
25	20	25	41	10
32	20	25	44	10
40	20	25	49	10
50	20	28	55	10
63	23	31	63	11
75	25	35	70	12
90	28	40	79	13
110	32	53	82	15
125	35	58	87	16
140	38	62	92	18
160	42	68	98	20
180	46	74	105	21
200	50	80	112	23
225	55	88	120	26
250	73	95	129	33
280	81	104	139	35
315	89	115	150	39
355	99	127	164	42
400	110	140	179	47
450	122	155	195	51
500	135	170	212	56
560	147	188	235	61
630	161	209	255	67

FIGURE 4.19: SPIGOT DIMENSIONS



Key

D_1	mean outside diameter of fusion end piece [a]
D_2	bore comprising minimum diameter of flow channel through body of fitting [b]
E	body wall thickness of fitting [c]
E_1	fusion face wall thickness [d]
L_1	cut-back length of fusion end piece [e]
L_2	tubular length of fusion end piece [f]
[a] D_1	is measured in any plane parallel to the plane of the entrance face at a distance not greater than L_2 (tubular length) from the plane of the entrance face.
[b]	The measurement of this diameter does not include the fusion pad (if present).
[c]	It comprises the thickness measured at any point of the wall of the fitting.
[d]	It is measured at any point at a maximum distance of L_1 (cut back length) from the entrance face and shall be equal to the pipe wall thickness and tolerance to which it is intended to be butt fused, as specified in ISO 4427-2:2007, Table 2. E_1 for small dimensions is at least 3 mm.
[e]	It comprises the initial depth of the spigot end necessary for butt fusion or reweld and may be obtained by joining a length of pipe to the spigot end of the fitting provided the wall thickness of the pipe is equal to E_1 for its entire length.
[f]	It comprises the initial length of the fusion end piece and shall allow the following (in any combination): the use of clamps required in the case of butt fusion; assembly with an electrofusion fitting; assembly with a socket fusion fitting; the use of a mechanical scraper.

TABLE 4.27: SPIGOT DIMENSIONS

Dimensions in millimetres

Nominal outside diameter of spigot d_n	Mean outside diameter of fusion end [a]			Electrofusion [e]				Socket Fusion	Butt fusion			
	$D_{1.min}$	Grade A $D_{1.max}$	Grade B $D_{1.max}$	Out-of-roundness max.	Min.bore D_2	Cut-back length $L_{1.min}$	Tubular length $L_{2.min}$	Tubular length $L_{2.min}$	Out-of-roundness max.	Cut-back length $L_{1.min}$	Tubular length $L_{2.min}$ Normal [c]	Tubular length $L_{2.min}$ Special [d]
20	20.0	-	20.3	0.3	13	25	41	11	-	-	-	-
25	25.0	-	23.5	0.4	18	25	41	12.5	-	-	-	-
32	32.0	-	32.3	0.5	25	25	44	14.6	-	-	-	-
40	40,0	-	40.4	0,6	31	25	49	17	-	-	-	-
50	50.0	-	50.4	0.8	39	25	55	20	-	-	-	-
63	63.0	-	63.4	0.9	49	25	63	24	1.5	5	16	5
75	75.0	-	75.5	1.2	59	25	70	25	1.6	6	19	6
90	90.0	-	90.6	1.4	71	28	79	28	1.8	6	22	6
110	110.0	-	110.7	1.7	87	32	82	32	2.2	8	28	8
125	125.0	-	125.8	1.9	99	35	87	35	2.5	8	32	8
140	140.0	-	140.9	2.1	111	38	92	-	2.88	8	35	8
160	160.0	-	161.0	2.4	127	42	98	-	3.2	8	40	8
180	180.0	-	181.1	2.7	143	46	105	-	3.6	8	45	8
200	200.0	-	201.2	3.0	159	50	112	-	4.0	8	50	8
225	225.0	-	226.4	3.4	179	55	120	-	4.5	10	55	10
250	250.0	-	251.5	3.8	199	60	129	-	5.0	10	60	10
280	280.0	282.6	281.7	4.2	223	75	139	-	9.8	10	70	10
315	315.0	317.9	316.9	4.8	251	75	150	-	11.1	10	80	10
355	355.0	358.2	357.2	5.4	283	75	164	-	12.5	10	90	12
400	400.0	403.6	402.4	6.0	319	75	179	-	14.0	10	95	12
450	450.0	454.1	452.7	6.8	359	100	195	-	15.6	15	60	15
500	500.0	504.5	503.0	7.5	399	100	212	-	17.5	20	60	15
560	560.0	565.0	563.4	8.4	447	100	235	-	19.6	20	60	15
630	630.0	635.7	633.8	9.5	503	100	255	-	22.1	20	60	20

[a] Tolerance grades A and B are in accordance with ISO 11922-1:1997.

[b] The values of L_2 (electrofusion) are based on the following equations:

- for $d_n \leq 90$, $L_2 = 0.6d_n + 25$ mm;
- for $d_n \geq 110$, $L_2 = d_n/3 = 45$ mm.

[c] Used by preference.

[d] Used for fittings fabricated in the factory.

[e] Spigot fittings designed for electrofusion are also suitable for butt fusion.

STRUCTURED WALL HIGH DENSITY POLYETHYLENE (PE-HD)

BASIC DESCRIPTION

POLYMER FOR STRUCTURED WALL PE-HD

Only raw materials complying to SANS ISO 4427 raw material requirements are allowed for the manufacture of large diameter structured wall pipe.

COMMON APPLICATIONS

Storm Drainage

Structured wall PE-HD has become the pipe of choice for many of these drainage applications. Stormwater systems require a wide range of pipe sizes and cover requirements in both landscaped and parking areas.

Structured wall PE-HD is a durable and cost-effective pipe material for these on-site drainage facilities.

The pipe materials approved for drainage conveyance in public rights-of-way are determined by the jurisdiction responsible for maintenance of such facilities. HPDE has been used for highway and roadway drainage culverts and storm drainage systems for more than 20 years. Government Departments of Transportation, cities and municipal, have included PE-HD in their Departments' Standard Construction Specifications. Installations have included culverts under very high fills and under minimal cover.

Many installations have been monitored and have demonstrated satisfactory to exceptional performance. Concerns of insufficient strength, cracking, and deterioration over time have proven to be unwarranted.

Subsurface Drainage

Structured wall PE-HD pipe can also be produced with perforations. The perforations allow subsurface water to be collected and transplanted to favorable locations for discharge. Subdrainage systems are used to collect leachate under landfill sites.

FIGURE 4.20: STRUCTURED WALL HIGH DENSITY POLYETHYLENE

Subdrainage systems also are used to control and direct underground water transport and to encourage proper surface water percolation in golf courses, athletic fields, hillside development projects, and in agricultural fields. Often, subdrainage systems are used to lower the groundwater table. For athletic field development, subdrainage systems have been connected to air vacuum systems to encourage the downward movement of surface and subsurface water.

Structured wall PE-HD pipe is often used to control water levels in agricultural land. Perforated pipe is installed to collect and transport subsurface drainage and/or groundwater or to control the depth to groundwater.

Sanitary Sewers

PE-HD pipe is an ideal septic system leach pipeline material. One type of PE-HD pipe has been specifically designed with special perforations to allow percolation.

Leachate Collection

The mining industry has a special application of subdrainage that is ideal for structured wall PE-HD perforated pipe. A technique called heap leaching is used to recover low-grade deposits of copper, gold and silver. A cyanide solution sprayed over soil containing gold or silver converts the minerals to a chemical compound. The solution is collected in a perforated pipe subdrainage system and transported to ponds. The gold or silver is recovered from the ponds using carbon absorption or precipitation. PE-HD is well-suited to this process because it is highly resistant to chemical attack. Tests have shown little or no degradation of PE-HD with long-term exposure to a pH range from 1.5 to 14.0.

Detention/Retention Storm Water Management Systems

Current regulations in most areas limit the rate of storm water runoff as well as the level of pollutants allowed in discharged storm water.

Urbanisation of land can dramatically alter the natural movement of water. When runoff is transported away from critical areas, it can cause problems where recharge of aquifiers is necessary to maintain a steady groundwater supply. To counter these problems, storm water retention systems hold runoff until the surrounding soil can accept it via percolation, allowing aquifiers to be recharged. In other cases, the existing storm drainage trunk system is not designed to accept increased peak flow and the runoff must be retained until the peak flow has subsided.

Many jurisdictions require developers of projects to assure that downstream peak storm discharge flows remain the same after development.
Storm water retention and detention systems can be either above-ground ponds or subsurface piping. Ponds are the least prone to early siltation and clogging, but could present child safety and long-term aesthetic problems such as insect breeding, weed growth, odor and refuse control. Subsurface retention/detention systems use available land efficiently at a low maintenance cost, while presenting little or no public safety or aesthetic issue. Here underground storage facilities developed by placing several pipes in series are a common use of structured Wall PE-HD pipe.

Other Systems

Structured Wall PE-HD polyethylene pipe is used in a wide variety of other applications, several of which are described below. Contact the manufacturer for detailed information for these and other applications.

Roof Leader and Landscape Area Drainage

Residential, industrial and commercial buildings all have demand for roof leader and landscape area drainage facilities. Small diameter structured wall interior and exterior PE-HD is the most commonly used product available for these types of uses. The combination of flexibility, durability, and strength is not offered by other materials.

Ventilation Systems

Perforated structured wall PE-HD pipe has also become the product of choice for ventilation systems. Pipe placed in the bottom of grain storage bins introduces air via blowers to evaporate moisture from the grain piles. Another application utilises perforated PE-HD pipe to collect air from the discharge of an air scrubber for disbursement under a filter medium to remove contaminant particles.

Earth Cooling Tubes

Earth cooling tubes are a viable method for space cooling, and are being used as an alternative to conventional air conditioning. In these systems, warm air is moved through the cool earth via tubes, and subsequently used to achieve a cooling effect. Corrugated polyethylene tubing is particularly suited for this application because the corrugations provide a greater surface area for the heat transfer process to take place.

Floating Systems

PE-HD is resistant to corrosion and chemical attack. Those properties, along with its relative light weight, have allowed it to be used as a holding vessel for floats. Polystyrene-filled corrugated PE-HD pipe is used for floats in various applications.

A common use of these floats is as pontoons for floating boat docks. Various dock materials are easily attached to the corrugated PE-HD pontoons of any length to form the appropriately shaped floating dock. Similar floats also have been used to provide the support for polyurethane covers of liquid waste and chemical storage ponds.

Subsurface Irrigation and Drainage

Relining of Failed Pipes with structured wall PE-HD

Structured wall PE-HD pipe can be used as a structural liner inside failing culverts, storm drains, or sewers made of structured wall metal or concrete. The PE-HD pipe becomes the load-bearing structure after the annulus is filled with grout. Structured wall PE-HD pipe with a smooth interior must be inserted from a pit, or at the end of the existing culvert. The inserted PE-HD pipe will reduce the original inlet area. If the reduction is too drastic, a short, specially designed PE-HD taper may be attached to the inlet end to increase the inlet area.

Aeration in Sewer Sludge Composting

Perforated structured wall polyethylene pipe is an integral component when composting sewer sludge. The perforations allow controlled aeration of the sludge. Many communities have found that they can compost sewer sludge and market the finished compost.

FIGURE 4.21: STRUCTURED WALL PE-HD FLOATING SYSTEM

TYPICAL PHYSICAL PROPERTIES

PE-HD PIPE CHARACTERISTICS

PE-HD pipe is relatively lightweight, allowing for easier and less costly transportation and installation costs. It is not brittle and therefore not susceptible to cracking during pipe handling and installation activities. Once formed into a pipe, PE-HD has a smooth surface, which is resistant to abrasion, corrosion, and chemical scouring. The smooth surface provides excellent pipeline flow characteristics. PE-HD pipe is structurally strong and has the ability to support large loads.

PE-HD has the ability to relax under stress. This characteristic provides advantages for underground structures and also helps define limitations of use. As PE-HD pipe is loaded, the pipe relaxes over time, allowing the load to be transferred to the adjacent soil. This characteristic allows the pipe to off-load points of local stress. Stress relaxation may result in slight pipe reformation over time to accommodate in-place loading conditions. Such re-formations are believed to cause long-term structural stability.

Corrugated PE-HD is an excellent choice for gravity flow or low-head pipeline situations. The structural stability of corrugated PE-HD pipe is produced by three pipe designs. According to SANS/ISO 21138 1, 2 and 3, they are defined as:

- Type A – Circular cross section consisting of an essentially smooth inner wall joined to an essentially smooth outer wall with annular or spiral connecting elements.
- Type B – Full circular dual-wall cross section, with an outer corrugated pipe wall and a smooth inner liner.

Pipe with interior and exterior corrugated walls is available in 50mm through 160mm diameters. Interior and exterior corrugated pipes in smaller diameters are connected with separate snap-on connections with no gasket. In larger diameters, the connections are made with corrugated bands secured with plastic ties. Reference: SANS 61386-24 : 2005

An alternative to the interior and exterior corrugated walls will be a smooth inner wall. Each section is associated with specific structural properties and performance characteristics. Those characteristics are available from the manufacturer for use in load calculations.

Pipe manufacturers provide various pipe joining methods depending on the pipe style and project requirements. Coupling bands, with or without a gasket, wrap around the pipe and are secured with plastic ties. Gasketed bell and spigot joints are also widely used. Nonrated and nonpressure tested watertight joints are suitable for the majority of nonpressure (gravity flow) drainage applications, typically they do not experience significant leakage (if any), and may be air/or water tested as determined by the end user.

For environmental and other reasons, most manufacturers also have a pressure-rated watertight joint suited for nonpressure applications rated at 1 bar.

Although PE-HD pipe products are versatile, the primary use of structured wall PE-HD is for gravity flow water management. Examples of these water management systems include:

- storm drainage
- subsurface drainage
- sanitary sewers
- leachate collection
- detention/retention stormwater management systems
- bulk-outfall sewers

RIGID POLYVINYL CHLORIDE (PVC)

BASIC DESCRIPTION

COMPOSITION OF PVC PIPE MATERIAL

57% of PVC's feedstock is derived from salt. It is from salt (sodium chloride) that the chlorine in the PVC is derived. The balance of 43% of PVC's feedstock ethylene is derived from oil. Because of the lower dependence of PVC feedstock on oil, PVC is considered to be one of the least energy intensive thermoplastics, and PVC pipes therefore have lower embodied energies than alternate materials.

The pipe manufacturer's objective is to manufacture pipe within tight dimensional tolerances at high output rates while maintaining mechanical performance requirements. PVC polymers for pipe production are therefore manufactured to a high degree of consistency, with the emphasis on maintaining tight control of the key properties.
PVC processed as a pure polymer will decompose at the necessary processing temperatures needed for moulding or extrusion of PVC, and will be prohibitively viscous, hence the need for incorporation of other additives.

Additive Selection

There is a vast array of additives that can change the physical properties and costs of pure PVC. Certain additives are vital to process PVC, others lower the formulation cost. It can be both costly and detrimental to use more of an additive than is necessary to accomplish a desired effect.

Heat Stabilisers

The total energy input which a PVC product experiences includes the shear and heat energy of the mixing cycles, extrusion or moulding process, fabrication, reprocessing of scrap rework, together with the heat and light energy of outdoor exposure. In light of these conditions, a heat stabiliser functions in multiple ways: absorption of evolved hydrochloric acid, minimisation of double bond formation, free radical scavenging, deactivation of resin impurities, and degradation of formed byproducts.

Today the choice of Heat stabilisers is wide and includes lead-based systems, as well as tin, calcium zinc and organic stabilisers. SAPPMA has implemented the use of Heavy Metal Free stabilisers in 2006.

Lubricants

Lubricants act in different ways. The effect they have between resin particles before and after fusion can be characterised as acting as internal lubricants. Internal lubricants are generally compatible with the PVC resin, and lower the melt viscosity of the PVC melt. The lubricants that act between the polymer melt and the metal surfaces of the processing equipment are generally classified as external lubricants, and are incompatible with the PVC melt and consequently stop adhesion of the melt to the metal surfaces.

Impact Modifiers

Impact modifiers are added specifically to improve the impact strength, ductility, and toughness of the pipes manufactured. The fillers are added to absorb the energy within the crack in a rubber-like manner, to prevent further crack propagation. Sufficient work or shear must be achieved during processing to derive the optimum dispersion of the modifier to achieve the maximum benefit of the quantity used.

Fillers

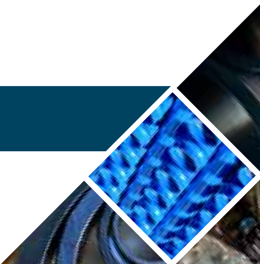
Fillers are generally used in rigid PVC pipe formulations as extenders for the purpose of reducing the formulation cost. They also raise the heat distortion temperature. Most commonly calcium carbonate is used. Consideration should be paid to the average particle size and the particle size distribution, as well as whether the filler is coated or not.

Pigments

Pigments are used to achieve the desired aesthetic effect and colour of the final product. Some types, such as titanium dioxide, contribute to improved UV resistance and improve the weathering properties of the final product.

Processing

Once the formulation has been compounded, it is essential that the material is processed with adequate shear and heat to derive the optimum level of gelation on the PVC. If this is done, the maximum physical properties of the formulation can be realised.



COMMON APPLICATIONS

Applications for PVC Pipe Systems

PVC pressure pipes are specified with confidence in the following applications:

- Water mains and reticulation systems
- Irrigation
- Mining
- Industrial applications
- Sewer effluent control and water purification

Sewer & Drainage Pipes – Gravity Sewers

Introduction

PVC is the preferred material for gravity sewers worldwide. PVC sewer pipes and fittings are practical and economical. Flexible pipes, like PVC, are regarded as having benefits over rigid pipes when it comes to load shedding. Although flexible pipes have higher deformation than rigid pipes, they have the following benefits:

- Yield under vertical soil load reduces the total soil load as more friction is transferred to the side of the trench.
- The pipe carries relatively less load than the side fill as it yields, i.e. it sheds load to the sidefill.
- The pipe deflects out laterally thereby activating soil support and creating an arching action.
- Yielding of plastics results in stress redistribution across a section, thereby utilising the entire section in load resistance.

PVC sewer pipes and fittings have smooth inner surfaces, which results in low frictional resistance in gravity sewers. Structured wall PVC sewer pipes offer high hoop stiffness and light weight.

PVC sewer fittings are available with either rubber seal sockets or solvent cement type sockets.

PVC has good UV stability which is enhanced by the addition of additives which improve UV resistance. As a result PVC soil, waste, and vent pipes and fittings are formulated for long term use in direct sunlight. PVC can also be painted for additional protection or aesthetic reasons.

PVC also has good resistance to a wide range of chemicals that commonly occur in gravity sewers. For more information on chemical resistance, please see the chemical resistance table in Appendix B.

TYPICAL PHYSICAL PROPERTIES

TABLE 4.28: TYPICAL PHYSICAL PROPERTIES OF PVC

Physical	Units	PVC-U	PVC-M	PVC-O
Co-efficient of linear expansion	K^{-1}	6×10^{-5}	6×10^{-5}	8 x 10-5
Density	kg/m^3	1.4×10^3	1.4×10^3	1.35 x 103 to 1.46 x 103
Flammability (oxygen index)	%	45	45	45
Shore hardness (D)		70 - 80	70 - 80	70 - 80
Softening point (Vicat - minimum)	°C	78 - 81	78 - 81	78 - 81
Specific heat	J/kg/K	1.0×10^3	1.0×10^3	1.0×10^3
Thermal conductivity (at 0°-50°C)	W/m/K	0.14	0.14	0.14
Mechanical				
Elastic Modulus (long term - 50 years)	MPa	1 500	1 400	1 800
Elastic Modulus (short term - 100 seconds)	MPa	3 300	3 000	4 000
Elongation at break	%	50	75	75
Poisson Ratio		0.4	0.4	0.4
Tensile strength (50 year - extrapolated)	MPa	26	26	50
Tensile strength (short-term)	MPa	52	48	75

Friction Factors				
Manning		0.008 - 0.009	0.008 - 0.009	0.008 - 0.009
Hazen Williams		150	150	150
Nikuradse roughness (k)	mm	0.03	0.03	0.03

Physical Properties

Polyvinyl Chloride (PVC) is a thermoplastic material and different formulations are used to obtain specific properties for different applications. Pipes can therefore be developed to meet the requirements of a wide variety of applications and conditions. The major part of each formulation is the PVC resin.

General (PVC-U, PVC-M, PVC-O)

The general properties given in table 25 are those for PVC formulations used in pipe manufacture. It should be noted that these properties are dependant on temperature and the duration of stress application.

PVC-U is unplasticized (Rigid) PVC and is the oldest PVC pipe technology.
PVC-M is modified PVC to provide improved ductility and impact resistance.

Biaxially oriented PVC (PVC-O) pressure pipes are produced by a special process where the molecules are stretched or oriented to provide significant increases in strength and toughness.

Properties of PVC-U , PVC-M and PVC-O

The PVC family of pipe materials comprises PVC-U , PVC-M and PVC-O pipe.

PVC-U (Unplasticised PVC) is a rigid pipe material that contains the original PVC polymer without the plasticising agents that make PVC flexible.

PVC-M (Modified PVC) is essentially an alloy of the PVC-U polymer and several modifying agents that improve ductility as well as resistance to impact and crack growth. These improved material characteristics allow for a thinner wall, larger internal diameter and increased hydraulic efficiency than PVC-U pipe of the same nominal diameter and pressure class.

PVC-O (Oriented PVC) has the same input materials as PVC-U , but undergoes a molecular orientation process during manufacturing which converts the amorphous polymer structure of PVC into a more ordered structure. The process requires specific conditions of temperature, pressure, stretching, and extrusion speed to align the molecules both longitudinally and circumferentially. PVC-O pipe is classified by pressure class and the degree of orientation achieved by the process. PVC-O 500 is currently (2013) the highest grade of orientation. Up until recently PVC-O have not been manufactured in South Africa. Since the second half of 2016 the production of PVC-O pipes has been ongoing in South Africa, and it does not have to be imported anymore.

The orientation process produces a higher material strength and higher allowable operating stress (better impact and crack resistance) than both PVC-U and PVC-M .

Table 4.29 (page 126) compares some pertinent information relating to u-, m- and PVC-O pipes.

Benefits

- Resistance to abrasion and scouring
- Resistance to attack by acid or alkaline soils
- Impervious to chemicals found in sewerage
- Good flow characteristics
- Not damaged by modern cleaning methods
- Good impact properties (an important factor in installation, transportation and operation)
- Durability and toughness: resistance to handling and installation damage
- Corrosion resistance: greater service life
- Inflamable: self extinguishing
- Lower mass: ease of handling and installation, particularly suited to labour-intensive projects
- Ease of repair
- Elastomeric, locked-in sealing ring system - no specialist installation skills required. No power required onsite during installation
- Service performance in excess of 100 years
- (Applicable to PVC pipes only, the joints have to be confirmed, appropriate factors and design coefficients should be applied)
- Unique combination of properties
    - Toughness
    - Stiffness
    - High Tensile and hoop strength
    - Excellent resistance of creep
- Predictable long-term behaviour
- Excellent strength/cost ratio

SPECIFIC DESIGN CONSIDERATIONS

Design Features

General

Once installed, PVC pressure pipes will operate efficiently under pressure, without failure or leakage, over long periods of time, while simultaneously preserving water quality.

Modified PVC (PVC-M) Pressure Pipes

PVC raw material formulations used for the manufacture of PVC pressure pipes result in specific and controllable mechanical properties. Pipes can therefore be engineered to cater for a wide variety of applications and conditions. In particular, the toughness of PVC-M pressure pipe is enhanced by the incorporation of impact modifying additives.

The enhanced toughness results in improved resistance to crack propagation and therefore enables the use of a higher design stress, which results in significantly reduced mass. The mass reduction and larger pipe bore brings about savings in energy consumed during manufacture and subsequent operation.

Biaxially Oriented (PVC-O) Pressure Pipes

The molecular orientation process is used in the manufacture of plastic products where increased strength is required. In the case of PVC-O pipes the process is one of biaxial orientation when the molecules are stretched (oriented) in both the circumferential (hoop) and axial (length) directions, and thus aligned to provide strength in both directions. A small diameter, thick-walled pipe is extruded and then stretched under controlled conditions of temperature and pressure to achieve optimum molecular orientation and improvement in strength in the two directions.

The increased resistance to internal pressure makes the product extremely well suited to pressure applications. Biaxial orientation also leads to marked increase in toughness properties.

It is this combination of strength and toughness which leads to the unique properties of PVC-O pipes. These properties provide:

- Material efficiency, giving lower pipe mass for easier handling and installation
- Higher flow capacity and lower pumping costs
- Resistance to damage during transport, handling and installation
- High resistance to crack propagation due to layered structure

- Very low wave celerity, thereby reducing water hammer.
- Energy efficiency due to material efficiency and improved flow capacity.

