HDPE Physical Properties

HDPE_physical-properties_v001

MARLEY pipesystems

an Aliaxis company

Contents

Introduction

High Density Polyethylene (HDPE) is a thermoplastic material which is supplied by the manufacturer in a ‘ready to use’ pelletised form. The grades suitable for pipe manufacture are PE 63, PE 80 and PE100. The pipe manufacturer converts this material into pressure pipe.

Table of Physical Properties

The properties given below are for HDPE grades used to manufacture pipe. It should be noted that many of these properties are relative to temperature and the duration of stress application.

Property		Value	Unit	Test Method	Test Specimen
Density at 23ºC		0.958	g/cm³	ISO 1183	10mm x 10mm x 4mm
Viscosity Number		380	ml/g	ISO 1628-3	0.1% solution of granules in decahydronaphthalene
Melt Flow Rate	MFR 190/5	0.23	g/10min	ISO 1133	granules sample weight 3g to 6g
	MFR 190/21.6	6.5	g/10min		
Tensile Properties	Yield Stress	26	N/mm²	ISO 527, Test Rate 50mm/min	ISO 3167, 4mm thick (test specimen no. 3, 4mm thick according to DIN 53 455
	Enlonggation at Yield Stress	10	%	ISO 527, Test Rate 50mm/min	
	Tensile modulus of Elasticity (secant between 0.05 & 0.25% strain)	900	N/mm²	ISO 527	
	Tensile Creep Modulus (1 hour value)	650	N/mm²	ISO 899, Test Load 2M/mm²	
	Tensile Creep Modulus (1000 hour value)	350	N/mm²		
Flexural Properties	Flexural Creep Modulus (1 min value)	1100	N/mm²	DIN 54852-Z4 σb=2N/mm²	110mm x 10mm x 4mm loaded flat
	Flexural Stress (3.5%deflection)	20	N/mm²	ISO 178, Test Rate 2mm/min	80mm x 10mm x 4mm
Stiffness in Torsion		180	N/mm²	DIN 53447	60mm x 6.35mm x 3mm
Hardness	Ball Indentation Hardness	41	N/mm²	ISO 2039 part 1 Test Load 132N	4mm sheet
	Shore Hardness D (3 sec value)	61	~	ISO 868	6mm sheet
	Shore Hardness D (15 sec value)	59	~		
Nothed Impact Strength acN (test specimen from compression moulded sheet)	at 23ºC	20	kJ/m²	ISO 179/1eA	80mm x 10mm x 4mm
	at -30ºC	10	kJ/m²		
Vicat softening Point VST/B/50		67	ºC	ISO 306	4mm sheet
Oxidation Induction Time	200ºC in O_2	>=60	min	ISO TR 10837	granules

Comparison with Other Plastic Materials

Property	HDPE	PP	PVC	PVC-C*	PB*
Surface feel	Waxy	Waxy	Smooth	Smooth	Waxy
Appearance (water pipes)	Black	Pale grey-beige	Blue	Grey-beige	Black
Sound produced when dropped	Medium clatter	High clatter	High clatter	High clatter	Dull thud
Combustibility and appearance of flame	Bright flame: Drops continue to burn after falling	Bright flame: Drops continue to burn after falling	Carbonises in flame: Extinguishes away from flame	Carbonises in flame: Extinguishes away from flame	Bright flame; Drops continue to burn after falling
Odour of smoke after flame is extinguished	Like candles	Like resin	Pungent like hydrochloric acid	Pungent like hydrochloric acid	Like candles but more acrid than HDPE
Nail test (impression made by fingernail)	Impression possible	Very light impression possible	Impression not possible	Impression not possible	Impression easily poduced
Special features					Smears when sawn
Floats in water	Yes	Yes	No	No	Yes
Notch sensitivity	No	Slight	Yes	Yes	Yes
Weather resistance	Stabilised, good	Stabilised, good	Stabilised, good	Stabilised, good	Stabilised, good
Method of permanent joining	Fusion	Fusion	Solvent cement	Solvent cement	Fusion
Suitable fo mechanical jointing	Yes	Yes	Yes	Yes	Yes
Stress crack sensitivity with regard to jointing with save media, e.g water	Some	Slight	None	None	None
Linear expansion mm/m/ºC	0.2	0.15	0.08	0.07	0.12
Thermal conductivity kcal/mhºC	0.4	0.19	0.14	0.14	0.2
Specific heat kcal/mhºC	0.42	0.4	0.23	0.23	0.47
Specific weight kg/cm²	0.955	0.905	1.42	1.5	0.92
Tensile strength at 20ºC kp/cm²	240	320	550	550	200
Modulus of elasticity at 20ºC kp/cm²	8000	15000	30000	30000	5000