Hoop Stiffness and Creep Rupture Strength

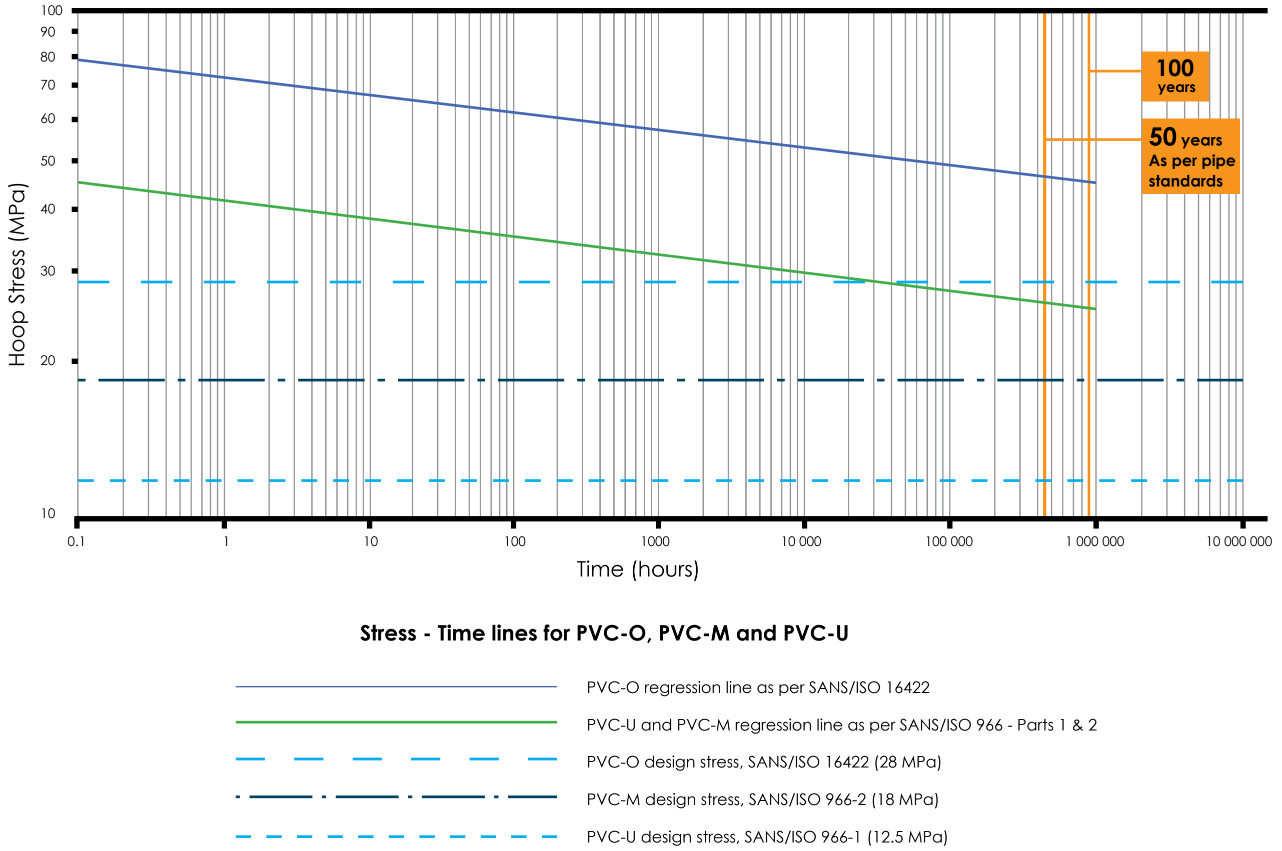
The hoop stress (from Barlow's formula) is plotted against the time (in hours) to rupture, using log scales on both axes.

The resultant creep rupture regression lines for PVC-U/M and PVC-O pressure pipes are given in figure 4.22 at 20°C. *(Note: These curves may vary between manufacturers, and should be confirmed by the manufacturer since manufacturers of PVC pipes have proprietary pressure pipe formulations.)*

TABLE 4.29: COMPARISON OF PVC-U, PVC-M AND PVC-O

Property	Pipe Material		
	PVC-U	PVC-M	PVC-O
SANS Standard	SANS 966-1	966-2	16422
Service design factor (water @ 20 °C)	2	1.4	1.6
Minimum Required Strength (MRS) (MPa)	25	25	50
Design Stress (MPa)	12.5	18	32
Density (kg/m^3)	1440	1430	1450
Short-term Young's Modulus (MPa)	3300	3000	4000
Long-term Young's Modulus (MPa)	1500	1400	1800
* Diameter Range	DN 16 to DN 630	DN 16 to DN 630	DN 90 to DN 630 (larger sizes available upon request)
* Pressure Range	PN 4 to PN 20	PN 6 to PN 25	Class 12.5 to Class 25

** Dependent on pipe manufacturer*



Notes

1. 20°C Regression Line
   The line for PVC-U and PVC-M meets the requirements of SANS/ISO 966, (Parts 1 and 2 respectively.) while the line for PVC-O meets SANS/ISO 16422.

FIGURE 4.22: COMPARISON OF REGRESSION CURVES FOR PVC-U, PVC-M AND PVC-O

Hydrostatic Strength

The addition of modifying agents reduces the short term strength but leads to a considerable increase in toughness in PVC-M pressure pipe, especially the resistance of the material to the propagation of cracks. The 1 hour hydrostatic strength at 20°C of PVC-M is 40Mpa, compared to 42Mpa for PVC-U pipe. The failure stresses of both PVC-U and PVC-M at 50 years are similar, i.e. 25 MPa.

Testing at elevated temperatures is essential for the identification of ductile-brittle transitions. Should operating temperatures rise above 25°C, the working pressures should be de-rated.

Impact Resistance

The measurement of the impact performance under external blows is a major requirement of SANS/ISO 966-2. The ductility of PVC-M pipe is shown by the standard quality control test for impact; when impacted by masses of up to 30kg dropped from a height of 20m, there is no evidence of brittle failure as experienced with PVC-U.

A comparison of the impact properties of PVC-U, PVC-M and PVC-O pressure pipes tested as per SANS/ISO specifications is given in table 4.30.

TABLE 4.30: COMPARISON OF IMPACT PROPERTIES FOR PVC

Material Specification	Drop Test Height (m)	Temperature °C	Mass of Striker (kg)	Remark
PVC-U SANS/ISO 966-1 & SANS/ISO 966-2	2.0	23	5	Pipe must not shatter.
PVC - M SANS/ISO 966-2	20.0	23	20	Pipe must not shatter Pipe must fail in ductile manner (smooth hole).
PVC-O SANS/ISO 16422	2.0	0	10	Pipe must not shatter.

Note: The mass of the Striker may vary depending on the pipe size

Pipe Design Principles: PVC-U, PVC-M and PVC-O

Design Stress (σs) and the Long-Term Safety Factor

The design stress is defined as the constant stress that the pipe wall can withstand for 50 years, with a defined safety factor.

A safety factor or overall service (design) co-efficient (C) is applied to take into account minor variations in pipe quality, the possibility of the occurrence of brittle failure, slight surges or fluctuations in pressure, superimposed bending stresses or point loads on the pipe, or slight surface damage resulting during installation (refer SANS/ISO 966, SANS/ISO 16422 and SANS/ISO 4427). Thus, the design coefficient is applied to account for any 'unknown' loading or environmental conditions. In addition to water-hammer, static, and dynamic loads, the designer should also apply the relevant derating factors to account for fatigue.

The design stress is derived from the stress-time line (refer Figure 4.22) which gives the minimum required strength (MRS), as follows:

$$\sigma_s = \frac{\mathrm{MRS}}{\mathrm{C}} \qquad (59)$$

Where σ_s - Design stress

MRS - Minimum required strength at 50 years

C - Design coefficient (safety factor).

- PVC-U pipes designed as per SANS/ISO 966 Part 1 have a design coefficient of 2.5 for pipe diameters of 90mm and below, and 2.0 for pipe diameters 110mm and above. These design coefficients relate to design stresses of 10.0 and 12.5 MPa respectively.
- PVC-M pipes designed as per SANS/ISO 966-2 have a design coefficient of 1.4.
- PVC-O pipes designed as per SANS/ISO 16422 may have a design coefficient of 1.4 (32 mpa) or 1.6 (28 mpa)

Short-term Safety Factors

It should be noted that the short-term safety factor is much higher. In fact, the more rapid the rate of pressure increase the higher the strength exhibited by the pipe. Short-term safety factors for PVC-U, PVC-M and PVC-O are over three times the design working pressure. Thus, at high pressurisation rates, pipes are better able to resist the higher stress levels generated by surge.

STRENGTH AND TOUGHNESS

PVC-M Pressure Pipes

The stress-time lines for PVC-U, PVC-M, and PVC-O are related to the strength properties of these materials. However, strong materials are not necessarily tough and in many cases can be quite brittle. The best example is glass, which, in its purest form, is extremely strong but by the introduction of a small defect or notch becomes very brittle indeed. This is due to the high stresses that develop at the tip of the notch, which lead to unstable crack growth. In the case of engineering materials, especially those used for pipes, in addition to strength and stiffness, a major requirement is toughness since it is this property that increases the resistance of the material to the propagation of cracks.

The E modulus of PVC-U is almost three times that of PE but, because of its higher susceptibility to brittle failure, this cannot be fully exploited. Thus, based on the widely used safety factors of 2.0 and 1.25 for PVC-U and HPDE respectively, the wall thickness of PVC-U is only about 50% that of the equivalent PE pipe, and not 33% as it would be purely on a strength basis.

The reason for the relatively large design coefficient with PVC-U against that of PE is the greater ductility of polyethylene. Larger design coefficients are a requirement for more brittle materials, even though the strength of the material is greater.

In the development of PVC-M advantage was taken of many years of work on the science and technology of alloys and blends, the objective being to develop a material with the long-term strength of PVC-U along with the toughness of polyethylene. The excellent long-term strength properties of PVC-U have been retained, while the toughness of the material has been enhanced by the incorporation of impact modifiers which, even in relatively small amounts, significantly change the characteristics of the pipe, such that a completely ductile failure mode may be achieved in the fracture toughness, high speed impact, and other tests as per SANS/ISO 966 Part 2.

PVC-M pressure pipe is produced so as to have the optimum balance between strength and toughness, which allows the material to survive point loads, for example, without embrittlement or loss in pressure carrying capacity.

The larger design coefficient used in the design of PVC-U pipes is not necessary with tougher materials such as PVC-M, since this material's failure mode is dominated by ductile yielding. The safety factor for PVC-M is 1.4 and a design stress of 18 MPa is used to calculate the wall thickness according to Barlow's formula:

$$e = \frac{PD}{2\sigma_s + P} \qquad (60)$$

where e - minimum wall thickness (mm)
P - maximum operating pressure (MPa)
D - mean external diameter (mm)
σ_s - design stress (MPa)

The improved material efficiency and hydraulic capacity give significant life cycle energy savings.
Thus, in addition to strength, toughness is the other important property of plastic pipe materials. PVC-O is unique in that it has both very high strength and high toughness. Long-term pipeline performance is dependent on both of these properties. Toughness can be defined as resistance to impact and 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 stress concentration effects in the pipe which can eventually result in failure. It is the toughness properties of PVC-O which prevent this common cause of pipeline failure. To prevent stress cracking as a result of fatigue, the design needs to be adjusted, as discussed in Chapter 2.

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

Given the outstanding strength and toughness properties, a 50 year safety factor of 1.6 can be applied for MRS 45 PVC-O materials, as specified in SANS/ISO 16422. Design stress of 28 MPa is used for these PVC-O pipes resulting in material savings of over 50% and 30% against the equivalent PVC-U and PVC-M products, respectively.

Advantages of PVC-O pipes which relate to the higher design stress are increased hydraulic capacity and improved handling and installation characteristics. The greater flow capacity of PVC-O pipes provides greater energy savings, and thus they have less effect on the environment than other pipe materials, including traditional materials such as ductile iron.

Pressure Variation and Surge Pressures

The stress regression lines are derived using constant stresses; in pipelines the stress on the material is rarely constant, varying as the pressure superimposed loads vary.

The latter usually stabilise fairly quickly, at least within the first year of the network life, but pressure variations are there forever. As with any other pipe material, due allowance for this must be made in designing a water reticulation network with PVC pipes. Anti-surge devices such as air vessels, non-return valves, programmed use of pumps etc, should be incorporated where necessary. Lower surge pressures develop in PVC pipes as a result of lower surge wave velocities and this has enabled PVC pipes to be used in areas where water hammer has caused pipes manufactured from other materials to fracture. Above all, it enables one to operate with lower pressure classes for PVC.

Considerable research has been done on the fatigue properties of plastic pipelines. Recently work has been published on fatigue properties of PVC-M related to actual site conditions in water distribution systems. It is concluded that PVC-M pipes will not fail under conditions of dynamic and static stress within 50 years provided the total stress does not exceed 17.5MPa and the stress amplitude over one million pressure cycles (equal to 55 cycles per day for 50 years) is below 3.0MPa

EFFECT OF TEMPERATURE CHANGE

Working Pressure

20°C is the standard design temperature for PVC pipes, and rated working pressures are usually quoted for this temperature. PVC pressure pipe functions perfectly well below 20°C right down to freezing point, and can in fact withstand higher pressures than those quoted at 20°C.

Above 20°C, working pressures must be down-rated if the same factors of safety are to be held. The reduction factors as given in table 3.2 (Chapter 3) should be applied.

Sub Zero Temperatures

Water has been known to freeze in PVC pipes without causing fractures, but permanent strain can result, leading to severe reduction in the working life of the pipe. Hence PVC pipes – like other pipes – should be protected against sub zero temperatures.

Expansion and Contraction

All plastics have high co-efficients of expansion and contraction, several times those of metals. This must be allowed for in any installation by the use of expansion joints, expansion loops etc.

TABLE 4.31: COMPARISON OF CO-EFFECIENT OF THERMAL EXPANSION

Material	Co-efficient of expansion mm/m/°C
PVC	0.07
PE	0.2
Steel	0.012
Copper	0.02

Ultra Violet Resistance

Most plastics are affected by U.V. light. PVC pressure pipes have pigments and light stabilisers incorporated in their formulations, and if pressure pipes have to be exposed for an indefinite period, they should be painted, preferably with one coat of white alkyd enamel or PVA, or suitable covering should be provided. Paint containing solvent thinners should be avoided.

PIPE LAYING AND JOINTING

1. *Maximum gradients and anchor blocks*

Grade the sewer to follow the slope of the ground as far as is practical. Where slopes greater than 1 in 10 are required, provide 20MPa concrete anchor blocks that are at least 300mm wide and embedded into the sides and bottom of the trench to a depth of 150mm. Avoid sharp transitions at the bottom of steep slopes.

2. *Minimum gradients*

The minimum possible full bore velocity, normally 0.9 m/s, determines the minimum gradient. In exceptional circumstances only, a minimum velocity of 0.6 m/s may be used.

Cutting and jointing of sewer & drainage pipes

Cutting

Cut the pipe square with a cross cut saw or angle grinder, depending on the pipe size. Clean away swarf. The pipe end must be chamfered again to 15° to ensure easy insertion when making a joint.

Note: Make sure no sharp notches are present at any position of the cut joint area

Cleaning the seal

It is important to ensure that the seal is free of grit and mud before making the joint. Pipe ends are often accidentally dipped into the sand.

Lubrication

Use only lubricant recommended from the pipe manufacturer. Lubricants are supplied in liquid or gel form. Do not use grease or petroleum products to lubricate seals, as they attack the rubber and will lead to leakage. In order to make a leak-free joint effortlessly, use liberal amounts of lubricant, but avoid getting it into the seal housing. Ensure the seal and pipe ends are free of dirt.

Depth of entry

Unlike a pressure pipe, no depth of entry mark is provided. Insert the pipe fully to avoid hang-up and possible blockages. Make sure not to over insert the pipe, since this could result in unnecessary stresses within the sockets.

Jointing

It is important that the pipe ends and the sockets are aligned and free of burrs, otherwise insertion into the seal ring will be difficult. Insert the pipe into the socket fully. For protection of pipe ends, use a lever against a wooden block.

Joints

Flexible rubber ring joints are available for all types of pipe and should be used in preference to rigid joints, allowing the pipeline to flex in the event of soil movements and also allowing for thermal change. Thrust blocks should be included where necessary.

Testing of sewer pipelines

Air testing (Manometer test) in sewers and drains is the accepted method that has been adopted by the industry as the most effective means of establishing acceptance by the respective authorities. Water testing is an easier method of finding leaks, but water is not always available and generally is too costly an exercise. SANS 2001 describes the "Test and Acceptance/Rejection Criteria".

Equipment required

1. An approved Manometer in a leak free condition.
2. Testing plugs in a leak free condition (ensure that the rubber seals are not perished and that the end caps are sealed and not cracked).
3. Stopwatch for recording time.
4. Bottle of soapy water to check for air leaks.
5. Large bucket.
6. Small funnel for filling Manometer tube.

FIGURE 4.23: AIR TESTING EQUIPMENT

Useful tip

Test line at short intervals to simplify the locating of possible leaks. Allocate responsibility of testing to a crew. Their familiarity with the equipment will save time and effort.

Procedure

1. Check all equipment for leaks.
2. Ensure that the section of pipeline to be tested has been sealed off at all branches and that all access openings are secure.
3. Insert testing plugs and secure.
4. Adjust the water level in the Manometer to zero on the scale (by adding water slowly).
5. Open the valve on the Manometer and pump until a reading of 400mm is reached (this reading equals a pressure of 4.00kPa). 400mm has been selected as it is easier to read than 375mm (3.75kPa) referred to in the specification.
6. Close the valve and allow the water column to settle for two minutes. (There might be a marginal drop in pressure). Should it not stabilise, check the connections to the Manometer and plugs for leaks by pouring soapy water over them. Should there be any leaks, these must be repaired before proceeding with the test.
7. Open the valve and adjust the pressure to a reading of 250mm (2.50kPa) and start recording time. The pressure is permitted to drop to a reading of 125mm (1.25kPa) and the time taken to drop to this level should be no less than the time stated in table 4.32 below.

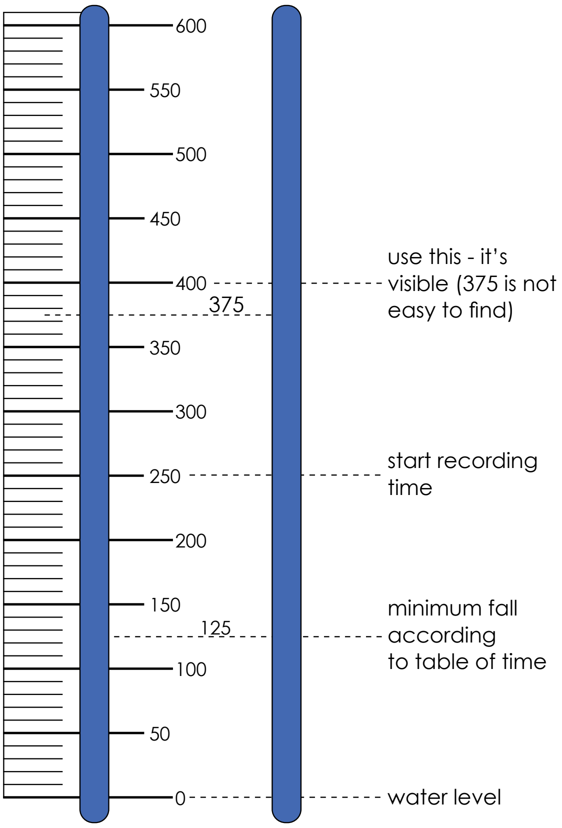


FIGURE 4.24: TIME FOR PRESSURE DROP DURING AIR TEST

TABLE 4.32: TIME FOR PRESSURE DROP DURING AIR TEST

PIPE SIZE (mm)	MINIMUM TIME FOR PRESSURE TO DROP FROM 250MM (2.50KpA) TO 125MM (1.25KpA) IN MINUTES
110	2
160	3
200	4
250	4.5
315	6
355	7.5
400	8
450	9
500	10

TABULATION OF DIMENSIONS

TABLE 4.33: DIMENSIONS OF UN-PLASTISIZED POLYVINYL CHLORIDE (PVC-U) PIPES AS PER SANS 966 -1

		Outside Diameter		O.D. At Any Point		Wall Thickness		
Size	Class	^{e}Min.	^{e}Max.	^{e}Min.	^{e}Max.	^{e}Min.	^{e}Max.	Avg Id
mm	PN (Bar)	mm	mm	mm	mm	mm	mm	mm
16	20	16	16.2	15.5	16.5	1.5	1.9	12.7
20	16	20	20.2	19.5	20.5	1.5	1.9	16.7
	20	20	20.2			1.9	2.3	15.9
25	12	25	25.2	24.5	25.5	1.5	1.9	21.7
	16	25	25.2			1.9	2.3	20.9
	20	25	25.2			2.3	2.8	20
32	9	32	32.2	31.5	32.5	1.5	1.9	28.7
	12	32	32.2			1.8	2.2	28.1
	16	32	32.2			2.4	2.9	26.8
	20	32	32.2			2.9	3.4	25.8
40	6	40	40.2	39.5	40.5	1.5	1.9	36.7
	9	40	40.2			1.8	2.2	36.1
	12	40	40.2			2.3	2.9	34.9
	16	40	40.2			3.0	3.6	33.5
	20	40	40.2			3.7	4.3	32.1
50	6	50	50.2	49.4	50.6	1.8	2.2	46.1
	9	50	50.2			2.2	2.7	45.2
	12	50	50.2			2.8	3.3	44
	16	50	50.2			3.7	4.3	42.1
	20	50	50.2			4.6	5.3	40.2
63	6	63	63.2	62.2	63.8	1.9	2.3	58.9
	9	63	63.2			2.7	3.2	57.2
	12	63	63.2			3.6	4.2	55.3
	16	63	63.2			4.7	5.5	52.9
	20	63	63.2			5.8	6.4	50.9
75	4	75	75.2	74.1	75.9	1.5	1.9	71.7
	6	75	75.2			2.2	2.7	70.2
	9	75	75.2			3.2	3.8	68.1
	12	75	75.2			4.3	5.2	65.6
	16	75	75.2			5.6	6.5	63
	20	75	75.2			6.9	8.0	60.2
90	4	90	90.3	88.9	91.1	1.8	2.3	86.0
	6	90	90.3			2.7	3.2	84.2
	9	90	90.3			3.9	4.5	81.7
	12	90	90.3			5.1	5.9	79.1
	16	90	90.3			6.7	7.6	75.8
	20	90	90.3			8.2	9.5	72.4
110	4	110	110.3	108.6	111.4	2.2	2.7	105.2
	6	110	110.3			2.6	3.1	104.4
	9	110	110.3			3.9	4.5	101.7
	12	110	110.3			5.1	5.9	99.1
	16	110	110.3			6.7	7.6	95.8
	20	110	110.3			8.2	9.5	92.4
	25	110	110.3			10.0	11.6	88.5

TABLE 4.33: DIMENSIONS OF UN-PLASTISIZED POLYVINYL CHLORIDE (PVC-U) PIPES AS PER SANS 966 -1 (CONTINUED)

		Outside Diameter		O.D. At Any Point		Wall Thickness		
Size	**Class**	**^{e}Min.**	**^{e}Max.**	**^{e}Min.**	**^{e}Max.**	**^{e}Min.**	**^{e}Max.**	**Avg Id**
mm	**PN (Bar)**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**
125	4	125	125.3	123.5	126.5	2.5	3.0	119.6
	6	125	125.3			3.0	3.6	118.5
	9	125	125.3			4.4	5.1	115.6
	12	125	125.3			5.8	6.7	112.6
	16	125	125.3			7.6	8.8	108.7
	20	125	125.3			9.3	10.5	105.3
	25	125	125.3			11.4	13.2	100.5
140	4	140	140.4	138.3	141.7	2.8	3.3	134.1
	6	140	140.4			3.3	3.9	133.0
	9	140	140.4			4.9	5.7	129.6
	12	140	140.4			6.5	7.5	126.2
	16	140	140.4			8.5	9.8	121.9
	20	140	140.4			10.4	12.0	117.8
	25	140	140.4			12.8	14.8	112.6
160	4	160	160.4	158.0	162.0	3.2	3.8	153.2
	6	160	160.4			3.8	4.4	152.0
	9	160	160.4			5.6	6.5	148.1
	12	160	160.4			7.4	8.6	144.2
	16	160	160.4			9.7	11.2	139.3
	20	160	160.4			11.9	13.7	134.6
	25	160	160.4			14.6	16.8	128.8
200	4	200	200.5	197.6	202.6	3.9	4.7	191.6
	6	200	200.5			4.7	5.5	190.0
	9	200	200.5			7.0	8.1	185.1
	12	200	200.5			9.2	10.7	180.3
	16	200	200.5			12.1	14.0	174.1
	20	200	200.5			14.9	17.2	168.1
	25	200	200.5			18.2	21.0	161.0
250	4	250	250.6	247.0	253.0	4.9	5.7	239.7
	6	250	250.6			5.9	6.7	237.7
	9	250	250.6			8.7	6.8	234.8
	12	250	250.6			11.5	13.3	225.5
	16	250	250.6			15.1	17.4	217.8
	20	250	250.6			18.6	21.4	210.3
	25	250	250.6			22.8	26.3	201.2
315	4	315	315.6	311.2	318.8	6.2	7.2	301.9
	6	315	315.6			7.4	8.6	299.3
	9	315	315.6			11.0	12.7	291.6
	12	315	315.6			14.5	16.7	284.1
	16	315	315.6			19.0	21.9	274.4
355	4	355	355.7	350.7	359.3	7.0	8.1	340.2
	6	355	355.7			8.4	9.7	337.2
	9	355	355.7			12.4	14.3	328.6
	12	355	355.7			16.3	18.8	320.2
	16	355	355.7			21.4	24.7	309.2
400	4	400	400.7	395.2	404.8	7.8	10.0	382.5
	6	400	400.7			9.4	10.9	380.0
	9	400	400.7			14.0	16.2	370.1
	12	400	400.7			18.4	21.2	360.7
	16	400	400.7			24.1	27.8	348.4
450	4	450	450.8	445.1	454.9	8.9	10.3	431.2
	6	450	450.8			10.6	12.2	427.6
	9	450	450.8			15.7	18.1	416.6
	12	450	450.8			20.7	23.9	405.8
500	4	500	500.9	494.0	506.0	9.8	11.3	479.3
	6	500	500.9			11.8	13.6	475.0
	9	500	500.9			17.4	20.1	462.9
	12	500	500.9			22.9	26.4	451.1
560	4	560	561.0			11.0	12.7	536.8
	6	560	561.0			13.2	15.2	532.1
	9	560	561.0	546.5	573.5	19.5	22.5	518.5
630	4	630	631.1			12.5	14.4	603.6
	6	630	631.1			14.8	17.1	598.6
	9	630	631.1	614.8	645.2	21.9	25.2	583.4

Note: For classes 4 & 6 there are no out of roundness requirement.

TABLE 4.34: DIMENSIONS OF MODIFIED POLYVINYL CHLORIDE (PVC-M) PIPES AS PER SANS 966 -2

		Outside Diameter		O.D. At Any Point		Wall Thickness		
Size	**Class**	^{e}**Min.**	^{e}**Max.**	^{e}**Min.**	^{e}**Max.**	^{e}**Min.**	^{e}**Max.**	**Avg Id**
mm	**PN (Bar)**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**
50	6	50	50.2	49.4	50.6	1.5	1.9	46.7
	9	50	50.2			1.5	1.9	46.7
	12	50	50.2			1.7	2.1	46.3
	16	50	50.2			2.2	2.7	45.2
	20	50	50.2			2.7	3.2	44.2
	25	50	50.2			3.3	3.9	42.9
63	6	63	63.2	62.2	63.8	1.5	1.9	59.7
	9	63	63.2			1.6	2.0	59.5
	12	63	63.2			2.1	2.6	58.4
	16	63	63.2			2.7	3.2	57.2
	20	63	63.2			3.4	4.0	55.7
	25	63	63.2			4.1	4.8	54.2
75	6	75	75.2	74.1	75.9	1.5	1.9	71.7
	9	75	75.2			1.9	2.3	70.9
	12	75	75.2			2.5	3.0	69.6
	16	75	75.2			3.2	3.8	68.1
	20	75	75.2			4.0	4.7	66.4
	25	75	75.2			4.9	5.7	64.5
90	6	90	90.3	88.9	91.1	1.8	2.2	86.1
	9	90	90.3			2.2	2.7	85.2
	12	90	90.3			3.0	3.6	83.5
	16	90	90.3			3.9	4.5	81.7
	20	90	90.3			4.8	5.6	79.7
	25	90	90.3			5.9	6.8	77.4
110	6	110	110.3	108.6	111.4	2.2	2.7	105.2
	9	110	110.3			2.7	3.2	104.2
	12	110	110.3			3.6	4.2	102.3
	16	110	110.3			4.7	5.5	99.9
	20	110	110.3			5.8	6.7	97.6
	25	110	110.3			7.2	8.3	94.6
122	6	122	122.3	120.6	123.4	2.4	2.9	116.8
	9	122	122.3			3.0	3.6	115.5
	12	122	122.3			4.0	4.7	113.4
	16	122	122.3			5.2	6.0	110.9
	20	122	122.3			6.5	7.5	108.1
	25	122	122.3			8.0	9.2	104.9
125	6	125	125.3	123.5	126.5	2.5	3.0	119.6
	9	125	125.3			3.1	3.7	118.3
	12	125	125.3			4.1	4.8	116.2
	16	125	125.3			5.4	6.3	113.4
	20	125	125.3			6.6	7.6	110.9
	25	125	125.3			8.2	9.5	107.4
140	6	140	140.4	138.3	141.7	2.8	3.3	134.1
	9	140	140.4			3.5	4.1	132.6
	12	140	140.4			4.6	5.3	130.3
	16	140	140.4			6.0	7.0	127.2
	20	140	140.4			7.4	8.6	124.2
	25	140	140.4			9.1	10.5	120.6

TABLE 4.34: DIMENSIONS OF MODIFIED POLYVINYL CHLORIDE (PVC-M) PIPES AS PER SANS 966 -2 (CONTINUED)

		Outside Diameter		O.D. At Any Point		Wall Thickness		
Size	Class	^{e}Min.	^{e}Max.	^{e}Min.	^{e}Max.	^{e}Min.	^{e} Max.	Avg Id
mm	PN (Bar)	mm	mm	mm	mm	mm	mm	mm
160	6	160	160.4	158.0	162.0	3.2	3.9	153.1
	9	160	160.4			4.0	4.7	151.5
	12	160	160.4			5.2	6.0	149.0
	16	160	160.4			6.9	8.0	145.3
	20	160	160.4			8.5	9.8	141.9
	25	160	160.4			10.4	12.0	137.8
177	6	177	177.5	175.0	179.0	3.5	4.1	169.6
	9	177	177.5			4.4	5.1	167.7
	12	177	177.5			5.8	6.7	164.7
	16	177	177.5			7.7	8.9	160.6
	20	177	177.5			9.4	10.9	156.9
	25	177	177.5			11.5	13.3	152.4
200	6	200	200.5	197.6	202.6	3.9	4.4	191.9
	9	200	200.5			4.9	5.7	189.6
	12	200	200.5			6.5	7.5	186.2
	16	200	200.5			8.6	9.9	181.7
	20	200	200.5			10.6	12.3	177.3
	25	200	200.5			13.0	15.0	172.2
250	6	250	250.6	247.0	253.0	4.9	5.7	239.7
	9	250	250.6			6.1	7.1	237.1
	12	250	250.6			8.1	9.4	232.8
	16	250	250.6			10.7	12.4	227.2
	20	250	250.6			13.2	15.2	221.9
	25	250	250.6			16.3	18.8	215.2
315	6	315	315.6	311.2	318.8	6.2	7.2	301.9
	9	315	315.6			7.7	8.9	298.7
	12	315	315.6			10.2	11.8	293.3
	16	315	315.6			13.5	15.6	286.2
	20	315	315.6			16.6	19.1	279.6
355	6	355	355.7	350.7	359.3	7.0	8.1	340.2
	9	355	355.7			8.7	10.1	336.5
	12	355	355.7			11.5	13.3	330.5
	16	355	355.7			15.2	17.5	322.6
	20	355	355.7			18.7	21.6	315.0
400	6	400	400.7	395.2	404.8	7.8	9.0	383.5
	9	400	400.7			9.8	11.3	379.2
	12	400	400.7			13.0	15.0	372.3
	16	400	400.7			17.1	19.7	363.5
	20	400	400.7			21.1	24.3	354.9
450	6	450	450.8	445.1	454.9	8.9	10.3	431.2
	9	450	450.8			11.0	12.7	426.7
	12	450	450.8			14.6	16.8	419.0
	16	450	450.8			19.2	22.1	409.1
	20	450	450.8			23.7	27.3	399.4
500	6	500	500.9	494.0	506.0	9.8	11.3	479.3
	9	500	500.9			12.2	14.1	474.1
	12	500	500.9			16.2	18.7	465.5
	16	500	500.9			21.3	24.5	454.6
	20	500	500.9			26.4	30.4	443.6
560	6	560	561.0			11.0	12.7	536.8
	9	560	561.0			13.5	15.6	531.4
	12	560	561.0	546.5	573.5	17.1	19.7	523.7
630	6	630	631.1			12.5	14.4	603.6
	9	630	631.1			15.4	17.8	597.3
	12	630	631.1	614.8	645.2	20.4	23.5	586.6

Note: For classes 4 & 6 there are no out of roundness requirements.

TABLE 4.35: DIMENSIONS OF UN-PLASTISIZED POLYVINYL CHLORIDE (PVC-U) PIPES AS PER SANS 967 & 791

SANS 967		Outside Diameter		O.D. At Any Point		Wall Thickness		
Size	**Class**	**^{e}Min.**	**^{e}Max.**	**^{e}Min.**	**^{e}Max.**	**^{e}Min.**	**^{e}Max.**	**Avg Id**
mm	**PN (Bar)**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**
40	N/A	40	40.2	39.5	40.5	2.0	2.4	36.0
50	N/A	50	50.2	49.4	50.6	2.2	2.6	45.0
75	N/A	75	75.3	74.1	75.9	3.2	3.8	68.0
110	N/A	110	110.3	108.6	111.4	3.2	3.8	103.0
160	N/A	160	160.4	158.0	162.0	3.3	3.9	153.0
SANS 791		**Outside Diameter**		**O.D. At Any Point**		**Wall Thickness**		
Size	**Class**	**^{e}Min.**	**^{e}Max.**	**^{e}Min.**	**^{e}Max.**	**^{e}Min.**	**^{e}Max.**	**Avg Id**
mm	**DUTY**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**
110	ND	110	110.3	108.6	111.4	2.2	2.8	105.0
	HD	110	110.3			3.0	3.5	104.0
160	ND	160	160.4	158.0	162.0	3.2	3.8	153.0
	HD	160	160.4			4.7	5.4	150.0
200	ND	200	200.5	197.6	202.6	3.9	4.5	192.0
	HD	200	200.5			5.9	6.7	188.0
250	ND	250	250.5	247.0	253.0	5.0	5.7	240.0
	HD	250	250.5			7.3	8.3	235.0
315	ND	315	315.6	311.2	318.8	6.2	7.1	302.0
	HD	315	315.6			9.2	10.4	296.0
400	ND	400	400.7	395.2	404.8	7.9	8.9	384.0
	HD	400	400.7			11.7	13.1	376.0
500	ND	500	500.9	494.0	506.0	9.8	11.0	480.0
	HD	500	500.9			14.6	16.3	470.0
560	ND	560	561.0	546.5	573.5	11.0	12.2	537.3
	HD	560	561.0			16.3	18.0	526.2
630	ND	630	631.1	614.8	645.2	12.4	13.9	604.2
	HD	630	631.1			18.4	20.5	591.6

NOTE: ND = Normal Duty SDR 51 (Class 51), HD = Heavy Duty SDR 34 (Class 34)

TABLE 4.36: DIMENSIONS OF MODIFIED POLY(VINYL CHLORIDE) (PVC-M) PRESSURE PIPE AND CUPLINGS FOR COLD WATER SERVICES IN UNDERGROUND MINING AS PER SANS 1283 (DESIGN STRESS 12.5 MPA)

		Outside Diameter		O.D. At Any Point		Wall Thickness		
Size	**Class**	**^{e}Min.**	**^{e}Max.**	**^{e}Min.**	**^{e}Max.**	**^{e}Min.**	**^{e}Max.**	**Avg Id**
mm	**PN (Bar)**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**
105	6	105	105.3	103.9	106.1	2.5	2.9	99.7
	9	105	105.3			3.7	4.2	97.2
	12	105	105.3			4.8	5.5	94.8
	16	105	105.3			6.4	7.2	91.5
	20	105	105.3			7.8	8.7	88.6
	25	105	105.3			9.5	10.6	85.0
110	6	110	110.3	108.6	111.4	2.6	3.0	104.5
	9	110	110.3			3.9	4.4	101.8
	12	110	110.3			5.1	5.8	99.2
	16	110	110.3			6.7	7.5	95.9
	20	110	110.3			8.2	9.2	92.7
	25	110	110.3			10.0	11.2	88.9
125	6	125	125.3	123.5	126.5	3.0	3.5	118.6
	9	125	125.3			4.4	5.0	115.7
	12	125	125.3			5.8	6.5	112.8
	16	125	125.3			7.6	8.5	109.0
	20	125	125.3			9.3	10.4	105.4
	25	125	125.3			11.4	12.8	100.9

TABLE 4.36: DIMENSIONS OF MODIFIED POLY(VINYL CHLORIDE) (PVC-M) PRESSURE PIPE AND CUPLINGS FOR COLD WATER SERVICES IN UNDERGROUND MINING AS PER SANS 1283 (DESIGN STRESS 12.5 MPA) (CONTINUED)

		Outside Diameter		O.D. At Any Point		Wall Thickness		
Size	Class	[e]Min.	[e]Max.	[e]Min.	[e]Max.	[e]Min.	[e]Max.	Avg Id
mm	PN (Bar)	mm	mm	mm	mm	mm	mm	mm
140	6	140	140.4	138.3	141.7	3.3	3.8	133.1
	9	140	140.4			4.9	5.5	129.8
	12	140	140.4			6.5	7.3	126.4
	16	140	140.4			8.5	9.5	122.2
	20	140	140.4			10.4	11.6	118.2
	25	140	140.4			12.8	14.2	113.2
155	6	155	155.4	153.1	156.9	3.6	4.1	147.5
	9	155	155.4			5.4	6.1	143.7
	12	155	155.4			7.1	8.0	140.1
	16	155	155.4			9.4	10.5	135.3
	20	155	155.4			11.5	12.8	130.9
	25	155	155.4			14.1	15.7	125.4
160	6	160	160.4	158.0	162.0	3.8	4.3	152.1
	9	160	160.4			5.6	6.3	148.3
	12	160	160.4			7.4	8.3	144.5
	16	160	160.4			9.7	10.8	139.7
	20	160	160.4			11.9	13.2	135.1
	25	160	160.4			14.6	16.2	129.4
200	6	200	200.4	197.6	202.6	4.7	5.3	190.2
	9	200	200.4			7.0	7.9	185.3
	12	200	200.4			9.2	10.3	180.7
	16	200	200.4			12.1	13.5	174.6
	20	200	200.4			14.9	16.5	168.8
	25	200	200.4			18.2	20.2	161.8
210	6	210	210.4	207.5	212.7	5.0	5.7	199.5
	9	210	210.4			7.3	8.2	194.7
	12	210	210.4			9.7	10.8	189.7
	16	210	210.4			12.7	14.4	183.1
	20	210	210.4			15.6	17.3	177.3
	25	210	210.4			19.1	21.2	169.9
225	6	225	225.5	222.8	227.2	5.3	6.0	213.9
	9	225	225.5			7.9	8.8	208.5
	12	225	225.5			10.3	11.5	203.4
	16	225	225.5			13.6	15.1	196.5
	20	225	225.5			16.7	18.5	190.0
	25	225	225.5			20.5	22.7	182.0
250	6	250	250.5	247.0	253.0	5.9	6.6	237.7
	9	250	250.5			8.7	9.7	231.8
	12	250	250.5			11.5	12.8	225.9
	16	250	250.5			15.1	16.8	218.3
	20	250	250.5			18.6	20.6	211.0
	25	250	250.5			22.8	25.2	202.2

TABLE 4.36: DIMENSIONS OF MODIFIED POLY(VINYL CHLORIDE) (PVC-M) PRESSURE PIPE AND CUPLINGS FOR COLD WATER SERVICES IN UNDERGROUND MINING AS PER SANS 1283 (DESIGN STRESS 12.5 MPA) (CONTINUED)

		Outside Diameter		O.D. At Any Point		Wall Thickness		
Size	**Class**	^{e}**Min.**	^{e}**Max.**	^{e}**Min.**	^{e}**Max.**	^{e}**Min.**	^{e}**Max.**	**Avg Id**
mm	**PN (Bar)**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**
315	6	315	315.6	311.2	318.8	7.4	8.3	299.6
	9	315	315.6			11.0	12.2	292.1
	12	315	315.6			14.5	16.1	284.7
	16	315	315.6			19.0	21.1	275.2
355	6	355	355.7	352.0	358.0	8.4	9.4	337.5
	9	355	355.7			12.4	13.8	329.1
	12	355	355.7			16.3	18.1	320.9
	16	355	355.7			21.4	23.7	310.2
400	6	400	400.7	396.8	403.2	9.4	10.5	380.4
	9	400	400.7			14.0	15.6	370.7
	12	400	400.7			18.4	20.5	361.4
	16	400	400.7			24.1	26.7	349.5
450	6	450	450.8	446.6	453.4	10.6	11.8	428.0
	9	450	450.8			15.7	17.4	417.3
	12	450	450.8			20.7	22.9	406.8
500	6	500	500.9	496.4	503.6	11.8	13.1	475.5
	9	500	500.9			17.4	19.3	463.7
	12	500	500.9			22.9	25.5	452.0

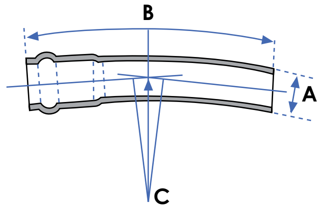
TABLE 4.37: DIMENSIONS OF MODIFIED POLY(VINYL CHLORIDE) (PVC-M) PRESSURE PIPE AND CUPLINGS FOR COLD WATER SERVICES IN UNDERGROUND MINING AS PER SANS 1283 (DESIGN STRESS 10 MPA)

		Outside Diameter		O.D. At Any Point		Wall Thickness		
Size	**Class**	^{e}**Min.**	^{e}**Max.**	^{e}**Min.**	^{e}**Max.**	^{e}**Min.**	^{e}**Max.**	**Avg Id**
mm	**PN (Bar)**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**
55	4	55	55.2	54.4	55.6	1.5	1.8	51.8
	6	55	55.2			1.6	1.9	51.6
	9	55	55.2			2.4	2.8	49.9
	12	55	55.2			3.2	3.7	48.2
	16	55	55.2			4.1	4.7	46.3
90	4	90	90.3	88.9	91.1	1.8	2.1	86.2
	6	90	90.3			2.7	3.1	84.3
	9	90	90.3			3.9	4.4	81.8
	12	90	90.3			5.1	5.8	79.2
	16	90	90.3			6.7	7.5	75.9

PVC-U AND PVC-M PRESSURE BENDS

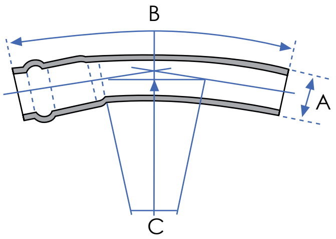
Bends are manufactured to Class 16 wall thickness. Bends to class 25 can be manufactured on request. Bends are available in 11.25°, 22.5°, 45° and 90°. *NOTE: Thrust blocks are to be used for the pipe and joints as per standard civil design practices, as well as manufacturers' requirements.*

TABLE 4.38: BENDS OF VARIOUS ANGLES ON PVC PIPES



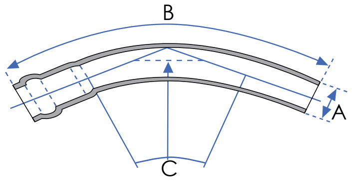
11.25° Pressure Bend with Joint

Outer Diameter A (mm)	Overall Length B (mm)	Radius C (mm)
50	580	175
63	600	220
75	620	260
90	660	315
110	680	385
125	730	440
140	770	490
160	850	560
200	960	700



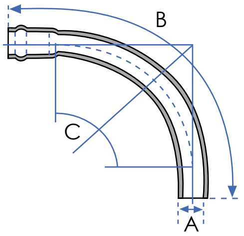
22.5° Pressure Bend with Joint

Outer Diameter A (mm)	Overall Length B (mm)	Radius C (mm)
50	620	175
63	640	220
75	670	260
90	720	315
110	750	385
125	820	440
140	860	490
160	950	560
200	1100	700



45° Pressure Bend with Joint

Outer Diameter A (mm)	Overall Length B (mm)	Radius C (mm)
50	680	175
63	730	220
75	770	260
90	840	315
110	900	385
125	990	440
140	1050	490
160	1170	560
200	1370	700
250	1540	875



90° Pressure Bend with Joint

Outer Diameter A (mm)	Overall Length B (mm)	Radius C (mm)
50	820	175
63	900	220
75	970	260
90	1085	315
110	1200	385
125	1330	440
140	1435	490
160	1610	560
200	1920	700
250	2220	875

POLYPROPYLENE

BASIC DESCRIPTION

Introduction

Before going on to discuss the applications for which different polypropylene materials are best suited, the reader needs to be aware of what is meant by the terms PP-H, PP-R, and PP-B. The key differences, from a polymer perspective, are given in figure 4.25.

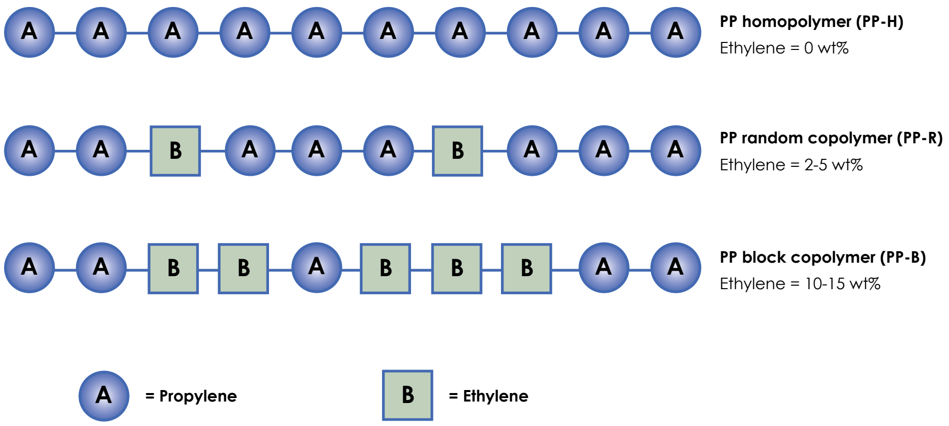


FIGURE 4.25: SIMPLIFIED VIEW OF THE DIFFERENT PP MOLECULAR STRUCTURES

Pure polypropylene (PP-H) is a comparatively rigid material that has poor low temperature impact resistance, unless a suitable modifier is added to the material. By adding a small amount of ethylene to the polypropylene polymer chain, the impact resistance and flexibility is improved and we get the material referred to as PP-R, Polypropylene Random Copolymer. If the quantity of ethylene is increased further, to the point where we get blocks of ethylene propylene dispersed in the polypropylene matrix, the impact resistance and flexibility is improved and we get a material referred to as PP-B, Polypropylene Block Copolymer (refer to page 127).

Hence the use of PP-H is mainly limited to high temperature and aggressive industrial applications, whilst PP-R is principally used for hot and cold water, and PP-B is used in the production of gravity pipes and fittings for sewage and drainage applications.

A) PP-H for high temperature and aggressive industrial applications

PP-H is used mainly in industrial applications that can make good use of its excellent chemical and high temperature resistance, while minimising the risk of the pipes and fittings being damaged due to their low impact resistance in low temperatures.

Piping systems formed from extruded PP-H pipes and injection moulded PP-H fittings are typically utilised in chemical applications at temperatures of between 0°C and 100°C and over a pressure range of 2 to 16 bar. Design lifetimes can be anything between 2 and 100 years, depending on the nature of the media being transported in the system and its temperature. The relevant standard is SANS/ISO 15494 – Plastics piping systems for industrial applications – Polybutylene(PB), polyethylene (PE), and polypropylene (PP).

B) PP-R for Hot and Cold Water Applications

Polypropylene Random Copolymers (PP-R) is an excellent material for the manufacture of pipes and fittings used for hot and cold water supply, heating, cooling, and drinking water systems within buildings. Compared to many other plastic pipe materials PP-R pipes and fittings have outstanding pressure resistance at higher temperatures and can be used at temperatures of up to 110°C, though the normal maximum temperature is 95°C. According to ISO/TR 9080, the proven MRS at 20°C can be taken as 10 MPa. For a 50 year design life the normal operating temperature is 70°C. This value can be de-rated further for a 100 year design live at a normal operating temperature of 60 Deg °C.

PP-R AREAS OF IMPLEMENTATION

1. Hot and cold potable water piping networks in residential and commercial buildings.
2. Heating systems.
3. Chilled water networks in air conditioning systems, as an effective light weight and corrosion free substitute for steel pipes.
4. Carrying a wide range of industrial chemicals.

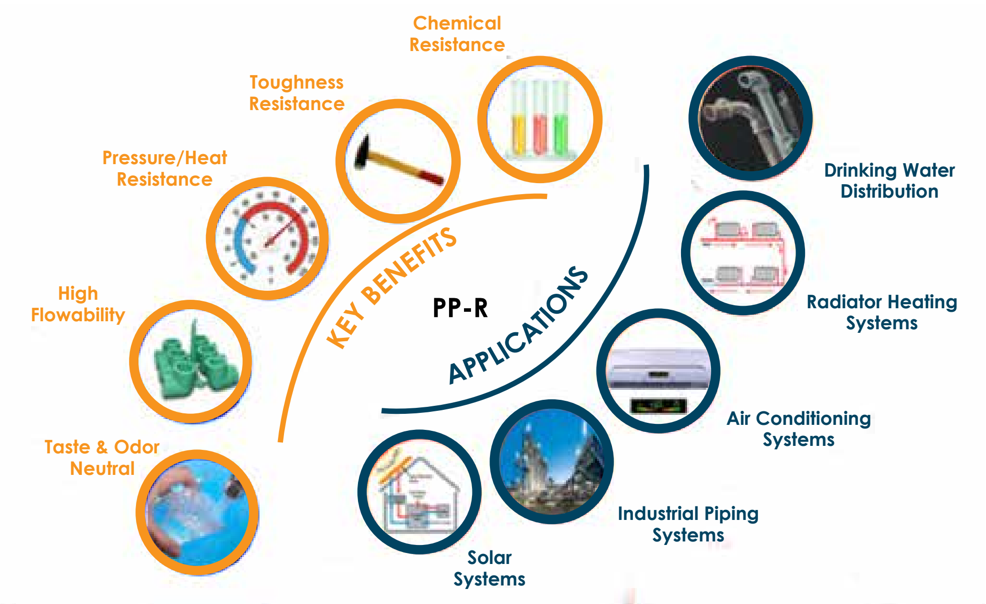


FIGURE 4.26: PP-R KEY BENEFITS AND APPLICATIONS

PP-R KEY FEATURES

1. Service Life: PP-R pipes are resistant to high temperatures, high pressures, and corrosion. Good quality PP-R pipes and fittings can be used for at least 50 years under working conditions of 70°C and 3.5 MPa.
2. PP-R pipes and fittings are lightweight and easy to install.
3. They can be joined using heat fusion technology, normally in the form of socket fusion, to ensure a reliable homogeneous connection.
4. The material also has a high level of abrasion and chemical resistance.
5. Energy saving: PP-R pipes minimise heat loss in hot water applications. The coefficient of heat conductivity is 0.24W/mK at 20°C as compared to 324W/mK of copper.
6. Recyclable material: PP-R scrap can be recycled for pipe and fitting production after purification and crushing. Providing that the amount of recycled material does not exceed 10% of total amount this will not affect the product quality.
7. Health hygiene: PP-R pipes and fittings comply with international regulations concerning food contact and contact with drinking water, such as WRAS.