The Stress Regression Line

The traditional method of portraying the primary mechanical property of HDPE, 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.

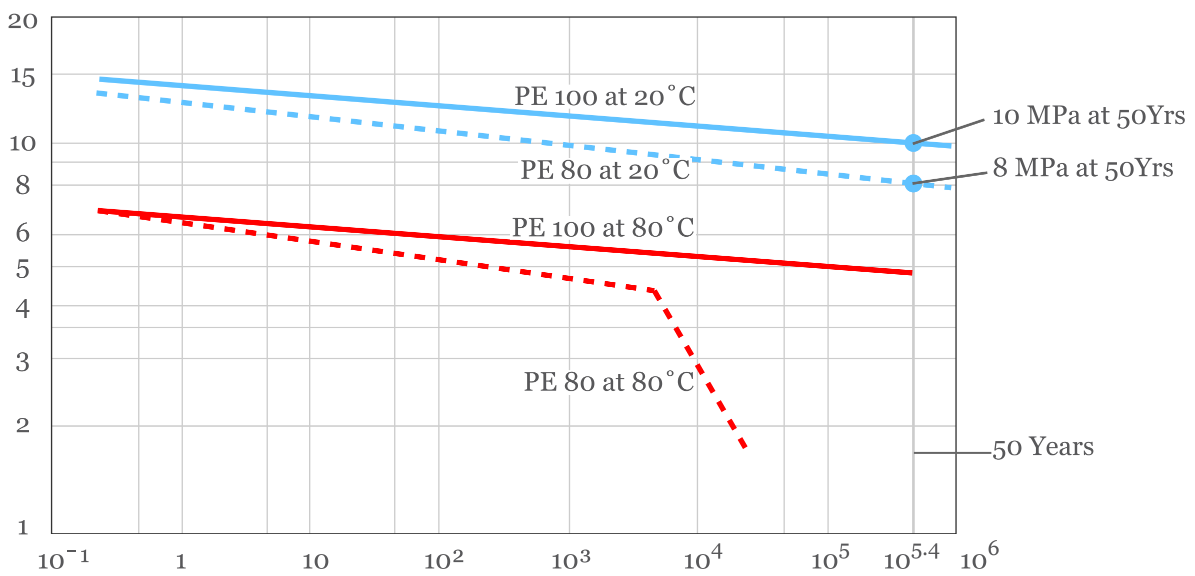
Numerous actual test results, measured at 20°C and 60°C, over a range of times up to 10,000 hours, are plotted on a log scale and a regression line is calculated to fit this data. The resultant regression line is then extrapolated to 50 years (438,000 hours). The method of calculation is an internationally accepted procedure described in ISO/TR 9080. The required values of stress and time are specified in SABS ISO 4427.

The internationally accepted method for calculating circumferential hoop stress is derived from Barlow's formula and is as follows:

$$\sigma = p(d - t)/2t$$

where:
- p = internal pressure (MPa)
- t = minimum wall thickness (mm)
- d = mean external diameter (mm)
- σ = circumferential hoop stress in wall of pipe (MPa)

The Stress Regression Line for HDPE is given below.