TABLE 4.39: TYPICAL PP-R PHYSICAL PROPERTIES

Property	Typical Value	Test Method
Density	905 kg/m^3	ISO 1183
Melt Flow Rate (230 °C/2.16 kg)	0.25 g/10min	ISO 1133
Flexural Modulus (2 mm/min)	800 MPa	ISO 178
Tensile Modulus (1mm/min)	900 MPa	ISO 527
Tensile Strain at Yield (50 mm/min)	13.5 %	ISO 527-2
Tensile Stress at Yield (50 mm/min)	25 MPa	ISO 527-2
Charpy Impact Strength, notched (23 °C)	20 kJ/m²	ISO 179/1eA
Charpy Impact Strength, notched (0 °C)	3.5 kJ/m²	ISO 179/1eA

STORAGE AND INSTALLATION OUTSIDE OF BUILDINGS

PP-R pipes and fittings should be stored in dry conditions at temperatures bellow 50°C, and protected from UV-light. Improper storage can initiate degradation, which can result in taste and odour generation, and colour changes, together with having a negative effect on the physical properties of the material.

Pipes and fittings can be installed outside of buildings, but only when protected by an external UV stabilised layer, such as a black polyethylene coating.

APPLICABLE STANDARDS

PP-R pipes and fittings should be manufactured in accordance with the standard EN ISO 15874 - Plastics piping systems for hot and cold water installations - which is in four parts, and was updated in 2013. Please note that some manufacturers still refer to the German standards DIN 8077, DIN 8078 and DVGW W544, which are still valid.

TABLE 4.40: PERMISSIBLE WORKING PRESSURE OF PP-R PIPE AND FITTINGS

Temperature	Service life (Years)	Pipe S 5		Pipe S 3.2		Pipe S 2.5	
		Pipe SDR 11		*Pipe SDR 7.4*		*Pipe SDR 6*	
		Pipe PN 10		*Pipe PN 16*		*Pipe PN 20*	
		Permissible working pressure (bar) (water)					
		SF=1.25	*SF=1.5*	*SF=1.25*	*SF=1.5*	*SF=1.25*	*SF=1.5*
10°	1	21.1	17.6	33.4	27.8	42.0	35.0
	5	20.0	16.6	31.6	26.4	39.8	33.2
	10	19.3	16.1	30.6	25.5	38.5	32.1
	25	18.7	15.6	29.6	24.7	37.3	31.1
	50	18.2	15.2	28.8	24.0	36.3	30.3
	100	17.7	14.8	28.1	23.4	35.4	29.5
20°	1	18.0	15.0	28.6	23.8	36.0	30.0
	5	16.9	14.1	26.8	22.3	33.8	28.1
	10	16.4	13.7	26.1	21.7	32.8	27.3
	25	16.0	13.3	25.3	21.1	31.8	26.5
	50	15.5	12.9	24.5	20.4	30.9	25.7
	100	15.0	12.5	23.8	19.8	29.9	24.9
30°	1	15.3	12.8	23.4	20.2	30.6	25.5
	5	14.4	12.0	22.8	19.0	28.7	23.9
	10	13.9	11.6	22.0	18.3	27.7	23.1
	25	13.4	11.2	21.3	17.3	26.8	22.3
	50	13.1	10.9	20.7	17.1	26.1	21.8
	100	12.8	10.6	20.2	16.9	25.5	21.2

TABLE 4.40: PERMISSIBLE WORKING PRESSURE OF PP-R PIPE AND FITTINGS (CONTINUE)

Temperature	Service life (Years)	Pipe S 5		Pipe S 3.2		Pipe S 2.5	
		Pipe SDR 11		Pipe SDR 7.4		Pipe SDR 6	
		Pipe PN 10		*Pipe PN 16*		*Pipe PN 20*	
		Permissible working pressure (bar) (water)					
		SF=1.25	*SF=1.5*	*SF=1.25*	*SF=1.5*	*SF=1.25*	*SF=1.5*
40°	1	12.9	10.8	20.5	17.1	25.8	21.5
	5	12.1	10.1	19.2	16.0	24.2	20.2
	10	11.8	9.8	18.7	15.6	23.6	19.6
	25	11.3	9.4	18.0	15.0	22.6	18.8
	50	11.0	9.2	17.5	14.5	22.0	18.3
	100	10.7	8.9	16.9	14.1	21.3	17.8
50°	1	11.0	9.2	17.5	14.5	22.0	18.3
	5	10.2	8.5	16.2	13.5	20.4	17.0
	10	9.9	8.2	15.7	13.1	19.7	16.5
	25	9.6	8.0	15.2	12.6	19.1	15.9
	50	9.3	7.7	14.7	12.2	18.5	15.4
	100	8.9	7.4	14.2	11.8	17.8	14.9
60°	1	9.3	7.7	14.7	12.2	18.5	15.4
	5	8.6	7.2	13.7	11.4	17.2	14.3
	10	8.3	6.9	13.2	11.0	16.6	13.8
	25	8.0	6.7	12.6	10.5	15.9	13.3
	50	7.7	6.4	12.1	10.1	15.3	12.7
70°	1	7.8	6.5	12.4	10.3	15.6	13.0
	5	7.2	6.0	11.4	9.5	14.3	11.9
	10	7.0	5.9	11.1	9.3	14.0	11.7
	25	6.1	5.1	9.6	8.0	12.1	10.1
	50	5.1	4.3	8.1	6.7	10.2	8.5
80°	1	6.5	5.5	10.4	8.6	13.1	10.9
	5	5.7	4.8	9.1	7.6	11.5	9.6
	10	4.8	4.0	7.6	6.3	9.6	8.0
	25	3.8	3.2	6.1	5.1	7.6	6.4
95°	1	4.6	3.9	7.3	6.1	9.2	7.7
	5	3.0	2.5	4.8	4.0	6.1	5.0
	10	2.6	2.1	4.0	3.4	5.1	4.2

C) PP-B KEY FEATURES

1. *Design Freedom*

The pipe system producer has freedom to develop products with the optimum stiffness-to-weight ratio in sizes from 100 to 4 000 mm diameter using solid wall or different structured wall designs such as cellular, corrugated, and spiral wound systems.

Injection moulded components and sheets can be produced from the same material and these can used to fabricate other system fittings, such as manholes and chambers as shown in the photographs on the following page.

The internal bore of the pipe can be coloured for optimum CCTV inspection, and a UV stabliser added to protect system components if they are stored outside prior to installation.

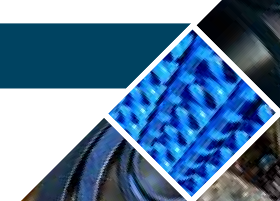


FIGURE 4.27

2. *Ease of manufacture*

PP pipes can be extruded on any modern single screw extruder that is used to produce PE pipes with only minor process adjustments to account for differences in viscosity and other properties. Twin walled PP pipes can be produced using PE corrugators but, to optimise the profile design, new mould blocks are recommended.

3. *Lightweight and easy to install*

The specific weight of PP is less than that of PE, and the stiffness is significantly higher, hence the pipes are lighter in weight and lower in cost than the equivalent size of PE pipe. Compared to concrete, clay, or asbestos cement pipes, PP systems are very easy to handle on site and require much less mechanical handling equipment. Figures 4.27-2.29 illustrate this point nicely.

4. *Flexibility and ability to absorb external loading*

Flexible pipes absorb external loads by deformation. This small amount of ovalisation transfers the stresses to the side-fill material around the pipe with a negligible reduction in the flow capacity of the sewer. In rigid pipes the stresses are retained in the pipe wall which can lead to cracking and failure especially where chemical attack has led to wall thickness reductions.

FIGURE 4.28

FIGURE 4.29

5. *Toughness and resistance to site and transportation damage*

PP materials are very tough and will not crack or shatter during transportation, handling and installation (as can be the case with concrete, clay, or asbestos cement pipes). Similarly, adding later house connections to the system does not pose a major problem or risk causing major damage to the existing pipe.

6. *Hydraulically smooth bore*

Plastic pipes have very smooth internal surfaces and consequently a very low friction factor. Typically a PP sewage pipe will have a friction factor (k) or equivalent sand roughness of 0.02 to 0.05 mm and there will be minimal increase during its lifetime.

7. *Easy to joint with high integrity welded jointing available*

Jointing can be using integral push-fit sockets with rubber rings or on plain ended pipes using double sockets or mechanical fittings. PP systems can also be welded to prevent the leakage of hazardous fluids or infiltration of ground water, or to eliminate the threat of root intrusion in heavily wooded areas. This can be done by the butt fusion of solid wall and some structured wall PP pipes, or the extrusion welding of socket joints.

8. *Corrosion Resistance*

Corrosion is a major problem with concrete and asbestos cement pipes due to the formation of sulphuric acid on the pipe wall as a result of the oxidation of hydrogen sulphide in the sewer atmosphere. This leads to loss of material from the pipe wall and the eventual collapse of the sewer, particularly at high temperatures and low flow rates. PP-B is resistant to acid attack and can be used to line corroded sewers.

9. *Abrasion Resistance*

Abrasion Resistance Polymers such as HDPE and PP have a much higher resistance to abrasion than concrete, clay or asbestos cement pipes. It is for this reason that PE and PP pipes are used to carry abrasive slurries in mining and mineral processing operations. Abrasion resistance can be critical in regions where sand is carried in the effluent.

PP-B AREAS OF IMPLEMENTATION

1. Soil and waste pipe systems inside buildings.
2. Sewerage networks including manholes and other chambers.
3. Storm water and other drainage networks including manholes, chambers and culverts.
4. High quality ducting and conduits.
5. Gravity pipe industrial applications including large diameter sea water cooling and desalination intakes and outfalls.
6. Storage tanks for a wide range of commercial and industrial applications.

PP-B for Gravity Sewage and Drainage Applications

In Europe, the use of PP-B for gravity applications has a long track record. It was initially used for soil and waste systems inside of buildings but then, as the material was further developed, large diameter pipe producers started switching over to PP-B from HDPE due to its higher level of stiffness. The short-term E modulus of HDPE is typically 1100 MPa, whilst PP-B can range from 1300 to 1700 MPA, with some grades even reaching 2000 MPa. Hence, PP-B pipes of the same nominal stiffness are considerably lighter than equivalent HDPE pipes.

PP-B is now established as the leading material for producing solid and structured wall gravity pipes and fittings in parts of Europe, and is now being adopted in countries such as China. Figure 4.30 shows the relative weights of nominal stiffness 8 KPa pipes manufactured from different materials, explaining the popularity of PP-B in Europe.

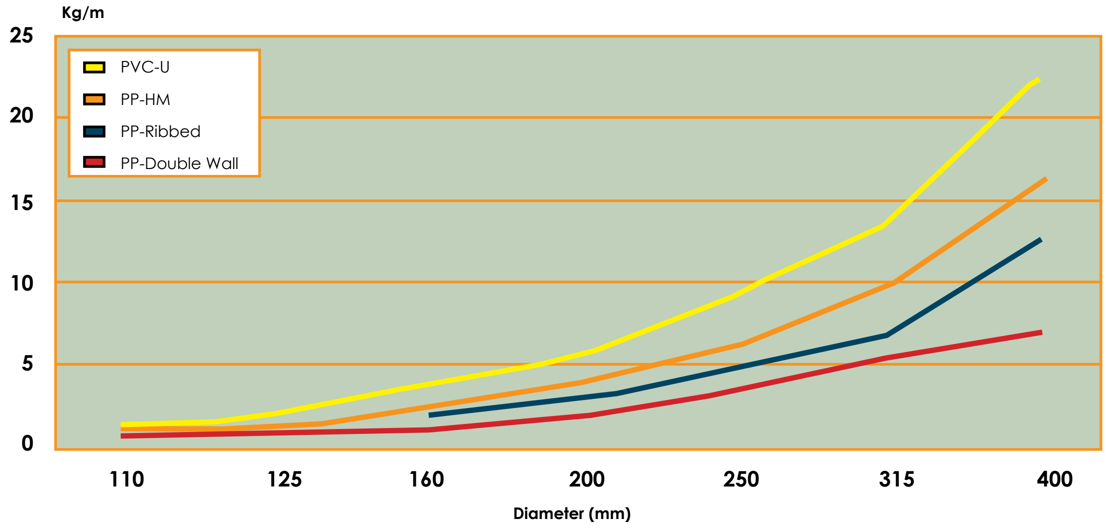


FIGURE 4.30: WEIGHT OF SN 8 PIPES MADE FROM PVC-U, PP-B AND HIGH MODULUS PP-B (PP-HM)

The PVC-U and PP-HM examples are solid wall pipes, while the PP ribbed and double walled pipes are examples of structured wall pipes produced using PP-B. A PP-B material having an E modulus of higher than 1500 MPa can be referred to as a PP-HM (High Modulus) material.

Figure 4.31 gives some examples of the different structured walled systems available. The key point to remember is that while structured wall pipes are more challenging and expensive to produce than solid wall examples, they use considerably less material to achieve the required level of stiffness, particularly at pipe sizes in excess of 300 mm diameter.

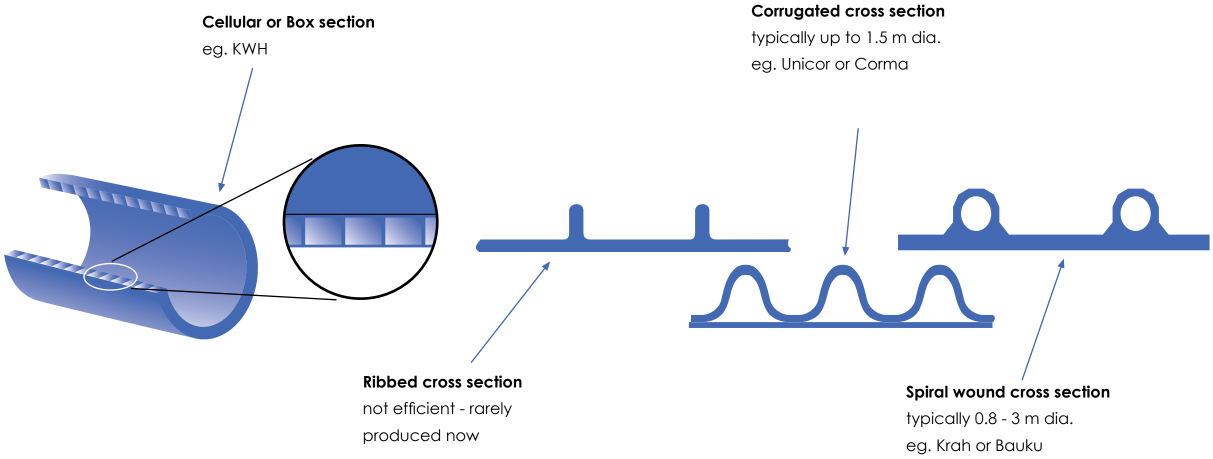


FIGURE 4.31: EXAMPLES OF STRUCTURED WALL PIPES THAT CAN BE PRODUCED USING PP-B (SANS / ISO 21138)

TABLE 4.41: TYPICAL PP-B PHYSICAL PROPERTIES

Property	PP-B Typical Value	PP-HM Typical Value	Test Method
Density	900 kg/m³	900 kg/m³	ISO 1183
Melt Flow Rate (230 °C/2.16 kg)	0.5 g/10min	0.3 g/10min	ISO 1133
Flexural Modulus (2 mm/min)	1500 MPa	1700 MPa	ISO 178
Tensile Strain at Yield (50 mm/min)	10 %	8 %	ISO 527-2
Tensile Stress at Yield (50 mm/min)	29 MPa	31 MPa	ISO 527-2
Charpy Impact Strength, notched (23°C)	60 kJ/m²	50 kJ/m²	ISO 179/1eA
Charpy Impact Strength, notched (-20°C)	6 kJ/m²	5 kJ/m²	ISO 179/1eA

APPLICABLE STANDARDS

Soild wall PP-B pipes and fittings for buried applications are covered by EN 1852 - Plastics piping systems for non-pressure underground drainage and sewerage – Polypropylene

Structured wall pipes and fittings for buried applications are covered by EN 13476 - Plastics piping systems for non-pressure underground drainage and sewerage - structured-wall piping systems of PVC-U, PP and PE, which is in three parts. The applicable ISO standard, ISO 21138, is essentially identical to EN 13476.

Soil and waste PP-B pipes and fittings are covered by EN 1451 – Plastics piping systems for soil and waste discharge (low and high temperature) within the building structure.

FLEXIBLE PVC HOSE

BASIC DESCRIPTION

Introduction

Flexible PVC hose for use in mining and industrial applications is manufactured to SANS 1086 “*Flexible polyvinyl chloride (PVC) pressure hose*”. The standard construction of these hoses consists of an inner layer, reinforcing yarn and an outer layer. The outer layer may be smooth or fluted for additional abrasion resistance.

The layers are manufactured from plasticised PVC (poly vinyl chloride) polymer, a plastic that is both flexible and durable. Hoses are marked with important information containing the manufacturer name, nominal size of the hose (refers to the nominal inner diameter), SANS mark and specification number, date of manufacture/batch number.

PVC flexible hoses are used for conveyance of water or air at temperatures between 10 and 40° C. The hoses offer the following properties:

- Excellent abrasion resistance
- Good flexibility
- Long service life
- Desirable fire properties - self extinguishing
- Good chemical resistance against a wide range of chemicals
- Supplied in various lengths, coiled for ease of transport

TYPES AND USES

Flexible PVC hoses have evolved into different applications due to their versatility. These include:

- Underground mining hoses for water and air conveyance (orange, green, blue)
- Dragline hoses with UV resistance for agricultural use (black)
- Clear PVC industrial hoses for water and air conveyance (clear)
- Red fire hoses for fire fighting equipment (red)

DIMENSIONS

Table 4.42 contains the standard dimensions of PVC flexible hose manufactured to SANS 1086.

TABLE 4.42: DIMENSIONS OF PVC FLEXIBLE HOSE

Nominal Size of Hose, mm	Internal Diameter (ID), mm	Wall Thickness , mm*
4	3.6 – 4.4	2.3
5	4.6 – 5.4	2.3
6.3	5.5 – 7.1	2.4
8	7.2 – 8.8	2.8
10	9.2 – 10.8	2.9
12.5	11.7 – 13.3	3.3
16	15.2 – 16.8	3.5
20	18.4 – 20.8	3.6
25	23.8 – 26.2	4.1
32	30.8 – 33.2	4.6
40	37.0 – 41.5	5.8
50	48.5 – 51.5	6.8

** Tolerance is applicable to this dimension*

TABLE 4.43: HYDRAULIC PRESSURE RATING OF FLEXIBLE HOSE

Nominal Size of Hose, mm	Maximum Operating Pressure, kPa
4	1 700
5	1 700
6.3	1 700
8	1 700
10	1 700
12.5	1 700
16	1 500
20	1 500
25	1 400
32	1 000
40	880
50	880

NOTE: 100 kPa = 1 Bar

Please bear in mind that maximum working pressure needs to be temperature de-rated for temperatures exceeding 25 °C. The following table contains de-rating factors to be multiplied by the working pressure when hoses are to be used at elevated temperatures.

TABLE 4.44: TEMPERATURE REDUCTION FACTORS FOR FLEXIBLE HOSE

Temperature	Multiply working pressure by
25°C	0.90
30°C	0.80
35°C	0.70
40°C	0.60

Note: For temperatures exceeding 40 °C the de-rating factors should be confirmed with the manufacturer.

Fittings

Laboratory tests confirm that correctly assembled open-ended fittings are the most reliable. Open-ended fittings comprise a tailpiece and a clamp, which leaves the end of the hose open to the atmosphere. Ball-end type tailpieces are recommended in preference to all other types.

Un-vented captive nut fittings should be used with caution, as a pressure buildup can occur inside the nut, forcing the fluid into the capillary space in the reinforcing yarn, which may ultimately lead to hose failure.

However, captive nuts can be made suitable by simply drilling a small hole through the back of the nut to ventilate the end of the hose to atmosphere. **Do not use sharp barb fittings!**

Mining Hoses

SAPPMA approved mining hoses were specially developed for South African mining conditions and are used for a range of applications including: compressors, jack hammers, pneumatic tools, high-pressure air and water conveyance, and explosives loading.

SAPPMA approved mining hoses are manufactured with a PVC inner liner, polyester reinforcing, and PVC outer cover, and have the following beneficial properties: long lasting, lightweight, flexible, cut and abrasion resistant, oil resistant and non-absorbent, tested for high burst pressures, and able to withstand temperatures ranging from 0˚C to 60˚C.

WARNING: As temperatures increase, pressure ratings decrease.

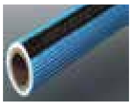
TABLE 4.45: MD500 ORANGE MINING HOSE

Standard Duty

Nominal Dimensions						
Internal Diameter (mm)	10	12	20	25	32	50
Pressure (kPa)						
Working	1 700	1 700	1 500	1 400	1 000	880
Burst	6 800	6 800	6 000	5 600	4 000	3 500
Mass per metre (g) (nominal)	185	259	415	586	852	1 936

TABLE 4.46: M4508 BLUE MINING HOSE

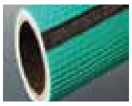
Medium Duty



Nominal Dimensions						
Internal Diameter (mm)	10	12	20	25	32	50
Pressure (kPa)						
Working	1 700	1 700	1 500	1 400	1 000	880
Burst	6 800	6 800	6 000	5 600	4 000	3 500
Mass per metre (g) (nominal)	185	259	415	586	852	1 936

TABLE 4.47: M5008 GREEN MINING HOSE

Heavy Duty



Nominal Dimensions							
Internal Diameter (mm)	10	12	20	25	32	40	50
Pressure (kPa)							
Working	1 700	1 700	1 500	1 400	1 000	880	880
Burst	6 800	6 800	6 000	5 600	4 000	3 500	3 500
Mass per metre (g) (nominal)	199	277	578	683	947	1 421	2 053

Dragline Irrigation Hoses

- Longitudinally reinforced to prevent stretching when dragged
- Long lasting
- Cut and abrasion resistant
- UV stabilised

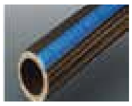
SAPPMA Dragline irrigation hoses have a PVC inner liner and outer cover, reinforced with polyester yarn.

Assembly:

Fittings must not have sharp edges or barbs. The hose should be fitted using at least one hose clamp. **See section on Hose Assembly.**

TABLE 4.48: I772

Standard Duty



Nominal Dimensions		
Internal Diameter (mm)	12	20
Pressure (kPa)		
Working	800	800
Burst	3 500	3 200
Mass per metre (g)	173	333

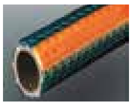
Garden Hoses

- Highly flexible
- Easy to coil all year round
- UV stabilised
- Suitable for: domestic gardens, certain agricultural and industrial applications

SAPPMA approved garden hoses have a PVC inner liner and outer cover, reinforced with polyester yarn.

TABLE 4.49: DLD25

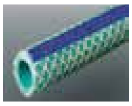
Standard / Orange stripe
Working pressure 750 kPa
Burst pressure of 3 000 kPa



Nominal Dimensions		
Internal Diameter (mm)	12	20
Mass per metre (g)	150	290

TABLE 4.50: DHD60

Industrial / Blue stripe
Working Pressure 1 000 kPa
Burst pressure of 4 000 kPa



Nominal Dimensions			
Internal Diameter (mm)	12	20	25
Mass per metre (g)	150	393	529

* *Design life is subject to adherence with the care instructions.*

Industrial Hoses

- Are flexible
- Have high burst and working pressures
- Have good resistance to fuels, gases and chemicals

TABLE 4.51: I6002

Clear Wall Hose

Low-pressure applications such as laboratory tubing, aquariums

Chemical and abrasion resistant*.

Good clarity

Nominal Dimensions													
Internal Diameter (mm)	3	4	5	6.3	8	10	12.5	16	20	25	32	40	50
Wall Thickness													
I6001	0.8	0.8	0.8	1.10	1.10	1.2	1.6	1.6	1.6	-	-	-	-
I6002	1.4	-	1.4	2.16	2.16	2.61	2.61	2.7	2.7	3.3	3.3	3.3	3.3

TABLE 4.52: I7009

Clear Reinforced Hose

High-pressure applications such as air, diluted acids and oils

Good chemical resistance*

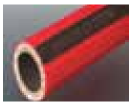
Nominal Dimensions												
Internal Diameter (mm)	3	5	6.3	8	10	12.5	16	20	25	32	40	50
Outside Diameter (mm)	5.8	7.6	9.6	13.4	15.6	16.4	20.5	24.4	30.8	39.4	49.1	59.6
Pressure (kPa)												
Working	1 700	1 500	1 300	1 200	1 100	1 100	1 000	1 000	1 000	900	800	700
Burst	7 000	6 600	5 900	5 200	4 500	4 200	4 000	4 000	4 000	3 800	3 600	3 000
Mass (g/m)	51	68	95	113	133	175	231	335	524	812	1 311	1 826

TABLE 4.53: F694

Fire Reel Hose

10-year design life / Specially designed for the fire-fighting industry

Features heavy duty nylon reinforcing to withstand the high pressure encountered in municipal mains



Nominal Dimensions		
Internal Diameter (mm)	12.5	20
Mass per metre (g)		
Working	1 700	1 500
Burst	6 800	6 000
Mass per metre (g)	259	414

Suction & Delivery Hoses

Suction & Delivery hoses are specifically designed for the suction of liquids and mixtures for various applications in the agricultural, building, mining, and fishing industries.

Suction & Delivery hoses feature the ability to withstand up to 99% vacuum and offers a full flow, smooth bore, ultra-violet stabilisation, and temperature range of 0°C to 60°C.

It has a rigid PVC core, co-extruding with a flexible PVC outer cover, which is spirally wound to form a reinforced hose.

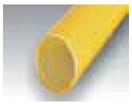
Note: these hoses falls within family of products carrying the SAPPMA mark of quality reassurance.

TABLE 4.54: IS655

Standard Duty

Yellow clear

Good flexibility / Lightweight

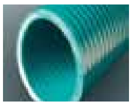


Nominal Dimensions (mm)							
Internal Diameter	25	32	40	50	64	75	100
Outside Diameter	30	39	47	57	73	85	111
Mass (kg/m)	0.32	0.56	0.67	0.79	1.32	1.61	3.08
Bending radius (mm)	40	60	80	105	135	180	295
% Vacuum	99	99	99	99	99	99	99

TABLE 4.55: IS866

Heavy Duty

Abrasion and crush resistant

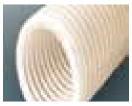


Nominal Dimensions (mm)											
Internal Diameter (mm)	25	32	40	50	64	75	100	125	150	200	250
Outside Diameter (mm)	32	41	49	60	76	87	116	140	170	229	279
Working Pressure (kPa)	970	720	720	620	620	480	380	380	240	240	240
Mass per metre (kg/m)	0.40	0.68	0.94	1.11	1.68	2.00	3.37	5.20	6.83	12.51	15.58
Bending Radius (mm)	80	120	170	250	350	400	500	1 000	1 500	2 000	2 500
% Vacuum	99	99	99	99	99	99	99	95	95	90	85

TABLE 4.56: IS868

Non-toxic

Specially formulated for the conveyance of food products



Nominal Dimensions (mm)										
Internal Diameter (mm)	25	32	40	50	64	75	100	125	150	200
Outside Diameter (mm)	32	41	49	60	76	87	113	140	170	221
Working Pressure (kPa)	970	720	720	620	620	480	380	380	240	240
Mass per metre (kg/m)	0.41	0.70	0.85	1.14	1.75	2.05	3.19	5.18	7.31	8.63
Bending Radius (mm)	80	120	170	250	350	400	500	1 000	1 500	2 000
% Vacuum	99	99	99	99	99	99	99	95	95	90

TABLE 4.57: IS863

Medium Duty White Super Flexi

Highly flexible

Lightweight

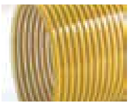
Nominal Dimensions					
Internal Diameter (mm)	100	125	150	200	250
Outside Diameter (mm)	111	136	159	210	266
Mass (kg/m)	2.88	4.53	4.73	8.36	11.28
Bending Radius (mm)	400	800	900	1 200	1 500
% Vacuum	98	96	95	90	90

TABLE 4.58: IS865

Extra-Heavy Duty

Abrasion resistant

Opaque



Nominal Dimensions					
Internal Diameter (mm)	100	125	150	200	250
Outside Diameter (mm)	118	141	171	239	280
Mass (kg/m)	3.31	5.13	7.00	12.53	15.50
Bending Radius (mm)	800	1 500	1 500	2 900	3 100
% Vacuum	98	97	95	90	85

HOSE CONSTRUCTION

Hoses consist of:

Liner *- Manufactured with flexible PVC. Resistant to the medium being conveyed. Temperature range -20° to +60°C. Can be conductive, non-conductive, or anti-static.*

Reinforcing *- Manufactured with high density polyester. Resists pressure. Types of reinforcing include polyester yarn, spiral rigid PVC, nylon, static wire, colour trace, tyre cord, rayon, and kevlar.*

Cover *- Manufactured with flexible PVC. Protects the reinforcing and resists the outer elements. The cover can have the following properties: abrasion resistance, UV resistance, weather resistance coloured, chemical resistance, and heat resistance.*

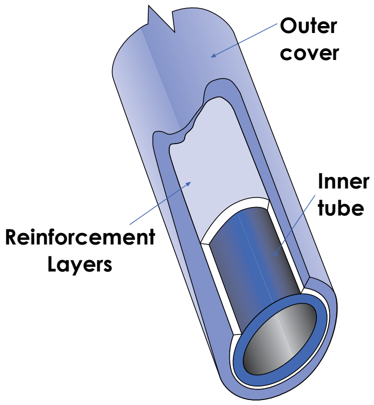


FIGURE 4.32: HOSE CROSS-SECTION

HOSE ASSEMBLY

Fittings must not have sharp edges or barbs. The hose should be fitted using at least one hose clamp.

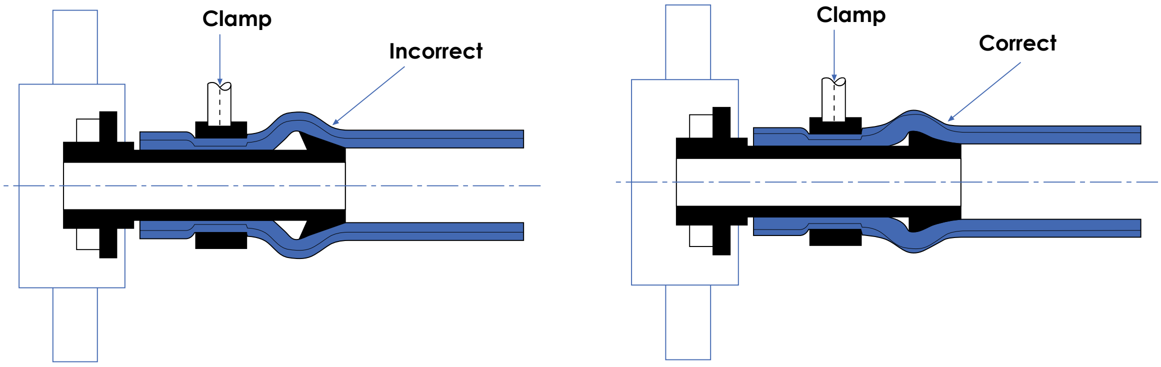


FIGURE 4.33: HOSE ASSEMBLY

CHAPTER 5:
SPECIFICATION

IMPORTANCE OF STANDARDS

ISO standards for piping are now forming the basis for the new generation of national standards issued by the SOUTH AFRICAN NATIONAL STANDARDS authority (SANS). The latest revised standards are even more comprehensive than earlier versions, and now cover aspects such as material selection, pipes, fittings, and assembly in greater detail.

Specific permit conditions for products are issued to pipe converters by certification authorities. In return, pipe manufacturers which comply with these permit conditions are entitled to print the relevant SANS standard's number and/or the logo of that particular certification authority on their products. The logo of the certification authority signifies that the manufacturer has adhered to the quality requirements according to a particular national standard. These permit conditions are enforced through audits and laboratory tests which are carried out according to the relevant SANS standard on a particular product by an independent certification authority accredited by the SOUTH AFRICAN NATIONAL ACCREDITATION SYSTEM (SANAS) to do product conformance certifications.

CODES OF PRACTICE

The main purpose of the standardisation of any code of practice is to improve, regulate, and promote quality (fitness for purpose) of goods and services, with the aim of maintaining and improving the quality of life throughout society. The legislation adopting a particular SANS standard is motivated by paying attention to matters within society such as the protection of public safety, health, and the environment. Standardisation provides guidelines to society such that resources can be utilised more efficiently through communication, simplification, and product identification. In return, this eliminates trade barriers between willing partners, and stimulates fair and efficient competition and trade at all levels throughout society.

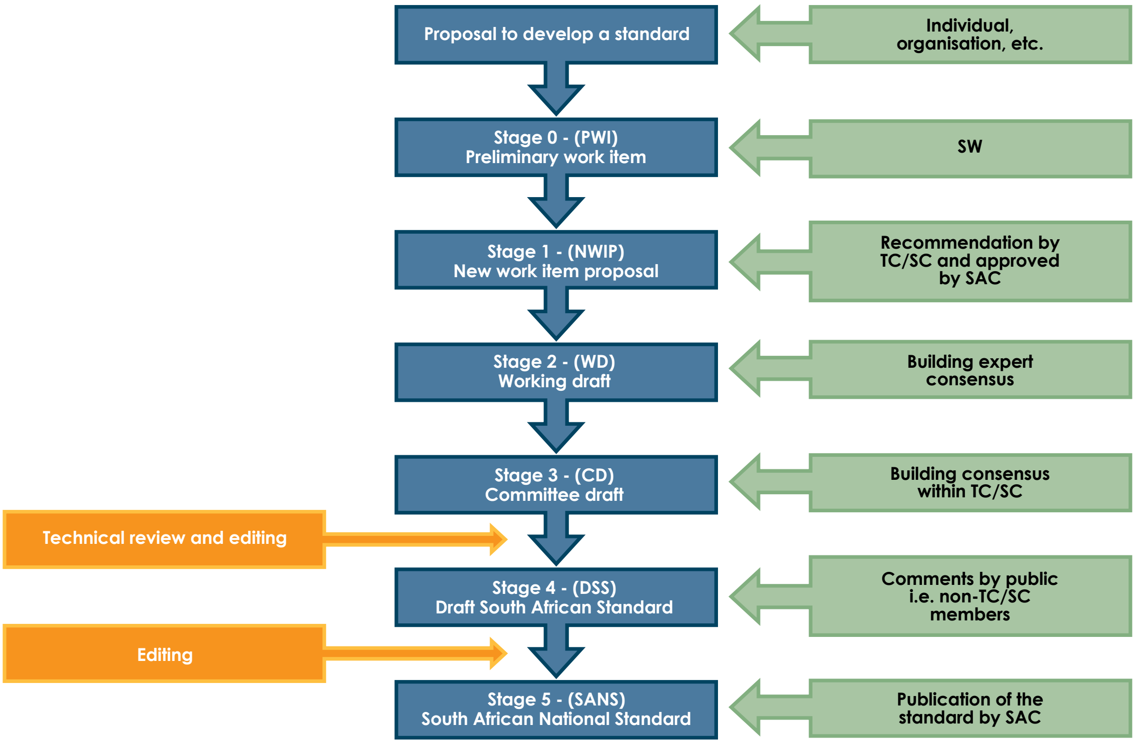


FIG 5.1 – STAGES IN THE DEVELOPMENT OF A SANS STANDARD

(Reference: SANS 1-1: 2012 figure 1)

STANDARDS RELEVANT TO PLASTIC PIPING SYSTEMS

The standard codes of practices relevant to ensure adequate quality for plastic piping systems are mainly divided into the three groups: raw material standards; product standards; and installation standards. In summary, the purposes of these standards are:

- **Raw material standards** are concerned with the quality and the properties of the raw material used to process and manufacture plastic pipes and its components. The raw materials used should meet the requirements in such a way that processing, manufacturing, and production of a given product is possible and that the final product will comply with the relevant product and performance standards and requirements.

Note: SANS 9080:2016 Plastics piping and ducting systems — Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation. Various other material properties important for the functioning of the system are referred to in raw material form as well as finished product.

- **Product standards** are concerned with the quality of the final product to ensure that the requirements of specifiers and/or the client for a given application are satisfied, as well as to ensure that the product and its components quality is such that it will meet the service demands it was intended for.

- **Installation standards** are concerned with the quality of the workmanship on-site, and the correct practices and procedures to be followed during the handling and installation of a product to meet the service requirements of the end-user.

TABLE 5.1: COMMONLY USED STANDARDS:

SANS Number	Year	Ed.	Title
SANS 10467	2010	1.00	Plastics piping systems for pressure and non-pressure drainage and sewerage – glass reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin
SANS 10639	2010	1.00	Plastics piping systems for pressure and non-pressure water supply – glass reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin
SANS 1086	2015	1.02	Flexible Polyvinal chloride (PVC) pressure hose
SANS 15874-1	2004	1.00	Plastics piping systems for hot and cold water installations - Polypropylene (PP) Part 1: General
SANS 15874-2	2004	1.00	Plastics piping systems for hot and cold water installations - Polypropylene (PP) Part 2: Pipes
SANS 15874-3	2004	1.00	Plastics piping systems for hot and cold water installations - Polypropylene (PP) Part 3: Fittings
SANS 15874-5	2004	1.00	Plastics piping systems for hot and cold water installations - Polypropylene (PP) Part 5: Fitness for purpose of the system
SANS 15875-1	2004	2.00	Plastics piping systems for hot and cold water installations - Crosslinked polyethylene (PE-X) Part 1: General
SANS 15875-2	2004	2.00	Plastics piping systems for hot and cold water installations - Crosslinked polyethylene (PE-X) Part 2: Pipes
SANS 15875-3	2004	2.00	Plastics piping systems for hot and cold water installations - Crosslinked polyethylene (PE-X) Part 3: Fittings
SANS 15875-5	2004	2.00	Plastics piping systems for hot and cold water installations - Crosslinked polyethylene (PE-X) Part 5: Fitness for purpose of the system
SANS 1601	2013	2.02	Structured wall pipes and fittings of unplasticized poly(vinyl chloride) (PVC-U) for buried drainage and sewerage systems

SANS Number	Year	Ed.	Title
SANS 16422	2007	1.00	Pipes and joints made of oriented unplasticised poly(vinyl chloride) (PVC-O) for the conveyance of water under pressure - Specifications
SANS 2001-DP1	2011	1.01	Construction works Part DP1: Earthworks for buried pipelines and prefabricated culverts
SANS 2001-DP4	2010	1.00	Construction works Part DP4: Sewers
SANS 21138-1	2008	1.00	Plastics piping systems for non-pressure underground drainage and sewerage - Structured-wall piping systems of unplasticized poly(vinyl chloride) (PVC-U), polypropylene criteria for pipes, fittings and system polyethylene (PE) Part 1: Material specifications and performance(PP) and
SANS 21138-2	2008	1.00	Plastics piping systems for non-pressure underground drainage and sewerage - Structured-wall piping systems of unplasticised poly(vinyl chloride) (PVC-U), polypropylene (PP) and polyethylene (PE) Part 2: Pipes and fittings with smooth external surface, Type A
SANS 21138-3	2008	1.00	Plastics piping systems for non-pressure underground drainage and sewerage - Structured-wall piping systems of unplasticised poly(vinyl chloride) (PVC-U), polypropylene (PP) and polyethylene (PE) Part 3: Pipes and fittings with non-smooth external surface, Type B
SANS 21307	2011	1.00	Plastics pipes and fittings – butt fusion jointing procedures for polyethylene (PE) pipes and fittings
SANS 22391-1	2008	1.00	Plastics piping systems for hot and cold water installations - Polyethylene of raised temperature resistance (PE-RT) Part 1: General
SANS 22391-2	2008	1.00	Plastics piping systems for hot and cold water installations - Polyethylene of raised temperature resistance (PE-RT) Part 2: Pipes
SANS 22391-3	2008	1.00	Plastics piping systems for hot and cold water installations - Polyethylene of raised temperature resistance (PE-RT) Part 3: Fittings
SANS 370	2013	1.02	Steel mesh reinforced polyethelene (PE) pipes for water supply
SANS 4427-1	2008	1.00	Plastics piping systems - Polyethylene (PE) pipes and fittings for water supply - Part 1: General
SANS 4427-2	2008	1.00	Plastics piping systems - Polyethylene (PE) pipes and fittings for water supply - Part 2: Pipes
SANS 4427-3	2008	1.00	Plastics piping systems - Polyethylene (PE) pipes and fittings for water supply - Part 3: Fittings
SANS 4427-5	2008	1.00	Plastics piping systems - Polyethylene (PE) pipes and fittings for water supply - Part 5: Fitness for purpose of the system
SANS 4437-1	2014	1.00	Plastics piping systems for the supply of gaseous fuels - Polyethylene (PE) Part 1: General
SANS 4437-2	2014	1.00	Plastics piping systems for the supply of gaseous fuels - Polyethylene (PE) Part 2: Pipes
SANS 4437-3	2014	1.00	Plastics piping systems for the supply of gaseous fuels - Polyethylene (PE) Part 3: Fittings

SANS Number	Year	Ed.	Title
SANS 4437-5	2014	1.00	Plastics piping systems for the supply of gaseous fuels - Polyethylene (PE) Part 5: Fitness for purpose of the system
SANS 674	2015	1.03	Steel-reinforced spirally wound PE drainage and sewer pipes
SANS 791	2014	5.04	Unplasticised poly(vinyl chloride) (PVC-U) sewer and drain pipes and pipe fittings
SANS 8772	2010	1.00	Plastics piping systems for non-pressure underground drainage and sewerage - Polyethelene (PE)
SANS 8773	2007	2.00	Plastics piping systems for non-pressure underground drainage and sewerage - Polypropylene (PP)
SANS 966-1	2014	3.07	Components of pressure pipe systems Part 1: Unplasticised poly(vinyl chloride) (PVC-U) pressure pipe systems
SANS 966-2	2013	1.07	Components of pressure pipe systems Part 2: Modified poly(vinyl chloride)(PVC-M) pressure pipe systems
SANS 967	2014	2.06	Unplasticised poly(vinyl chloride) (PVC-U) soil, waste and vent pipes and pipe fittings

This table is not exhaustive, many more types of plastic pipes are covered by the SANS. SAPPMA holds a list of standards related to the quality of the products, components and materials related to the products within the family of products audited by SAPPMA. Please refer to the SAPPMA website for further information www.sappma.co.za.
Note: All standards referred to are the latest revision at the date of publication.

STANDARDS AND ORGANISATIONS

Oftentimes there is a misconception with regard to the role of accreditation system authorities, certification bodies, and the national standards. In the last few years there have been significant changes between these authorities and their individual roles within the industry which, in some cases, affected their mandate. As a result of these changes it is essential to understand the differences and to be able to differentiate between the terms.

SANS

SANS is the abbreviation for the South African National Standard. This term refers to the standard (or for example a particular product standard / specification) itself. With regard to products, it is a document that specifies the minimum performance requirements for a product. It is not owned by any company, but by Standards SA. The mandate of Standards SA is to create, manage and maintain all the national and product standards. A client would typically specify that a product needs to comply with a specific SANS standard, i.e. SANS 966 for PVC pipes and components. Recently, these standards have mainly been adopted by Standards SA from the international ISO standards. However, the standard can originate from anywhere (refer to figure 5.1 on page 136).

SANAS

SANAS (South African National Accreditation System) is the only national authority authorised by government to accredit certification authorities, thereby allowing them to do product conformance certifications. In order for a third party certification body to be able to certify clients according to the SANS standards on a particular product, they need first to be accredited by SANAS, before they are able to do product conformance certifications on any product, system or service. The SANS/ISO 17065 is the only national standard which regulates how certification bodies are accredited as a certification authority. Certification to this standard enables a certification authority to carry out audits and retrieve samples from producers and manufacturers for laboratory testing. Once a certification authority has been accredited by SANAS to do conformance certifications, they are entitled to certify their clients' product to a specific SANS standard. They will then display the SANAS logo on the certificates they issue to indicate that they meet the requirements to carry out certifications for a given service or product.

SABS

SABS (South African Bureau of Standards) is a company accredited by SANAS to audit, sample, and certify manufacturers to a particular SANS standard on specified products. Although the SABS share a building in Pretoria with Standards SA, they do not own the SANS standards. They are, however, accredited by SANAS to do product conformance testing and certifications on various products according to the SANS standard. The SABS is able to sell the SANS standards to the public, but it should be noted that they do not own the SANS standard, since the standards have been adopted by Standards SA and belong to the public. A product bearing the SABS mark complies with the SANS standard as long as they are accredited by SANAS to do certifications on a particular product.

FIG 5.2 – TYPICAL EXAMPLE OF A SABS MARK ON A PRODUCT OR CERTIFICATE

SATAS

SATAS (South African Technical Auditing Service) is a company accredited by SANAS to audit, sample, and certify manufacturers to a particular SANS standard on specified products. The SATAS mark can therefore be specified and carries the same weight as an SABS mark does on various products for which SANAS has accredited SATAS to do so. A product bearing the SATAS mark complies with the SANS standard as long as they are accredited by SANAS to do certifications on a particular product.

FIG 5.3 – TYPICAL EXAMPLE OF A SATAS MARK ON A PRODUCT OR CERTIFICATE

SABS

Permit to Apply Certification Mark

EXAMPLE

CERTIFICATE

No 000/0

This is to certify that:

……………………..

Company registration no. …………..

is hereby granted permission to apply the following logo to plastic products EAC/IAF 14 NACE 22, manufactured and in compliance with

SANS ……….

as described in schedule MS25 of this certificate.

South African Technical Auditing Services Pty Ltd

(ISO 17065 : Product Certification)

……………………………………

Managing Director

Date issued: ……………

Expiry date: …………..

EXAMPLE

Note: An approved certification body permits a manufacturer to apply the certification mark to the products falling within the requirements of the specific permit conditions and standard. The holder shall perform on the commodity all inspection and testing necessary to prove compliance with the applicable requirements of the standard/specification.

JASWIC

JASWIC (Joint Acceptance Scheme for Water Services Installation Components) is a scheme that maintains a list of acceptable SANS standards for use by water service providers and others in the water industry. JASWIC is not SANAS accredited and is not mandated to issue product compliance certificates according to the SANS standards, although they are involved with the revision, amendment and development of certain SANS standards related to water services and components.

OTHER BODIES

Overseas certification bodies, like AENOR, Kiwa, NSF, etc. may be able to certify products, through their accreditation by the IAF (International Accreditation Forum) or one of its affiliates. Such a company would, however, need to be accredited locally by SANAS prior to certifying certain products according to the SANS standards.

ISO

ISO (International Standardisation Organisation) is an organisation that produces international standards. Products cannot be certified to pure ISO standards, as the standard first has to be adopted by the standards authority within a specific country, eg. **SANS** ISO 4427 or **BS** ISO 15874-2, etc. A product can not be accredited locally according to an ISO standard until the standard has been adopted locally. If a national standards body adopts an ISO standard, it may not change the content, but may specify requirements for local conditions in the national foreword of the standard.

Note: International supporting certificates can and may be required for products not certified by a local certification body.

SAPPMA

SAPPMA is a voluntary, self-regulating association. It represents plastic pipe manufacturers and other stakeholders in the Industry. The Southern African Plastic Pipe Manufacturers Association (SAPPMA) was launched in 2004 to represent the interests of the well-developed plastic pipe business in South Africa and surrounding countries. The scope and purposes of SAPPMA are far-reaching and cannot be overemphasised. Benefits of membership to companies, and benefits of specification to engineers, are substantial.

The purpose of SAPPMA is to create consumer confidence within the Plastic Pipe Industry and to promote the production and use of **high quality** plastic pipes and pipe systems. The scope of activities includes matters such as product quality, product standards, technical information, market education, environment, ethics, and others. Pipes produced by member companies carry the registered SAPPMA logo for clear identification. SAPPMA is affiliated to Plastics|SA and has a seat on the Federal Council.

SAPPMA

FIG 5.4 – TYPICAL EXAMPLE OF A SAPPMA MARK ON A PRODUCT OR CERTIFICATE

FIG 5.5 - TYPICAL EXAMPLE OF A OLD SAPPMA MARK ON A PRODUCT OR CERTIFICATE

Note: The old SAPPMA logo as shown in Fig 5.5 have been replaced by the logo in Fig 5.4. Some old pipes might still display the old logo.

SAPPMA

southern african plastic pipe manufacturers association

CERTIFICATE

of membership

This certifcate is awarded to

Member of the Southern African Plastic Pipe Manufacturers Association

Category:

Pipe Manufacturer

2014 / 2015

Member since: 2004

Chairman

Date

CHAPTER 6: HANDLING AND INSTALLATION

INSTALLATION

TRANSPORT, HANDLING AND STORAGE

- Sharp projections or edges should be padded to limit the chaffing action that occurs between the vehicle body and pipe while the vehicle is in motion. A flat bodied vehicle is ideal for transporting pipe.
- Pipe sockets should not rest on pipe spigots, as this will cause damage during transport.

PVC PIPES:

- Due to the extreme lightness of PVC pipes, there is a tendency for the pipe to be thrown from vehicles onto the ground during offloading. This should be avoided, as damage can occur to the ends of the pipes, requiring unnecessary repair work before installation can begin.
- Contrary to the stacking procedure, it is permissible to load pipe to a greater height than 1.0 metre on vehicles, provided that the pipe is removed immediately after the vehicle reaches its delivery point, and is correctly stacked.
- Socketed pipes should be loaded with sockets and spigots alternating. Sockets should protrude past spigots. Heavy pipes must be placed at the bottom of the load.

FIGURE 6.1: STACKING OF PVC PIPES

- As far as possible pipes should be stored in the shade to eliminate distortion caused by excessive heat. Long term exposure to sunlight and ultra-violet radiation must be avoided. Storage in this case should be under cover like shade cloth.
- When pipes are temporarily stored in the field, care must be taken to ensure that the ground is level and free from stones or sharp protrusions.
- NB: Make sure the area is free from dry grass or any material likely to constitute a fire hazard.
- When stacking PVC pipes the bottom row of pipe should be on raised supports spaced at 1 – 2m intervals along the length of the pipe. The width of the supports must not be less than 75mm.

HDPE PIPES:

- Pipes and fittings should not be dropped, indented, crushed or impacted. Pipes and fittings must not be stored or transported where they are exposed to heat sources likely to exceed 70°C.
- While PE is very resistant to low temperatures, as the temperature drops below freezing the impact resistance will slowly drop, and therefore care must be taken to avoid damage by impact.
- Care should be taken in handling pipes and fittings in wet or frosty conditions as they may become slippery.
- Do not place pipes and fittings in contact with lubricating or hydraulic oils, petrol, solvents, or other aggressive materials.
- Scores or scratches to a depth of 10% or more of the wall thickness are sufficient to cause rejection for any pressure application.
- Pipes should be stored on a level surface and should not be stacked so high that they deform and become oval, as this will hamper welding/jointing.