Principal stress/time curves for PE 80 and PE 100 pipes at 20˚C and 80˚C. The standard curve for HDPE Type 2 at 80˚C (acc. to DIN 8075) is shown in comparison. The minimum required strength (MRS) at 20˚C and 50 years is 10 MPa for PE 100 and 8 MPa for PE 80 giving the design stress 8 MPa and 6 MPa respectively.

Design Stress and Safety Factor (service factor)

Safety factors take into account handling conditions, service conditions and other circumstances not directly considered in the design. In terms of SABS ISO 4427 the minimum safety factor is 1.25. This factor, when applied to the Minimum Required Strength (MRS), for the particular material classification (e.g. PE80, PE100), gives the maximum allowable hydrostatic design stress for the designated material.

Designation of material	MRS at 50 years and 20°C Mpa	Maximum allowable hydrostatic design stress, σ – Mpa
PE 100	10	8
PE 80	8	6.3
PE 63	6.3	5

The table below illustrates the relationship between MRS and σ for various design coefficients at 20° C.

Hydrostatic design stress of pipe, σ - MPa	MRS of material - MPa		
	10	8	6.3
	Design coefficient, C		
8	1.25		
6,3	1.59	1.27	
5	2	1.6	1.26

The design engineer may wish to apply a greater safety factor depending on operating conditions and environmental considerations. Applying Barlow's formula (below) it is possible to calculate the minimum wall thickness for any given size and pressure class of pipe.

$$t = p \times d/(2\sigma + p)$$

where:

t = minimum wall thickness (mm)
p = internal pressure (MPa)
d = mean external diameter (mm)
σ = design stress (MPa)

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

$$t = 1.0 \times 250/\{(2 \times 6.3) + 1.0\}$$
$$= 18.38 \text{ mm}$$

Round up to 18.4 mm for manufacture and/or the appropriate SDR for the Class and Material designation.

Melt Flow Index

The melt flow index of polyethylene materials is a measure of the mass of melted material, at 190°C, that will pass through a specific orifice in 10 minutes when subjected to a specific pressure. The melt flow index (MFI) is largely dependant on the molecular mass. Higher molecular masses result in lower MFI because long, well packed molecules do not flow as easily as short, less packed molecules.

Since both density and MFI are decisive for the strength properties, they are regulated in most standards for polyethylene pipes. In terms of the SABS specification the Melt Flow Index must conform to the raw material manufacturers pipe grade specification. This information can be obtained from the raw material manufacturers data sheets.
(See Table of Physical Properties on page 3)

Tensile Strength

The tensile strength of polyethylene materials increases with an increase in molecular mass since long, well packed molecules are more difficult to separate. This property is also effectively regulated by standards.
(See Table of Physical Properties on page 3)

Effect of Temperature Change

Working Pressure

The standard design temperature for HDPE pipes is 20°C and working pressures are usually quoted for this temperature. HDPE pressure pipes function perfectly well below 20°C right down to freezing point and can in fact, withstand higher pressures than those quoted at 20°C.

As can be seen from the stress regression lines, the creep rupture strength diminishes with increasing temperature and working pressures must be down-rated if the same factors of safety are to be maintained. The applicable reduction factors are given under “Temperature Considerations” in the HDPE Design Considerations PDF.

Sub Zero Temperatures
Water has been known to freeze in HDPE pipes without causing fractures, but permanent strain can result, leading to severe reduction in the working life of the pipe. Hence HDPE pipes - like other pipes - should be protected against sub zero temperatures.

Expansion and Contraction
All plastics have high a co-efficient of expansion and contraction, several times those of the metals. This must be allowed for in any installation by the use of expansion joints, expansion loops etc.