THE SIGNIFICANCE OF THE PIPE/SOIL SYSTEM

The manner in which loads are carried depends on the relative stiffness of the pipe and the surrounding soil. Refer to equation 61 and 62 where this interaction is explained using the Young and Trott approach as per the SANS 10102 part 1. In the case of rigid pipes, the pipe will carry the load, and the critical parameter is therefore the stiffness of the pipe itself, since the loads are carried by the pipe. However, for flexible pipes the pipe will deflect under an imposed load which will result in a counter reaction from the soil on the sides of the pipe. As such, the pipe relies on the horizontal support from the surrounding soil material on the sides of the pipe. For flexible pipes the importance of correct installation, trenching, and backfilling procedures cannot be overemphasised to ensure proper interaction between the pipe/ soil systems. Refer to equation 61 and 62 for more information on the interaction between the pipe and soil systems.

PIPE SOIL INTERACTION

Note that E' of soil in MPa E of pipe material in MPa x 10^3

$$Y = \frac{E^1}{PS} \qquad (61)$$

Where

$$PS = \frac{EI}{D^3} \qquad (62)$$

Note: Stiffness's: E'-soil; PS - pipe

REFERENCE: SANS 10102 Part 1

DIFFERENCE BETWEEN TRENCH AND EMBANKMENT INSTALLATION CONDITIONS

- Trench: When pipes are installed in a narrow trench, the settlement of the compacted backfill material which is placed after the pipe has been installed generates upward friction forces between the backfilled material and the surrounding undisturbed soil. This effects the manner in which the loads are transferred. The load is transferred to the prism of the backfilled material over the pipe, thereby significantly reducing the load the pipe would otherwise carry.

- Embankment: In normal embankment conditions the backfilled soil next to the pipe's wall will settle more than the backfilled soil directly above the pipe. The friction forces between the soil directly above the pipe and the soil on the side of the pipe act downwards, thereby increasing the amount of load on the pipe.

IMPORTANCE OF FOUNDING CONDITIONS

For pressurised flexible pipelines foundation is generally only required when the native soil conditions at the bottom of the trench do not provide a firm working platform for the placement of the pipe's bedding material. In gravity pipelines, the need for foundations and additional bedding material may be required if:

- the virgin material is unsuitable for use in bedding cradle, bedding blanket, or both

- the material through which the excavations are to be made is variable

- founding conditions could be poor, unyielding, or variable

- the trench bottom and/or the pipeline itself could be below the water table

EMBEDMENT AND BEDDING MATERIAL PROPERTIES

TABLE 6.1: TYPICAL SOIL PROPERTIES

E' Values expressed in MPa

Embedment material	Percentage proctor			
	Dumped	Slight < 85	Medium 85 - 95	High > 95
Compressible fine-grained soils	Medium - high plasticity / organic content not recommended			
Fine grained <30% coarse	0.35	1.40	2.80	10.5
Fine grained >30% coarse	1.05	2.80	7.00	17.5
Coarse grained <12% fines	1.40	4.90	14.0	21.0
Crushed rock <25% passing 9mm	7.00		21.0	

Reference: Amster Howard Pipeline Installation 2002 pr4-4

GENERAL GUIDELINES

EXCAVATION

Trench width shall be kept to a minimum width, allowing just sufficient working area for jointing and embedment compaction around the pipe. For small diameter pipes, a trench 300mm wider than the diameter of the pipe allows enough room for jointing. For pipes 300mm in diameter and larger the trench widths recommended in the relevant sections of SANS 1200 should be followed.

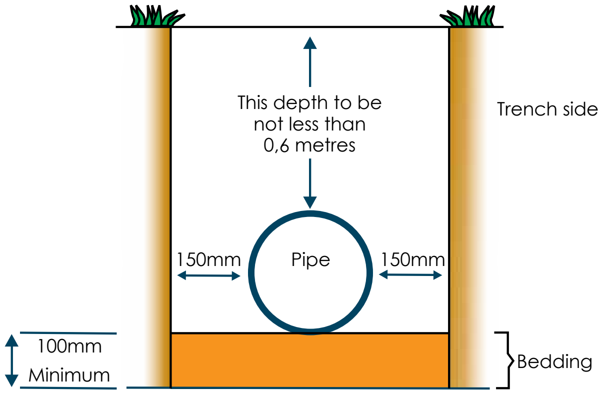


FIGURE 6.2: TRENCH INSTALLATION DETAILS

Do not trench too far in advance of the pipe laying operation. Pipes must be backfilled immediately after laying, with the joints left open for testing if practical.

When the *in situ* soils have low E[1] values, it is necessary to increase the trench width to accommodate additional embedment material to provide the pipes with adequate lateral support. It is recommended that the depth of cover from the top of the pipe to the ground surface is not less than 0.6 metres or 2xOD of the pipe diameter, whichever is the greater.

Note: E1 = Soil stiffness modulus, OD = Outside diameter of pipe

EMBEDMENT

The quality of the bedding material and its compaction, together with the nature of the undisturbed material of the trench wall are all relevant to the ultimate performance of all pipes once installed. The trench bed must be free from any stones or hard projections, which are likely to cause damage to the pipe. The bottom of the trench should be backfilled to a depth of 100mm, with suitable bedding material such as free drainage coarse sand, gravel, or soil of a friable nature. The majority size of soil particles in the bedding material should not exceed 20mm. The presence of some particles of up to 40mm in size is permissible, providing that the total quantity of these particles represents a very small fraction of the whole and that these particles have no sharp edges. Reference should be made to SANS 2001-4 for the bedding specification.

To determine the suitability of a soil for use as bedding material take a 2kg sample of the material and pass it through a sieve with a nominal aperture size of 20mm. If the weight of material retained on the sieve exceeds 25 grams or if on passing the retained material through a sieve of nominal aperture size of 40mm particles are again retained and will not break up under light finger pressure, the material must be regarded as unsuitable.

If the material passes the sieve test as indicated above, then proceed with testing as follows: Take a further sample of approx. 50kg in mass, heap on a clean level surface. Using a spade, divide this heap through the middle in two separate heaps. Sub-divide one of the heaps again and again until a sample which will fill a 2.0 litre container is obtained.

Cut a length of 250mm from a pipe, 160mm in diameter, and stand this upright on a level surface. Ensure that the moisture content of this sample is the same as that of the main body from which it was taken, and then loosely fill the pipe with this material. Empty the material from the pipe, into a suitable container. Using this same material, charge the pipe in layers of 60mm in height, firmly tamping each layer with a metal hammer weighing between 1 and 1.25 kg and having a striking face of approximately 40mm in diameter.

Use up all material from the container which originally was loosely filled into the pipe, tamping continually until no further compression of the material occurs. Measure the distance from the top of the pipe to the surface of the tamped material. If this measurement does not exceed 25mm, then the material is suitable for use.

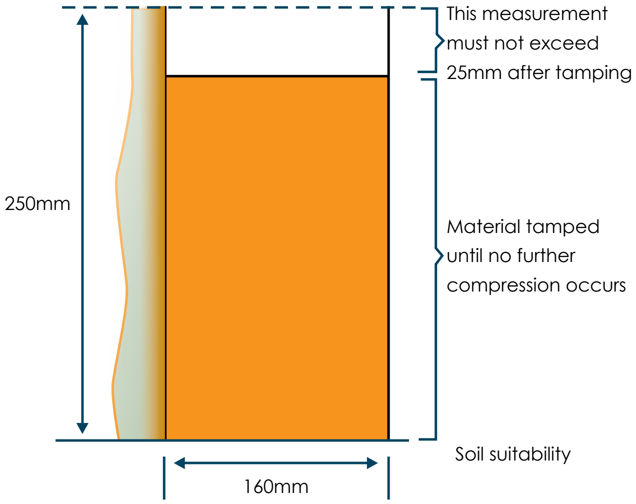


FIGURE 6.3: TESTING SUITABILITY OF BEDDING MATERIAL

PIPE LAYING AND JOINTING

The pipeline must be laid directly on the prepared bedding in the trench and any temporary supports, bricks or other foreign hard bodies must be removed. There are many joint types and the reader should refer to the particular supplier for their details.

By way of example, the procedure for a typical PVC pipe joint is described herein. All spigots must be checked to ensure that they are free from burrs. Both the spigot and socket surfaces must be carefully cleaned with a dry cloth prior to the application of the gel lubricant.

It is important to ensure that the rubber ring is clean and free of stones and grit. It is, however, not necessary to remove the rubber ring, as this has been fitted in the factory and held firmly in position.

Modern developments include steel reinforced rubber seals which cannot be dislodged on jointing, and are user friendly (especially for unskilled installers).

Check the chamfer on the spigot end: a uniform chamfer to approximately 15° must occur around the external circumference of the pipe for approximately half the wall thickness.

The depth of entry is marked on the spigot end, which must be so positioned as to be just visible outside the mouth of the socket. This allows for expansion and contraction in the pipeline.

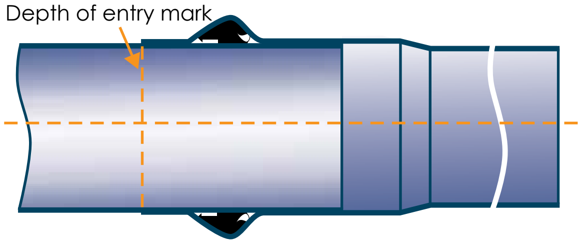


FIGURE 6.4: JOINING OF PVC PIPES

BACKFILLING

It is essential that plastic pressure pipes are backfilled immediately after each pipe is installed, in order to contain the expansion and contraction that may occur in an open trench. Immediate backfilling restricts expansion and contraction to each individual pipe length, where it is catered for by the integral socket.

Before doing the side-filling and initial backfilling, check that the depth of entry mark is just visible on all joints. Selected material (as for bedding) should be placed gently and evenly in uncompacted layers of 75mm in thickness between the sides of the trench and the pipe, as shown in Figure 6.2 Tamp each layer firmly with a hand tamper until the level of the crown of the pipe is reached, taking care to ensure that no voids are left under the pipe. All joints must be left exposed at this stage.

Movement of the pipe should be prevented by the filling and compaction of material simultaneously on either side of the pipe until level with the top of the pipe.

Selected material should be placed in even and uncompacted layers of 150mm in thickness over the entire width of the trench to a height of 300mm above the crown of the pipe. All layers must be firmly tamped by hand. All joints are still exposed at this stage.

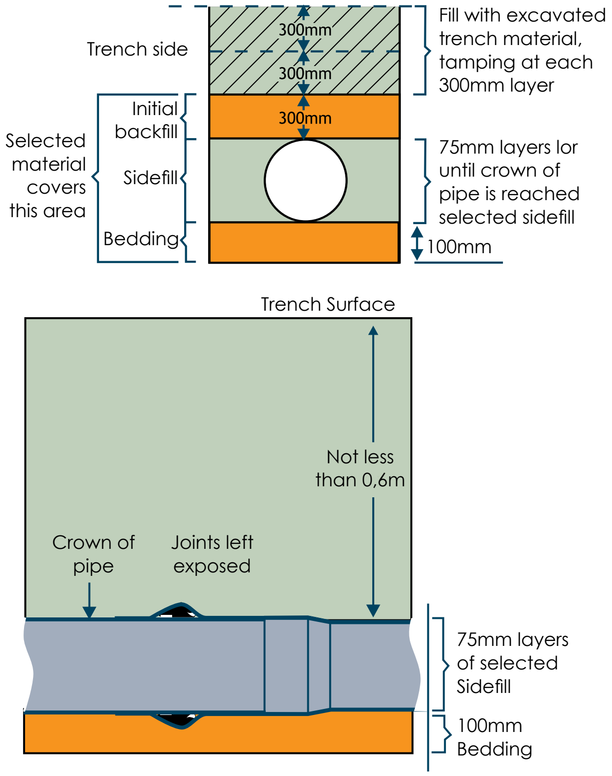


FIGURE 6.5: BEDDING AND BACKFILL DETAILS

The main backfill for the remainder of the trench, excluding the areas where joints must still remain exposed, should be placed and compacted in 300mm thick layers. Excavated trench material can be used. Each layer must be firmly tamped, the first layer by hand and subsequent layers by mechanical means if so required. The main backfill should be compacted to the same density as the surrounding *in situ* material. The final level to which the trench is backfilled should be slightly higher than the natural ground level to accommodate the consolidation of the backfill material in the trench.

ANCHORING

When an internal hydrostatic pressure is applied to the pipe, unbalanced forces develop at all changes of size and direction in a pipeline. Thrust blocks prevent the movement of fittings and must be placed at all changes of direction, valves, stop ends, and reducers.

Concrete thrust blocks are the most commonly used at all anchor points. The dimensions of the thrust blocks must be calculated to suit the pipe diameter, pressure, and the load bearing capacity of the soil. Typical thrust block sizes are given in Table 6.2. The actual size required for a particular project should be calculated and specified by the design engineer.

In recent years mechanical restraint joints have become an alternative option to concrete anchor blocks in some cases.

TABLE 6.2: TYPICAL THRUST BLOCK SIZES

Pipe Sizes (mm)	90° Bends AxB	45° Bends AxB	Tees AxB	End Caps, Valves, Reducers AxB
110	0.30x0.30 m	0.30x0.25 m	0.30x0.30 m	0.30x0.60 m
200	0.45x0.70 m	0.30x0.70 m	0.45x0.60 m	0.45x0.80 m
315	0.60x1.30 m	0.60x0.90 m	0.60x0.90 m	0.60x1.00 m
400	1.00x1.60 m	1.00x1.20 m	0.80x1.50 m	0.80x1.50 m

CUTTING TO LENGTH

When cutting pressure pipe, clearly mark the cutting position on the pipe, ensuring that the cut is square to the axis of the pipe. Use a fine-toothed saw or power saw to cut the pipe. Remove all burrs from the cut end and chamfer the pipe with a fine medium file, at 15° to half of the pipe wall thickness. Redraw the depth of entry mark.

SITE TESTS

Any pipeline that is to convey water under pressure must be pressure tested as soon as possible after it is installed, to check the integrity of installation. Only when any required remedial work has been done, and if necessary the pipeline has passed a retest, should the pipeline be backfilled. Both pressure and gravity pipelines should be checked with a CCTV camera after installation to detect any internal faults such as excessive deflections, open joints, and local damage. Any defects, no matter how small, that could result in the future malfunctioning of the pipeline must be rectified before the pipeline is commissioned. The purpose of site testing is to validate obvious construction errors for remedial work.

PIPELINE CONSTRUCTION TESTS

Medium Pressure Pipelines

Medium pressure pipelines are to be tested in accordance SANS 2001 – DP2:2008 paragraph 5.3.3 Hydraulic pipeline test (and any additional manufacturers guidelines.)

Sewers

Sewer pipelines and pre-fabricated HDPE manholes are to be tested in accordance with SANS 2001 – DP4:2008 paragraph 5.3.2 Tests and criteria.
(In high risk dolomitic areas, storm water pipelines are to comply with similar test requirements and dolomitic guidelines).

Note: Air testing of all sewers up to and including 1250 mm diameter are recommended through extrapolation of existing test requirements.

THE IMPORTANCE OF QUALITY CONTROL DURING CONSTRUCTION.

A trouble free service life of 50 years or more for PVC and PE-HD pipes is achievable if adequate inspection and quality control by experienced persons is provided during manufacture and construction.

Adequate quality control measures shall include:

- SANS conforming pipes (TT, BRT, PVT, AT, etc.)
- IFPA (Installation and Fabrication Plastics Pipe Association) member contractor for PE-HD pipe installations, jointing and any other specialist work on site. Fabrication of fittings and auxiliary items should be obtained from a SAPPMA member.
- SANS1671 conforming welding equipment for PE-HD pipe installations and SANS 10270 approval of welding procedures and welds
- SANS2001-DP2 conformance for construction methods, embedment and laying and or equivalent SANS standard
- Providing adequate on-site inspection services
- SANS 2001-DP2 conforming and or equivalent SANS standard

Membership of SAPPMA is indicative that good quality controls have been complied with in the manufacturing process. Member companies should prove compliance to the relevant standards on an order by order basis as this is a specific requirement from the standards. SAPPMA members should adhere to the code of conduct and regular third party validation to confirm compliance.

Note:
TT - Type tests
BRT - Batch Release tests
PVT - Process verification tests
AT - Approved testing body tests, quality plan document setting out the specific quality practices, resources and sequence of activities relevant to a particular product or range of products type test. (Refer to Page 35 for a description of these abbreviations).

PRESSURE AND ACCEPTANCE TESTING FOR PE-HD PIPES

Pressure testing of PE-HD pipelines, regardless of the grade of material used, is mandatory before commissioning. The use of standard tests for rigid materials such as PVC, steel or fibre cement are not appropriate for PE-HD. An appropriate and verified standard for pressure testing that accounts for the visco-elastic nature or 'elastic memory' of PE-HD must be used. *Note: Alternative process as per EN 805.*

The testing procedure typically comprises two phases:

- Expansion Phase, where the pipeline is filled and subjected to the test pressure. The pressure is maintained as the pipe expands by increasing the volume of water added. The pipeline is observed and inspected for leaks for 60 minutes.
- Test Phase, using either the Water Loss Method or the Pressure Drop Method.

The Water Loss Method compares the volume of water leaving the pipe as the pressure is decreased. If the maximum amount of water drawn out of the pipe is less than the theoretical maximum volume, the test is deemed to have been passed provided that no leakage has been observed.

The Pressure Drop Method entails pressurizing the pipe to its test pressure, maintaining the pressure for a specified time, and then releasing water to maintain a low nominal pressure. After 30 minutes of contraction, if the pressure is still increasing, the pipeline is deemed to have passed, provided that no leakage has been observed.

FIELD PRESSURE TESTING

1. Preparation of the pipeline for the field pressure test

1. **General**

   The purpose of the field pressure test is to test the design of the pipeline and the quality of the workmanship applied during construction. Batch samples of the pipes are pressure tested at the factory during manufacture. Pressure testing is to be carried out according to SANS 2001: DP2 or equivalent as applied in the contract documentation.

2. **Test lengths**

   The test should be carried out on a short length (> 500m). This is recommended as it will show up any leaking joints or pipes damaged through laying or handling. The test sections must be isolated to limit water loss in the event of a failure.

3. **Sealing of test section**

   The test section should be plugged with end-caps or end-plugs fitted with inlets and outlets for filling and bleeding purposes. The plugged ends must be braced to prevent movement when pressure is applied to the pipeline. It is not recommended that the test be carried out against closed inline valves.

4. **Before filling**

   Before filling the line, check that all joints are exposed, thrust blocks are set and, if the pipeline goes over a rise, there is enough backfill to prevent the pipes from lifting due to thrust. Open all air valves and open their isolating valves to release air when filling. Close all scour valves. Make provision to dispose of the water after the test.

5. **Filling of the test section**

   Fill the test section from the lowest point. The filling rate must be in accordance with the recommendation in table 5. Allow the line to bleed well through the isolating valves and ensure that all the air has been removed from the system before closing the bleed valves.

6. **Before testing**

   Allow the pipeline to stand for 12 hours under static pressure after it has been filled. This is to allow any remaining air to reach the highest point. Inspect the pipeline for leaks and settlement.

NB: Don't apply any pressure during this 12 hour period. Top up the line after 12 hours and bleed again to get rid of any remaining air. The presence of air can seriously affect the results of pressure test operations.

TABLE 6.3: RECOMMENDED FILLING RATE

Pipe Size	Liters / minute
50	5
63	8
75	11
90	15
110	20
125	30
140	37
160	50
200	95
250	150
315	215
355	290
400	380

2. *Applying Pressure*

Apply the required pressure slowly by means of a suitable test pump. (recommended test is for a 1 hour period, to a hydraulic pressure not exceeding 1.25 times the stated pressure of the class of pipe under test, as per SANS 2001: DP2 requirements). Take pressure readings from the lowest point. Once the pipeline has been pressurized to the test pressure, the drop in pressure must be recorded every 15 minutes, whereafter the test pressure must be restored and the make-up water recorded. Refer to table 6.4.

3. *Maximum Operation Pressures (MOP)*

Scenario 1: Pipelines with a MOP under 10 bar

- The highest point should be tested at no less than 1.25 x MOP
- The lowest point should be tested not higher than 1.5 x MOP

Scenario 2: Pipelines with MOP at 10 bar and above

- the highest point should be tested as follow: MOP (bar) + 5 bar
- The lowest point should be tested at 9% less, example...
- For a 10 bar pipeline, 10 + 5 = 15 bar at the highest point and 13.65 bar at the lowest point

TABLE 6.4: ALLOWABLE LEAKAGE RATES – ALR IN LITRES/KILOMETRE/HOUR (BASED ON TEST PRESSURE = 1.25 X RATED PRESSURE OF THE PIPE) (PVC-U)

Pipe OD (mm)	Test Pressure 750kPa (Class 6)	Test Pressure 1125kPa (Class 9)	Test Pressure 1500kPa (Class 12)	Test Pressure 2000kPa (Class 16)	Test Pressure 2500kPa (Class 20)	Test Pressure 3125kPa (Class 25)
50	0.43	0.53	0.61	0.71	0.79	0.88
63	0.55	0.67	0.77	0.89	1.00	1.11
75	0.65	0.80	0.92	1.06	1.19	1.33
90	0.78	0.95	1.10	1.27	1.42	1.59
110	0.95	1.17	1.35	1.57	1.74	1.94
125	1.08	1.33	1.53	1.77	1.98	2.21
140	1.21	1.48	1.71	1.98	2.21	2.47
160	1.39	1.70	1.96	2.26	2.53	2.83
200	1.73	2.12	2.45	2.83	3.16	3.54
250	2.17	2.65	3.06	3.54	3.95	4.42
315	2.73	3.34	3.86	4.46	4.98	5.57
355	3.07	3.77	4.35	5.02	5.61	6.28
400	3.46	4.24	4.90	5.66	6.32	7.07

4. Allowable Leakage Rates (ALR)

Seepage may occur at valve glands and areas of transition. Table 6.4 is an indication of allowable leakage rates. SANS 2001: DP2 section 7.3.3 (b) specifies the following equation to calculate allowable leakage rates in liters.

The system is isolated from the test pump for a period of one hour. The test is then deemed satisfactory if the quantity of water required to restore the pipeline to test pressure does not exceed the amount of liters calculated by the formula:

x diameter of pipe in mm
x length of test section in km
x square root of the test pressure in MPa.

5. The Effect of Entrapped Air on a Pressurised Pipeline

The effect entrapped air has on a pipeline is difficult to calculate or even evaluate. Independent international and local studies have shown that pressure surges in excess of 15 times the actual applied internal pressure can occur if entrapped air is released in an uncontrolled manner from a pressurised pipeline.

1. General

Entrapped air in a pipeline will have a different influence under the following conditions:

- **i.** Under static conditions, i.e. when no flow takes place and the pipe is only subjected to static pressure;
- **ii.** Under operational conditions, i.e. When flow takes place in the pipeline; and
- **iii.** When water hammer occurs for whatever reason.

During the design, filling, testing, commissioning and operation of any pipeline it is essential that the necessary precautions be taken to minimise the volume of air present in the system. Since it is not practically possible to totally prevent air from entering, it is necessary that provision be made to remove the remaining air from the system, thereby reducing the potential negative effect thereof.

2. The effect of entrapped air under static conditions

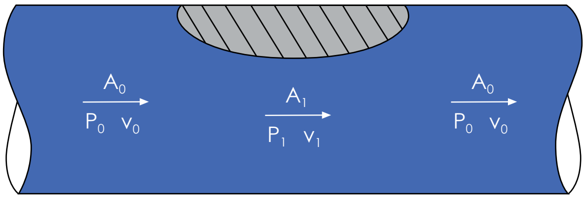
Joints are absolutely watertight but not necessarily airtight, especially when subjected to low and high pressures.

Should an air pocket be present in a pipeline when under static pressure, the pressure in that air pocket is equal to that in the water, say X MPa. Contrary to water, air is compressible and, under a pressure of X MPa its volume will be X times smaller than its initial uncompressed volume. If, at a certain instant, one or more couplings release air under the applied pressure, the compressed air escapes almost instantaneously and the surrounding water rushes rapidly into the created void. Unable to escape through the coupling, this results in water hammer in the "static" pipe. Experiments have shown that these openings through which air is able to escape are microscopically small and that a single drop of water completely seals such "openings". In the event of exposed high points in a PE-HD system it is possible that the material around the air bubble has cooled to be the same as the temperature of the water, while the area where the air is entrapped can have a temperature of as high as 65°C which could potentially result in premature failure if no temperature de-rating factor has been applied.

3. The effect of entrapped air under operational conditions

When an air pocket of considerable size occupies a certain part of a pipeline in which water is flowing, surge pressures may be created by the air pocket itself, without it actually escaping from the system.

The mechanics of this phenomenon can best be explained by means of the illustration in figure 6.6



The discharge through the pipeline is equal through cross-sections A_0 *and* A_1*. The flow velocity* v_1 *is thus greater than* v_0*. When the equation of Bernouli is applied, it follows that pressure* P_1 *must be smaller than pressure* P_0*.*

FIGURE 6.6: PRESSURE VARIATIONS CAUSED BY ENTRAPPED AIR IN A PRESSURE PIPELINE

The amount of air dissolved in water is a function of both the temperature and pressure, and when the temperature is constant and the pressure decreases, as in the vicinity of cross-section A_1, more air will be liberated from the water and the size of the air pocket will increase. This will result in further increase in velocity v_1 and decrease in pressure P_1. The air pocket may eventually get so big that it will occupy the whole cross-section of the pipeline for a short period at time, resulting in a momentary interruption in flow and collision of the two water columns, causing a surge wave of significant magnitude.

4. Influence of entrapped air on the magnitude of surge caused by waterhammer

Depending on the quantity of air present and the location thereof, the magnitude of the surge pressure caused by waterhammer can either be aggravated or reduced. It is thus important to try and minimise the quantity of air present in the system, and to make provision for the orderly release of remaining air.

5. Removal of entrapped air from a pipeline

There are two ways in which air can be removed from a pipeline:

- Hydraulically
- Mechanically

Both methods, however, only operate effectively when flow takes place in the pipeline, and a combination of the two methods is normally employed in practice, i.e. sufficiently high flow velocities, as well as correct sizes and effective air release valves are correctly positioned and installed.

i. Hydraulic removal of air

In order to remove air hydraulically, a certain minimum flow velocity, corresponding to the slope and diameter of the pipeline, is necessary to move the air to the air valves and/or outlet of the pipeline.

The minimum flow velocity necessary to move entrapped air along the pipeline can be calculated with either the Kaliske and Bliss, or Wisner formulae. Both have been derived mathematically, but in addition to this, Wisner's equation was modified through physical observations on experiments conducted on the drag forces on air bubbles. For this reason, the Wisner equation gives a higher minimum flow velocity, and is considered to be more accurate and therefore more commonly used.

These equations should be applied between air valves on the flattest sections to determine whether entrapped air will in fact be transported to the air valves thus enabling it to escape.

Wisner

$$V \geq (0{,}25\surd\ \sin\ddot{o} + 0{,}825)\ \surd gd \qquad \textbf{(63)}$$

Kaliske and Bliss

$$V = \surd 111.73gd\tan(-) \qquad \textbf{(64)}$$

where: V = Minimum velocity required to transport air along the pipe (m/s)
$\ddot{o}$ = Gradient of section of pipeline under consideration (degrees)
g = Gravity acceleration (m/s^2)
d = Internal pipe diameter (m)

The minimum flow velocity necessary to move entrapped air along the pipeline can be calculated using Wisner's formula.

ii. Mechanical removal of air

Entrapped air must be set free from pipelines by means of strategically positioned air valves. When designing, filing, testing, commissioning, and operating a pipeline the following must be kept in mind:

- Air valves must be positioned not only on local high points, but also at regular intervals along even or flat sections
- Air valves must not be positioned above the hydraulic gradient as air will be sucked in
- Air valves do not operate under static conditions
- Air valves do not function properly when filling a pipeline
- It is recommended that all air valves be installed on collector pipes of diameter of no less than that of the pipeline, extending at least half the pipe diameter above the pipe crown
- In order to prevent blowshut, the flow velocity of air through an air valve must not be more than 30m/s (consult valve manufacturer for accurate requirements)
- Air valves must be checked and serviced regularly.

More specific information on air valves should be obtained from the manufactures and relevant literature.

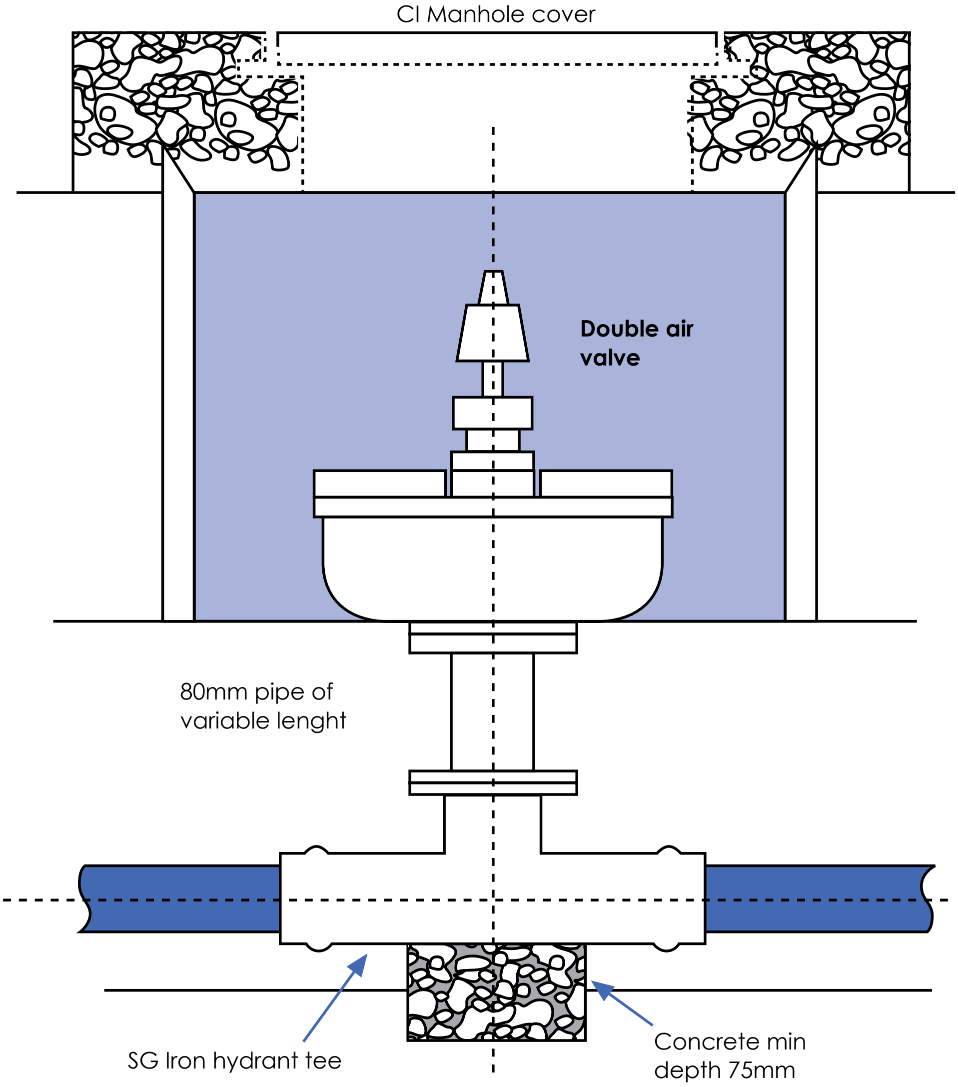
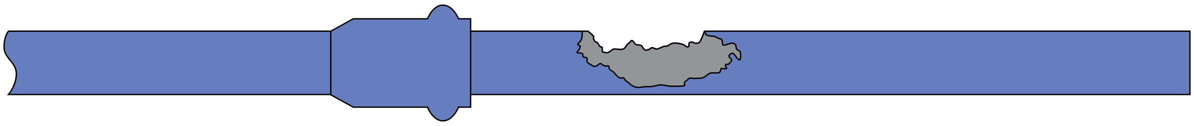


FIGURE 6.7: TYPICAL AIR VALVE INSTALLATION

6. Repair

SG Iron or PVC repair couplings are designed to slide over a damaged pipe in order to effect a repair. The SG Iron couplings are rated to Class 25 and are easily installed on the smooth constant diameter of the PVC pressure pipe. The installations in figure 6.8 indicate the method of use.

i. Damaged pipe



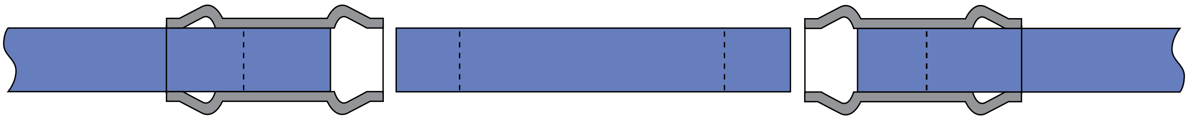
ii. Remove damaged section

iii. Install repair coupling

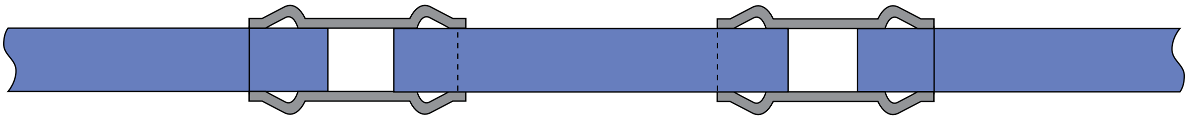
After chamfering ends with file, measure half of repair coupling length and mark each pipe end as shown. Using lubricant liberally, install repair couplings, one on each exposed pipe end.

iv. Insert new pipe section

After chamfering ends with file, measure half of repair coupling length and mark each pipe ends as shown. Using lubricant liberally, install repair couplings, one on each exposed pipe end.



v. Secure couplings in place



vi. Backfill after the system has been put under pressure

FIGURE 6.8: REPAIR OF DAMAGED PIPE

2. JOINTING – INTEGRAL JOINT

1.1. Procedure in making the joint

Assemble the following material:

- Clean cloth
- Penknife
- A soft soap gel lubricant such as Duroflo or similar
- Medium tooth saw and mitre box, angle grinder or wheel cutter designed to cut plastic (if cutting is anticipated)
- Medium file (if cutting is anticipated)

The procedure is illustrated in the final pictures of figure 6.9.

1.2. Joint assembly

1.2.1. Check the pipe spigot end and remove any burrs that may occur on the spigot end of the pipe

1.2.2. Check the entire spigot end of the pipe making sure that it is correctly chamfered to 15° to the pipe axis (picture 1)

1.2.3. The rubber ring seal is fitted in the factory. Check that the seals are seated correctly and that they are free from dirt or mud deposits (picture 2)

1.2.4. Clean the spigot end of the pipe checking to see that the surface is smooth and free from indentations or deep scratches. If the end has any indentations or deep scratches, place the pipe length to one side for inspection by a factory technical representative (picture 3)

1.2.5. Apply gel lubricant evenly around the spigot end to approximately half the distance between the pipe end and the mark which indicated the depth of entry. Lubricate the ring as well (picture 4). The use of grease or dishwashing liquid is not recommended.

1.2.6. Position the spigot end of the pipe so that the leading edge rests against the rubber ring in the socket.

1.2.7. Check the horizontal and vertical alignment of the pipe and socket. The long land canal of the mouth of the socket facilitates easy entry of the pipe.

1.2.8. Push the pipe into the socket and position it so that the depth of entry mark is just visible. This procedure should be done in one fluid movement. A twisting action will aid entry. The joint is now complete (picture 5).

FIGURE 6.9: JOINTING PROCEDURE

NOTE important point to remember about joints: if undue force is necessary to make the joint, the spigot should be withdrawn from the socket and the seating position should be checked. It is advisable that the depth of entry marks are checked along the length of the pipeline during installation to ensure all are visible.

2. JOINTING – SOLVENT CEMENT

Solvent cement joining of small bore (up to 160mm) PVC pressure pipes is an effective joining method, provided that care is taken when joining the pipes. When done properly, solvent cement joints are just strong as the pipe and fittings being used. The guidelines below will assist in ensuring that a proper joint is made every time. *(Reference: SANS 10268 - Solvent Welding)*

2.1. Equipment

In order to make a solvent cement joint one needs the following:

- A fine tooth hack saw or angle grinder
- The correct type of solvent cement. Be careful. A non-pressure solvent cement cannot sustain the forces encountered in pressure pipe systems. Ensure that a high pressure solvent cement is used for pressure pipelines.
- A brush for applying the solvent cement. A 50mm paint brush will do. Keep the brush as clean as possible all the time, as grit, dirt, and dried solvent cement will affect the quality of the joints.
- A clean rag for cleaning the pipe and fitting surfaces to be joined.
- A pipe cleaning solution. These are normally available with the solvent cement and are used to degrease the surfaces to be joined. Alternatively one can sand the surface using a 200 grit sanding paper.

2.2. Procedure

- Use the rag and pipe cleaning solution to clean the pipe and fitting surface to be joined. Do not touch the surface after cleaning as oils from your skin prevent bonding where you touch the joining surface. Let the solvent evaporate before continuing. When using sanding paper, sand the surfaces in the circumferential direction. Only dull the surface, do not sand too much.
- Apply the solvent cement evenly to the pipe and fitting using the brush. It is better to apply too much than too little.
- Immediately after applying the solvent cement, push he pipe into the fitting, turning the pipe a quarter turn as it is pushed home. Wipe any excess solvent cement from the joint.
- Leave the joint to cure before applying pressure. The instructions on the solvent cement container will indicate the curing time. Rule of Thumb: curing period of one hour per 100 KPa pressure rating; and a cure time of not less than 4 hours for any application.
- Apply pressure slowly and check for leaks.

2.3. Tips

- Before starting the procedure, ensure that the solvent cement has not exceeded it shelf life and is still fluid and smells sharply. The solvents evaporate out of the cement over time, reducing its effectiveness at softening the contact surfaces, and leading to poor joint integrity. Work in a well-ventilated but shady and windless environment or the cement may gel prior completion of the joint. This is especially applicable to larger joints which take longer for the cement to be applied.
- Work cleanly. Any dirt or greasiness on the bonding surfaces will compromise the joint integrity.
- Keep the solvent cement container closed at all times when not in use. If the solvent evaporates the solvent cement cannot etch into the bonding surfaces and joint integrity will be compromised. When in doubt, use a fresh batch of solvent cement.
- Solvent cement is able to join ABS and Polystyrene as well, although the strength of the joints may vary.

TRENCHLESS PIPE INSTALLATION

INTRODUCTION

Plastic piping, and particularly PE-HD piping, is often installed by trenchless methods and has become an integral part of the trenchless pipe for pipe rehabilitation and new pipe installations in the pipe laying industry. This is due to its ability to be butt-welded without an oversized joint, therefore allowing it to be installed in pipes and bored holes without a great loss of diameter.

The Southern African Society for Trenchless Technologies (SASTT) is representative of the pipe and equipment manufacturers, consultants, contractors, municipalities and Affiliated Societies such as SAPPMA and IMIESA are involved in this industry. In turn the International Society for Trenchless Technologies (ISTT) represents some 30 affiliated societies found world-wide, including SASTT.

The following techniques are widely used in the South African Trenchless pipelaying industries.

HORIZONTAL DIRECTIONAL DRILLING (HDD)

HDD is an extremely versatile trenchless technology used for the installation of pipes ranging from service connections to residences and buildings, to pipes and cables under roadways and rivers. HDD is best suited for installing pressure pipes and fiber optic conduits where precise grades are not required. Drilling to grade is also possible, but only in soft homogeneous soils.

The main components of HDD are: (1) a directional drill rig sized for the job at hand; (2) drill rods linked together to form a drill string for advancing the drill bit and for pulling back reamers and products; (3) a transmitter/receiver for tracking and recording the location of the drill and product; (4) a tank for mixing and holding drilling fluid; and (5) a pump for circulating the drilling fluid. Other components of an HDD operation include bits, reamers, swivels, and pulling heads.

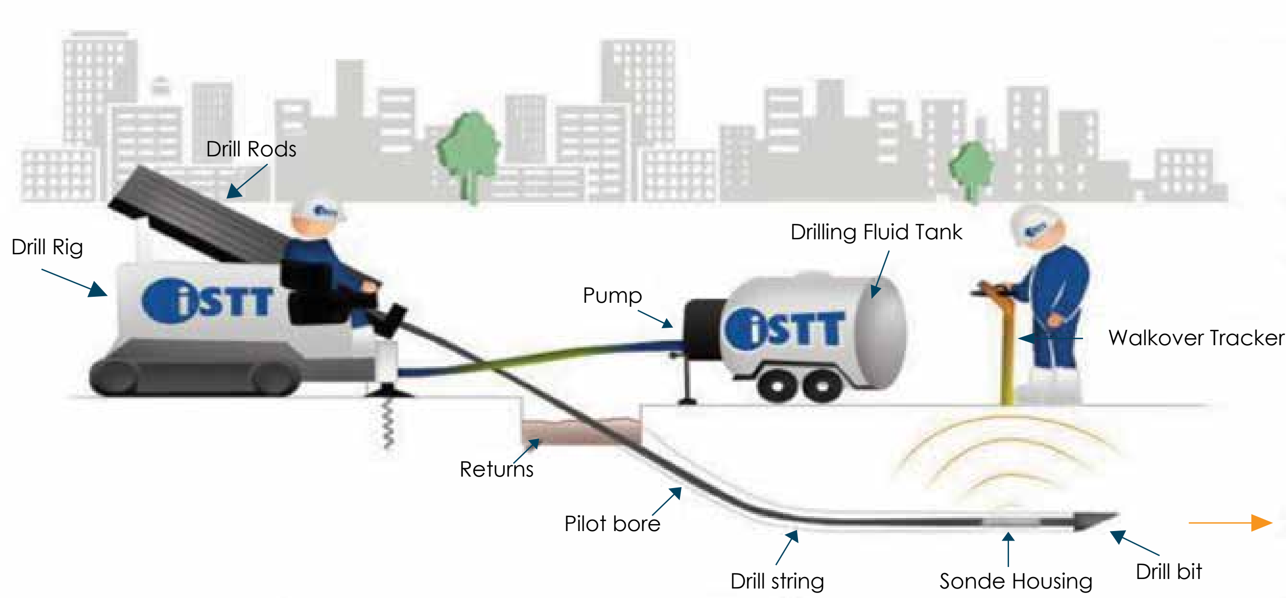


FIGURE 6.10: HORIZONTAL DIRECTIONAL DRILLING - (HDD)

Horizontal Directional Drilling (HDD)

Use in South Africa

From the introduction of the first HDD rig in South Africa around 1994, the industry has experienced an enormous uptake in the use of this technology. There are currently about 150 drill rigs operating in the country, installing hundreds of kilometers of PE-HD piping annually. Most are in the 6 to 12 ton pullback range (Mini-rigs), but there are several rigs in the 15 to 25 ton pull-back class (Midi-rigs) as well a few in the 50 to 150 ton class (Maxi-rigs).

Many rigs have rock drilling capability. The methodology is fast, effective and economical in a wide range of soil conditions, but is not suitable for use in mixed soils with boulders.

The smaller rigs are involved predominantly in installing conduits for South Africa's fast unfolding fibre optic networks, mainly using 110 PE 100 PN 8 PE-HD piping.

Larger rigs tend to service the civil industry predominantly for new bulk and network water pipe installations where drilling to grade is not required. Drilling to grade for sewers can also be undertaken using HDD, but it is important to only select job sites with soft homogeneous soils.

Sizes of installations range from 75mm to 1000mm using various classes of PE-HD piping. PVC-U restrained joint piping can also be installed for diameters up to 250ND.

The SASTT Technical Standard for Horizontal Directional Drilling is currently under development and will soon be available for viewing on the SASTT website, www.sastt.co.za

IMPACT MOLING

The impact mole or piercing tool is one of the oldest and simplest of the trenchless technologies. It is ideally suited for installation of small diameter pipes in compressible soils over short distances. Under suitable conditions, the installation of a product using an impact mole is simple and straightforward.

The impact mole is positioned on a skid or cradle at the desired line and grade determine by a sighting level positioned on the mole. Once the mole is in the desired position, the compressor is activated, advancing the mole through the hammering action of the reciprocating head. The chisel-tip head creates a bore hole. The long body length of the mole helps the mole hold line and level as it advances through the bore hole. Marking on the air hose allows the operator to track the mole's location as it advances through the ground. Once a bore hole has been completed, the product pipe is pulled in as the mole is extracted. A bore hole is typically 15-25 percent bigger than the product pipe.

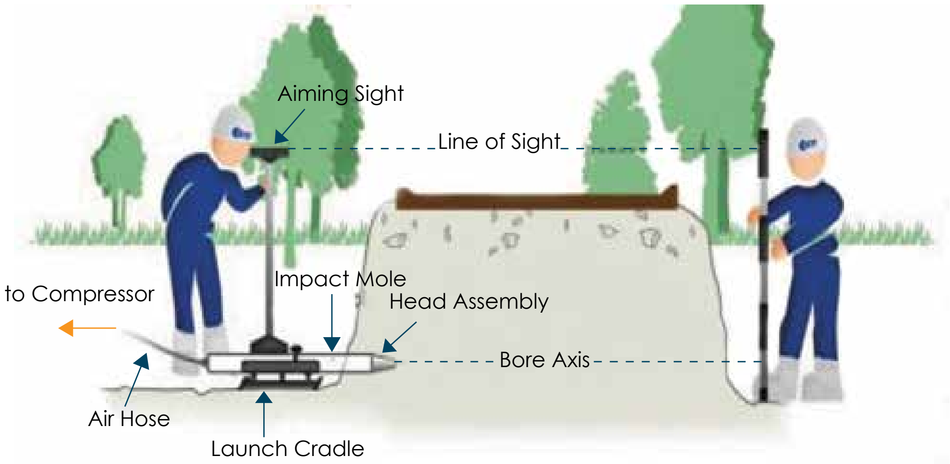


FIGURE 6.11: IMPACT MOLING

Impact Moling in South Africa

Impact moling became popular in South Africa from the late 1980s onwards, as it provided the first economical means of installing pipes and conduits below roadways.

The methodology is only successful in displaceable soils, and can be problematic if equipment gets stuck while boring. It is used mainly to install PE-HD and PVC-U water pipes up to 160 OD and PE-HD erf connections up to 50 OD as well as for electrical and fiber optic conduits using 110 OD PE-HD piping.

Many Municipalities own their own moles, and several contractors use the moles to compliment their HDD rigs where there is limited space available, precluding the use of a larger HDD drill, for example on sidewalks where a water erf connection needs to be installed.

SLIP LINING

Slip lining is perhaps the oldest of all trenchless techniques. It involves the insertion of a new pipe into an existing pipe.

Under the right conditions, slip lining is also the simplest trenchless technique. A new pipe with an outside dimension smaller than the inside dimension of the host pipe is either pulled or pushed into the host pipe. The ideal host pipe for slip lining is clean, straight, contains no deformities or bends, no severe protrusions into the pipe, and only modest offset joints. Slip lining may be undertaken using continuous butt-welded or segmental piping.

Generally PE-HD pipes up to 1000mm in diameter are butt-welded into long continuous lengths. The new PE-HD pipe is laid out above ground and pulled through an excavated launch pit into the host pipe. The PE-HD pipe is then winched through the host pipe to an exit pit or manhole. Individual lengths of up to 800 metres can be pushed and pulled into place.

After the new pipe has been installed, the annular space between the new and host pipe is grouted.

Sliplining has been in use in South Africa since the late 1980s, with many successful contracts undertaken, particularly using large diameter PE-HD piping. Several kilometers of PE-HD are installed in this manner annually throughout South Africa.

The SASTT Technical Standard for Sliplining is available for viewing on the SASTT website, www.sastt.co.za

FIGURE 6.12: SLIP LINING

PIPE BURSTING

Pipe bursting and pipe splitting are trenchless methods used to replace existing pipelines in the same alignment without physically removing the existing pipeline. Bursting and splitting by using the existing alignment to replace a pipe avoids the need to secure additional wayleaves to install the replacement pipe. Bursting and splitting can be used to upsize the pipeline, increasing its flow capacity.

Pipe bursting was initially developed in the 1980s to replace small diameter cast iron gas distribution lines, but has since grown in acceptance as an effective method for replacing pipelines of diverse size, material type, and function, including water, sewer, or gas pipelines.

Pipe bursting is used to replace brittle pipes such as clay, asbestos cement, concrete, and cast iron through the application of a static or pneumatic bursting head to fragment the existing pipe. Simultaneously, a new product pipe attached to the back of the bursting head is installed in the same alignment as the original pipe.

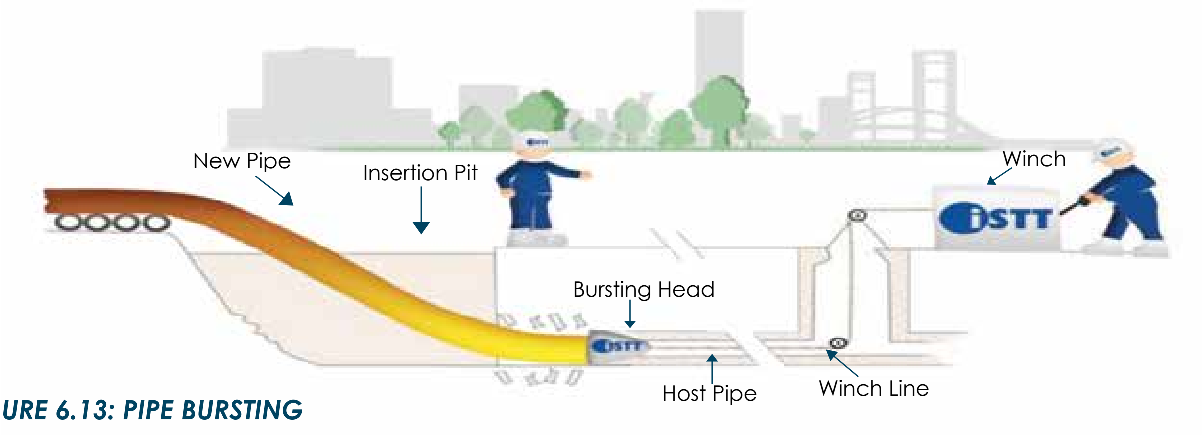


FIGURE 6.13: PIPE BURSTING

Pipe Bursting in South Africa

Pipe bursting to install PE-HD pipes from 110 to 630 mm OD is the most utilised form of trenchless pipe replacement in South Africa, and has been in use since 1989. It is commonly used on a daily basis in all major municipalities for both water and sewer pipe replacement. Of note is that many smaller municipalities are now also making use of pipe bursting for water replacement, driven by the need to bring their leaking water pipes into a manageable range amidst looming water shortages.

Pipe bursting is often cheaper than open cut methods and offers the advantage of being able to upsize an existing pipe.

In South Africa today around 20 pipe bursting crews are busy installing more than a kilometre of PE-HD pipe each working day, or about 200 to 300 km of pipe a year.