Material	**Co-efficient of expansion (K-l)**
MPVC	8×10^{-5}
HDPE	20 xlO^{-5}
LDPE	20×10^{-5}
Steel	$1,2 \times 10^{-5}$
Copper	$2,0 \times 10^{-5}$

Impact Resistance
It should be noted that it is possible to change the impact strength of certain plastic materials, however this usually comes at the expense of properties such as tensile strength, hardness or stiffness. This property is therefore effectively regulated (as with density and MFI) by most standards.

Ultra Violet Resistance
HDPE pipes, when manufactured to SABS ISO 4427, contain 2.5% (by mass) of carbon black. This provides exceptional protection against the effects of ultra violet light.

Flammability
As with impact resistance, it is possible to improve the fire resistance of HDPE by the addition of various compounds. Again this comes at the expense of other properties. Fire resistance is measured by a limiting oxygen index (LOI).

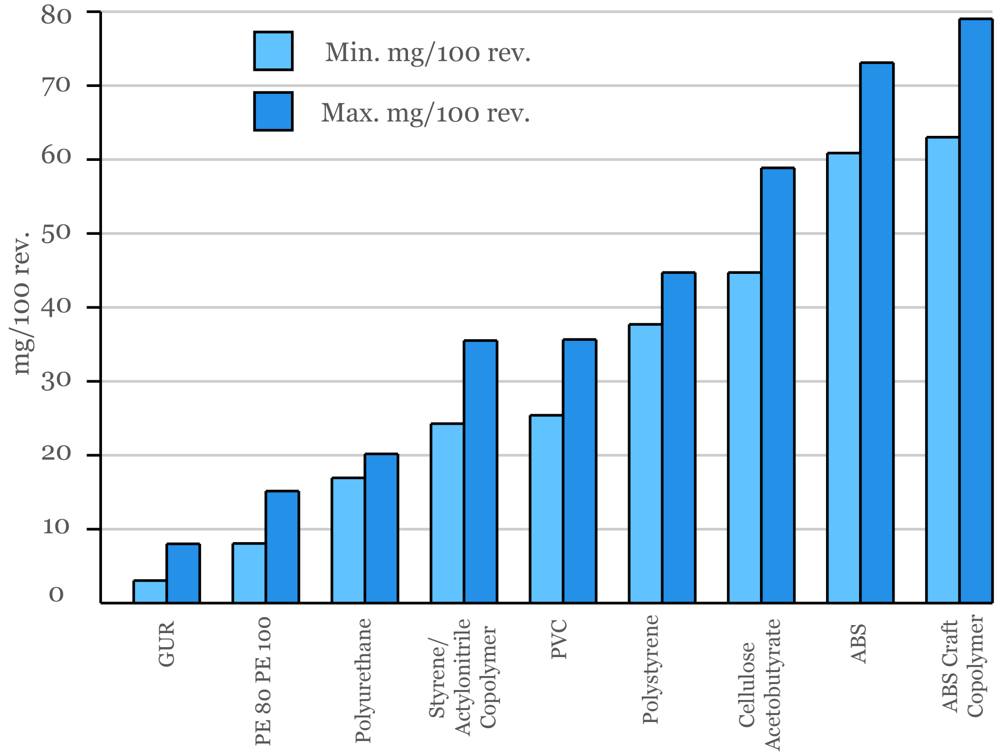
Abrasion Resistance

A number of international investigations to assess the abrasion resistance of various plastic materials have been carried out. Generally the results of such investigations are expressed as a loss of volume in relation to the original wall thickness. The results to date have varied in regard to the abrasion resistance of various pipe materials. However, what they all show is that plastics possess superior abrasion resistance relative to other pipe materials.

For example, in one investigation, HDPE pipes suffered wear to the extent of 4mm after 1600 hours while the corresponding wear occurred in steel pipes after 1000 hours.

The graph below provides a further indication of relative wear rates.

Graph of Relative Wear rates



Dry sliding abrasion of a number of PE 80, PE 100 and some other grades of thermoplastic materials.
Taber Abrasion Method in accordance with DIN 53754 E

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