The draft SASTT Technical Standard for Pipebursting is available for viewing on the SASTT website, www.sastt.co.za

MORE SOPHISTICATED TRENCHLESS TECHNIQUES

Spiral Wound Lining

Spiral wound liners can be used to rehabilitate gravity pipeline applications such as storm water and sewer pipes. The configuration of spiral wound liners often allows installation of the liner without the use of over-pumping. The liner is installed into the host pipe through a manhole. Profile strips of PVC, steel reinforced PVC, or PE-HD located on spools above ground are fed to a winding machine. The winding machine rotates, causing the edges of the profile strips to interlock, and forming a water-tight liner. The rotational action advances the liner through the host pipe. In smaller diameter pipes, the liner can be expanded by the winding machine to form a tight fit with the host pipe. Alternatively, a fixed diameter, field-fabricated liner can be installed, and the annular space between the host pipe and liner grouted. Diameters up to 2.8m are possible.

Spiral Wound Lining has been used in South Africa since 2009, with several successful contracts undertaken. Notably a project that utilised this technology to rehabilitate two parallel sewers running beneath Govan Mbeki Avenue in Port Elizabeth's CBD won the ISTT Project Award in 2012

Close-Fit Slip Lining

A new PE-HD (thermoplastic) pipe can be installed in a host pipe with the outside diameter (OD) of the new pipe in close fit with the inside diameter (ID) of the host pipe. Close-fit pipe slip lining is an ideal application for the rehabilitation of pressure pipes that are relatively straight or have only modest bends, and that have largely maintained their circular profile.

Close-fit slip-lining is possible because of the "memory" properties of PE-HD (thermoplastic) materials. Thermoplastic materials will change shape when force is applied to the material either through the application of compression or tension, but will return to original shape when the external force is removed or internal pressure is applied.

This property allows the thermoplastic pipe to be temporarily deformed and pulled into the host pipe. When the new pipe has been pulled to the desired position, tension on the pipe is no longer applied, or internal pressure is applied, and the pipe will return to its original shape. The versatility of thermoplastic pipe has spawned the development of a wide range of innovative close-fit pipe lining systems. These systems can be classified under one of two generic system types, *i.e.* concentric reduction/expansion liners and folded liners.

Both the reduction type and folded liners are available in South Africa.

CIPP Lining

Cured in Place pipe (CIPP) can be used to rehabilitate sewers, storm water pipes and pressure pipelines for water, gas, and process effluents. Circular pipe from 100-2,700mm and a variety of noncircular pipe such as egg shapes, ovoids, and box culverts can be lined. Lining with CIPP removes the pipe from service for the duration of the installation and reinstatement process, so overpumping or provision of an alternate source of supply may be necessary.

CIPP liners may be installed using inversion, or pulled into place and inflated or inverted with air or water pressure. Lengths installed may vary from short repair sections over a localised joint or defect, to full length linings from manhole to manhole. Long lengths are also possible.

The resin impregnated liner may cure at ambient temperature, but the cure is usually accelerated by the application of heat by circulation of hot water through the inside of the liner, steam, or by pulling through a UV light train. Generally, sewers have utilised polyester needle felt liners (which may be reinforced with glass fibre) with a plastic outer lining with polyester resin. CIPP for water pipes can involve reinforced stand-alone liners with plastic outer lining using epoxy resin.

Cured in Place piping was first utilised in South Africa in 1986 on the Newlands outfall sewer and for several years has been commonly utilised using ambient, thermal, and UV curing.

APPENDICES

APPENDIX A: IDENTIFICATION OF PLASTICS

International identification number for benefit of recyclers

INT. ID NO FOR BENEFIT OF RECYCLERS	TYPE OF PLASTIC	PROPERTIES	COMMON USES	RECYCLED IN :
1 PET	**PET** Polyethylene Terephthalate	Clear, tough, solvent resistant, barrier to gas and moisture, softens at 80°.	Soft drink and water bottles, salad domes, biscuit trays, salad dressing and containers.	Pillow and sleeping bag filling, clothing, soft drink bottles, carpeting, building insulation.
2 PE-HD	**PE-HD** High Density Polyethylene	Hard to semi-flexible, resistant to chemicals and moisture, waxy surface, opaque, softens at 75°C, easily coloured, processed and formed.	Shopping bags, freezer bags, milk bottles, ice cream containers, juice bottles, shampoo, chemical and detergent bottles, buckets, pressure pipe, crates.	Recycling bins, compost bins, buckets detergent containers, posts, fencing, pipes, plastic timber.
3 PVC	**PVC** Unplasticised Polyvinyl Chloride PVC-U PVC-M PVC-O Plasticised Polyvinyl Chloride PVC-P	Strong, tough, can be clear, can be solvent welded, softens at 80°C. Flexible, clear, elastic, can be solvent welded.	Cosmetic containers, electrical conduit, plumbing pipes and fittings, blister packs, wall cladding, roof sheeting, bottles, pressure pipe.	Flooring, film and sheets, cables, speed bumps, packaging, binders, mud flaps and amts, new gumboots and shoes Non presure pipes and cable ducts.
4 PE-LD	**PE-LD** Low Density Polyethylene	Soft, flexible, waxy surface, translucent, softens at 70°C, scratches easily.	Cling wrap, garbage bags, squeeze bottles, irrigation tubing, mulch film, refuse bags.	Bin liners, pallet sheets.
5 PP	**PP** Polypropylene	Hard but still flexible, waxy surface, softens at 140°C, translucent, withstands solvents, versatile.	Bottles and ice cream tubs, potato chip bags, straws, microwave dishes, kettles, garden furniture, lunch boxes, packaging tape, pressure pipe.	Pegs, ins, pipes, pallet sheets, oil funnels, car battery cases, trays.
6 PS	**PS** Polystyrene **PS-E** Expanded Polystyrene	Clear, glassy, rigid, opaque, semi-tough, softens at 95°C. affected by fat, acids and solvents, but resistant to alkalis, salt solutions. Low water absorption, when not pigmented is clear, is odour and taste free. Special types of PS are available for special applications.	CD cases, plastic cutlery, imitation glassware, low cost brittle toys, video cases. Foamed polystyrene cups, takeaway clamshells, foamed meat trays, protective packaging and building and food insulation.	Coat hangers, coasters, white ware components, stationary trays and accessories, picture frames, seed trays, building products.
7 OTHER	**OTHER** Letter below indicates ISO code for plastic type e.g SAN, ABS, PC, Nylon	Includes all resins and multi-materials (e.g. laminates). Properties dependent on plastic or combination of plastics.	Automotive, and appliance components, computers, electronics, cooler bottles, packaging.	Automotive components, plastic timber.

APPENDIX B: CHEMICAL RESISTANCE OF THERMOPLASTICS USED FOR PIPES

Introduction

Pipes and fittings made of thermoplastic materials are widely used in industries where conveyance of highly corrosive liquids and gases requires high quality products featuring excellent corrosion resistance.

Thermoplastic materials can often economically, safely, reliably, and efficiently replace coated steel, stainless steel, glass, and ceramic materials under similar operating conditions.

Variations in the analyses of the chemical compounds or the operating conditions can significantly modify the actual chemical resistance of the materials in comparison with the values indicated.

Jointing

Where threaded joints are made, only PTFE tape must be used for sealing.

Where fusion welding is used, the resulting assembly has the same chemical resistance as the materials joined.

Degree of Chemical Resistance

This guide specifies three "Classes" of chemical resistance:

Class 1: HIGH RESISTANCE all materials belonging to this class are completely or almost completely corrosion proof against the conveyed liquid at the specified operating conditions.

Class 2: LIMITED RESISTANCE the materials belonging to this class are partially attacked by the conveyed chemical compound. The average life of the material is therefore shorter, and it is advisable to use a higher safety factor than the one adopted for Class 1 materials.

Class 3: NO RESISTANCE all materials belonging to this class are subject to corrosion by the conveyed fluid, and should therefore not be used.

Where no class is indicated this means that no data is available concerning the chemical resistance of the material in respect of the fluid to be conveyed.

ABBREVIATIONS AND MAXIMUM OPERATING TEMPERATURES

Material	Abbreviation	Max. Temperature in continuous service °C
High Density Polyethylene	PE-HD	45
Unplasticised Polyvinyl Chloride	PVC-U PVC-M PVC-O	45-60
Polypropylene	PP	70
Chloroprene Rubber	CR	80
Natural Rubber	NR	70
Chlorinated Polyvinyl Chloride	PVC-C	100
Acrylonitrile-butadiene Styrene	ABS	70
Butadiene-acrylnitrile Rubber	NBR	110
Ethylene-propylene Copolymer	EPM	120
Ethylene Propylene Diene Monomer	EPDM	90

Note: maximum operating pressure should be de-rated at temperatures above 20°C.

Abbreviations

SAT : saturated solution at 20°C
ND : undefined concentration
DEB : weak concentration
COMM : commercial solution
DIL : diluted solution

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
ACETALDEHYDE	CH_3CHO	100	25	1	3	2	2	3	1
			60	2	3				
			100						
ACETIC ACID	CH_3COOH	≤ 25	25	1	1	1	1	2	1
			60	1	2	1	1	2	1
			100			1			1
		30	25	1	1	1			1
			60	1	2	1			1
			100			1			1
		60	25	1	1	1			2
			60	1	2	1			3
			100			2			3
		80	25	2	1	1			2
			60	3	2	3			3
			100			3			3
ACETONE	CH_3COCH_3	10	25	1	3	1	1	3	1
			60		3	3		3	3
			100			3			3
		100	25	2	3	1		3	1
			60	2	3	3		3	3
			100			3			3
ALUMINIUM CHLORIDE	$AlCl_3$	ALL	25	1	1		1	1	1
			60	1	1				
			100						
ALUMINIUM FLUORIDE	AlF_3	100	25	1	1		1	1	1
			60	1	1				
			100						
ALUMINIUM SULPHATE	$Al(SO_4)_3$	DEB	25	1	1	1	1	1	1
			60	1	1	1			
			100						
		SAT	25	1	1	1	1	1	1
			60	1	1	1			
			100			2			
AMMONIA DRY GAS		100	25	1	1	1	1	1	1
			60	1	1	1			
			100						
AMMONIA LIQUID		100	25	1	2	1	1		1
			60	1	3				
			100						
AMMONIUM ACETATE	CH_3COONH_4	SAT	25	1	1	1	1	2	1
			60	1	1	1			
			100						
AMMONIUM CHLORIDE	NH_4Cl	SAT	25	1	1	1	2	1	1
			60	1	1	1			
			100			2			

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
AMMONIUM HYDROXIDE	NH_4OH	28	25 60 100	1 1	1 2	1 1	1	1	1
AMMONIUM NITRATE	NH_4NO_3	SAT	25 60 100	1 1	1 1	1 1 1	3	1	1
AMMONIUM PHOSPHATE (meta)	$(NH_4)_4P_4O_{12}$	ALL	25 60 100	1 1	1 1	1 1	1	1	1
AMMONIUM SULPHIDE	$(NH_4)_2S$	DEB	25 60 100	1 1	1 2	1 1	3	1	1
		SAT	25 60 100	1 1	1 1	1 1			
BARIUM CHLORIDE	$BaCl_2$	10	25 60 100	1 1	1 1	1 1	1	1	1
BARIUM SULPHATE	$BaSO_4$	ND	25 60 100	1 1	1 1	1 1	1	1	1
BEER		COMM	25 60 100	1 1	1 1		1	1	1
BENZENE	C_6H_6	100	25 60 100	3 3	3 3	3 3 3	3 3	3 3	3 3
BENZOIC ACID	C_6H_5COOH	SAT	25 60 100	1 1 -	1 2 -	1 1 3	3	3	
BENZYL ALCOHOL	$C_6H_5CH_2OH$	100	25 60 100	1 2		1 2	3	2	2
BI-AMMONIUM PHOSPHATE	$NH_4(HPO_4)_2$	ALL	25 60 100	1 1	1 1	1 1			
BLEACHING LYE	NaOCl+NaCl	12.5% Cl	25 60 100	2 2	1 2	2			
BRINE		COMM	25 60 100		1 1	1	3	2	2

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
BROMIC ACID	$HBrO_3$	10	25 60 100	1 1	1 1				
BUTANE GAS	C_4H_{10}	10	25 60 100	1 1	1	1	3	1	1
BUTYL ALCOHOL	C_4H_9OH		25 60 100	1 1	1 2	1 2 2	1	1	1
CALCIUM CARBONATE	$CaCO_3$	ALL	25 60 100	1 1	1 1	1 1 1	1	1	1 1
CALCIUM CHLORIDE	$CaCl_2$	ALL	25 60 100	1 1	1 1	1 1 2	1	1	1 1
CALCIUM HYDROXIDE	$Ca(OH)_2$	ALL	25 60 100	1 1	1 1	1 1	1	1	1
CALCIUM HYPOCHLORITE	$Ca(OCl)_2$	SAT	25 60 100	1 1	1 1	1 1	2	3	3
CALCIUM NITRATE	$Ca(NO_3)_2$	50	25 60 100	1	1 1	1	1	1	1
CALCIUM SULPHATE	$CaSO_4$	ND	25 60 100	1 1	1 1	1 1	1	1	1
CARBON DIOXIDE GAS	CO_2	100	25 60 100	1 1	1 1	1 1	1	1	1
CARBON MONOXIDE	CO	100	25 60 100	1 1	1 1	1 1	1	1	1
CARONIC ACID AQ. SOL.	H_2CO_3	SAT	25 60 100	1 1	1 1	1 1	1	1	1
CARBON TETRACHLORIDE	CCl_4	100	25 60 100	2 3	2 3	3 3	3	3	3
CHLORIC ACID	$HClO_3$	20	25 60 100	1 3	1 2	1 3 3	3	3	1
CHLORINE	Cl_2	SAT	25 60 100	2 3	2 3	3 3	3	3	3

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
CHLORINE LIQUID		100	25 60 100	3	3	3 3			3
CHLORO-BENZENE	C_6H_5Cl	ALL	25 60 100	3 3	3 3	3 3	3	3	3
CHROME ALUM	$KCr(SO_4)_2$	ND	25 60 100	1 1	1 1	1 1 2			
CHROMIC ACID	CrO_3+H_2O	10	25 60 100	2 3	1 2	1 2 3	3	3	3
		30	25 60 100	2 3	1 2	2 3 3			
		50	25 60 100	2 3	1 2	2 3 3	3	3	1
COPPER CHLORIDE	$CuCl_2$	SAT	25 60 100	1 1	1 1	1 1	3	2	1
COPPER NITRATE	$Cu(NO_3)_2$	ND	25 60 100	1 1	1 2	1 1			1
COPPER SULPHATE	$CuSO_4$	DIL	25 60 100	1 1	1 1	3 3	1	1	1
		SAT	25 60 100	1 1	1 1	1 1			
DEMINERALIZED WATER		100	25 60 100	1 1	1 1	1 1 1			
DICHLORO-ETHYLENE	$ClCH_2Cl$	100	25 60 100	3 3	3 3	2	3	3	3
ETHYL ALCOHOL	CH_3CH_2OH	ND	25 60 100	1 2	1 2	1 1 1	1	1	1
ETHYL CHLORIDE	CH_3CH_2Cl	ALL	25 60 100	3 3	3 3	3 3	3	3	2
FERRIC SULPHATE	$Fe(SO_4)_3$	ND	25 60 100	1 1	1 1	1	3	2	1

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
FERROUS CHLORIDE	$FeCl_2$	SAT	25 60 100	1 1	1 1	1	3	2	1
FERROUS SULPHATE	$FeSO_4$	ND	25 60 100	1 1	1 1	1	3	2	1
FERTILIZER		≤10	25 60 100	1 1	1 1	1 1			
		SAT	25 60 100	1 1	1 1	1 1			
FLUORINE GAS DRY	F_2	100	25 60 100	2 3	2 3	3 3	3	3	3
FRUIT PULP AND JUICE		COMM	25 60 100	1	1 1	1 1	1	1	1
FUEL OIL		100	25 60 100	1 2	1 1	1 2	3	3	3
FUEL OIL		COMM	25 60 100	- 2	1 1	1 2			
HYDROCHLORIC ACID	HCl	<25	25 60 100	1 1	1 2	1 1 1	2	1	1
HYDROCHLORIC ACID	HCl	<37	25 60 100	1 1	1 1	1 1 2	2	1	2
HYDROFLUORIC ACID	HF	10	25 60 100	1 1 -	1 2 -	1 1 3	2	1	1
		60	25 60 100	1 - -	2 3 -	1 3 3			
HYDROGEN	H_2	ALL	25 60 100	1 1	1 1	1 1	1	1	1
HYDROGEN PEROXIDE	H_2O_2	30	25 60 100	1 1 1	1 1	1 1	3	3	1
		50	25 60 100	2 -	1 1	1 2			
		90	25 60 100	1 2	1 1	1 2			

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
HYDROGEN SULPHIDE WET		SAT	25 60 100	1 1	1 2	1 1	3	1	1
ISOPROPYL ALCOHOL	$(CH_3)_2CHOH$	100	25 60 100	1 1	1 1	1 1	1	1	1
LEAD ACETATE	$Pb(H_3COO)_2$	SAT	25 60 100	1 -	1 1	1 2 2	1	1	1
LINSEED OIL		COMM	25 60 100	2	1 2	1 1	3	3	3
LUBRICATING OILS		COMM	25 60 100	3	1 1	1 2	3		3
MAGNESIUM CARBONATE	$MgCO_3$	ALL	25 60 100		1 1	1 1	1	1	1
MAGNESIOUM CHLORIDE	$MgCl_2$	SAT	25 60 100	1 1	1 1	1 1 2	1	2	1
MAGNESIUM HYROXIDE	$Mg(OH)_2$	ALL	25 60 100	1 1	1 1	1 1	2	2	1
MAGNESIUM NITRATE	$MgNO_3$	ND	25 60 100	1 1	1 1	1 1	1	1	1
MAGNESIUM SULPHATE	$MgSO_4$	DIL SAT	25 60 100 25 60 100	1 1 1 1	1 1 1 1	1 1 1 1	2	2	1
METHYL ACETATE	CH_3COOCH_3	100	25 60 100	- -	3 3	1 1	3	2	1
METHYL ALCOHOL	CH_3OH	ND	25 60 100	1 1	1 1	1 2 2	1	1	1
METHYL BROMIDE	CH_3BR	100	25 60 100	3 3	3 3	3 3	3	3	3
METHYL CHLORIDE	CH_3Cl	100	25 60 100	3 3	3 3	3 3 3	3	3	3

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
MILK		100	25	1	1	1	1	1	1
			60		1	1			
			100			1			
MOLASSES		COMM	25	1	1	1	1	1	1
			60	2	2	1			
			100			2			
NAPHTA		100	25	2	2	1	3	3	3
			60	3	3	3			
			100						
NAPHTHALENE		100	25	3	3	3	3	3	3
			60	3	3	3			
			100			3			
NICKEL CHLORIDE	$NiCl_2$	ALL	25	1	1	1	1	1	1
			60	1	1	1			
			100			1			
NICKEL NITRATE	$Ni(NO_3)_2$	ND	25	1	1	1	1	1	1
			60	1	1	1			
			100			2			
NICKEL SULPHATE	$NiSO_4$	DIL	25	1	1	1	3	2	1
			60	2	1	1			
			100						
		SAT	25	1	1	1			
			60	1	1	1			
			100						
NITRIC ACID	HNO_3	ANHI-DROUS	25		3	3			
			60		3	3			
			100		-	3			
		<20	25	1	1	1			
			60	2	2	2			
			100		-	3			
		40	25	-	1	2	3	2	1
			60	2	1	3			
			100	-	-	3			
		60	25	3	1	2	3	3	3
			60	3	2	3			
			100		-	3			
		98	25	3	3	3	3	3	3
			60	3	3	3			
			100		-	3			
OLIVE OIL		COMM	25			1	3	2	2
			60	3	2	1			
			100						

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
OXYGEN	O_2	ALL	25 60 100	1 2	1 1	3 3			1
OZONE	O_3	ND	25 60 100	2 3	1 2	3 3	3	2	1
PARAFFIN		ND	25 60 100	 2	1 2	 1	3	2	3
PETROL REFINED		100	25 60 100	1 1	1 3	1 3	3	3	3
PETROL UNREFINED		100	25 60 100		1 1	1 3			3
PHOSPHORIC ACID	H_3PO_4	<25	25 60 100	1 1	1 2	1 1 1			1
		<50	25 60 100	1 1	1 1	1 1 1			1 1
		<85	25 60 100	1 2	1 1 -	1 1 1			1
PROPANE LIQUID		100	25 60 100	2	1	2	3	2	3
PROPYL ALCOHOL	C_3H_7OH	100	25 60 100	1 1	1 2	1 1	1	1	1 1
SEA WATER		100	25 60 100	1 1	1 1	1 1 1	1	1	1
SILICONE OIL		ND	25 60 100	1 2	1 3	1 1	1	1	1 1
SILVER NITRATE	$AgNO_9$	ND	25 60 100	1 1	1 2	1 1 2	1	1	1

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
SOAP IN AQ. SOL.		HIGH	25 60 100		1 2	1	1 1	1 1	1 1
SODIUM BICARBONATE	$NaHCO_3$	ND	25 60 100	1 1	1 1	1 1 1	1	1	1
SODIUM CARBONATE	Na_2CO_3	SAT	25 60 100	1 1	1 1	1 1 1	1	1	1
SODIUM CHLORIDE	NaCl	DIL	25 60 100	1 1	1 2	1 1	1	1	1
		SAT	25 60 100	1 1	1 1	1 1 3	1	1	1
STEARIC ACID	$CH_3(CH_2)_{16}CO_2H$	100	25 60 100	 2	1 1	2 2	3	3	3
SUGAR SYRUP		HIGH	25 60 100	1 1	1 2	1			1
SULPHUR	S	100	25 60 100	1 1	1 2	2 1	3	1	1
SULPHUR DIOXIDE AQ.	SO_2	SAT	25 60 100	1	1 2	1			
SULPHUR DIOXIDE DRY		ALL	25 60 100	1 1	1 1	1 1 3	3	3	1
SULPHUR DIOXIDE LIQUID		100	25 60 100	1 2	2 3	2 3	3	3	1

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
SULPHURIC ACID	H_2SO_4	<10	25 60 100	1 1	1 1	1 1 1	1	1	1
		<75	25 60 100	1 2	1 2	1 2 2	3	3	3
		<90	25 60 100	2 2	1 2	1 2 3	3	3	3
		<96	25 60 100	2 2	2 3	3 3 3			
TANNIC ACID	$C_{14}H_{10}O_9$	10	25 60 100	1 1	1 1	1 1	1	2	1
TARTARIC ACID	$HOOC(CHOH)_2COOH$	ALL	25 60 100	1 1	1 2	1 1	2	2	2
TRANSFORMER OIL		ND	25 60 100	1 2	1 2	1 2	3	2	3
TRICHLORO-ETHYLENE	Cl_2CCHCl	100	25 60 100	2 2	3 3	3 3	3	3	3
TURPENTINE		100	25 60 100	2 3	2 2	3 3	3	3	3
UREA AQ. SOL.	$CO(NH_2)_2$	<10	25 60 100	1 1	1 2	1 1	2	1	1
		33	25 60 100	1 1	1 2	1 1			
URIC ACID	$C_5H_4N_4O_3$	10	25 60 100	1 1	1 2				
VINYL ACETATE	$CH_3CO_2CHCH_2$	100	25 60 100		3 3		3	2	3

Medium	Formula	Conc %	Temp. (°C)	PE-HD	PVC	PP	NR	CR	EPDM
WINE		COMM	25	1	1	1	1	1	1
			60		1	1			
			100			1			
WINE VINEGAR		COMM	25	1	1	1	1	1	1
			60	1	2	1			
			100						
ZINC CHLORIDE	$ZnCl_2$	DIL	25	1	1	1	1	1	1
			60	1	1	1			
			100						
		SAT	25	1	1	1			
			60	1	1	1			
			100			2			
ZINC CHROMATE	$ZnCRO_4$	ND	25		1	1			
			60		1	1			
			100						
ZINC CYANIDE	$Zn(CN)_2$	ALL	25		1			1	1
			60		1				
			100						
ZINC NITRATE	$Zn(NO_3)_2$	ND	25	1	1	1		1	1
			60	1	1	1			
			100						
ZINC SULPHATE	$ZnSO_4$	DIL	25	1	1	1	1	1	1
			60	1	1	1			
			100						
		SAT	25	1	1	1			1
			60	1	1	1			
			100						

APPENDIX C: LIST OF FIGURES AND TABLES

Where figures are accompanied by dimensional tables, we have followed the convention of only numbering the figures.

FIGURES

FIGURES

TABLES

IFPA
INSTALLATION AND FABRICATION PLASTICS
PIPE ASSOCIATION

WHO IS IFPA?

The Installation and Fabrication Plastics Pipe Association (IFPA) was formed to expand regulation of the Plastic Pipe Industry to include fabrication and installation of pipe. The association is an initiative of SAPPMA (The Southern African Plastic Pipe Manufacturers Association).

Objectives

- A consistently high standard of fabrication and installation
- Commitment to honest business practices and ethical standards
- Support and assistance to consulting engineers and customers who specify or use these products and services
- A reliable database of trained installers
- Compliance with the Competition Act 89 of 1998
- Ensuring that members comply with all environmental laws and regulations

The association is open to all fabricators and installers of plastic pipe, as well as suppliers of pipe fittings and related equipment. Membership approval is dependent on passing an audit of their systems and standards and the payment of the membership fee. In addition, a Code of Conduct needs to be signed by the managing director of the business. All IFPA Members are required to obtain the official welder stamp from the Association and to use it on all welds. This is an additional safeguard against poor quality, and facilitates traceability. Being part of the IFPA is a way of differentiating the responsible players in the field from those who are reckless about quality and ethics.

Visit www.sappma.co.za for a list of SAPPMA and IFPA Members

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