Gas Industry Standard

GIS/PL2-1:2022

Specification for

Polyethylene pipes and fittings for natural gas and suitable manufactured gas

Part 1: General and polyethylene compounds for use in polyethylene pipes and fittings

Contents

Foreword

Gas Industry Standards (GIS) are revised, when necessary, by the issue of new editions. Users should ensure that they are in possession of the latest edition. Contractors and other users external to Gas Transporters should direct their requests for copies of a GIS to the department or group responsible for the initial issue of their contract documentation.

Comments and queries regarding the technical content of this document should be directed in the first instance to the contract department of the Gas Transporter responsible for the initial issue of their contract documentation.

This standard calls for the use of procedures that may be injurious to health if adequate precautions are not taken. It refers only to technical suitability and does not absolve the user from legal obligations relating to health and safety at any stage.

Compliance with this engineering document does not confer immunity from prosecution for breach of statutory or other legal obligations.

Relationship with other publications

GIS/PL2 Polyethylene pipes and fittings for natural gas and suitable manufactured gas consists of the following parts:

Part 1: General and polyethylene compounds for use in polyethylene pipes and fittings.

Part 2: Pipes for use at pressures up to 5.5 bar.

Part 3: Butt fusion machines and ancillary equipment.

Part 4: Fusion fittings with integral heating element(s).

Part 5: Electrofusion ancillary tooling.

Part 6: Spigot end fittings for electrofusion and/or butt fusion purposes.

Part 7: Squeeze-off tools and equipment

Part 8: Pipes for use at pressures up to 7 bar.

Mandatory and non-mandatory requirements

For the purposes of a GIS the following auxiliary verbs have the meanings indicated:

can indicates a physical possibility;

may indicates an option that is not mandatory;

shall indicates a GIS requirement;

should indicates best practice and is the preferred option. If an alternative method is used then a suitable and sufficient risk assessment needs to be completed to show that the alternative method delivers the same, or better, level of protection.

Disclaimer

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Brief history

Edited by BSI in accordance with BS 0-3:1997	July 2006
Annex C updated to allow simplified testing for minor changes to compound / pigment	January 2008
Reviewed on behalf of the Gas Distribution Networks' Technical Standards Forum by BSI	November 2014
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1. Scope

This part of GIS/PL2 specifies general requirements for polyethylene piping systems in the field of the supply of gaseous fuels and in particular natural gas having a composition specified in BS EN ISO 13686 or suitable manufactured gases.
In particular, it specifies requirements for polyethylene compounds with a strength classification of PE80 and PE100 (as determined by BS EN ISO 12162 and BS EN ISO 9080) together with other important properties to ensure a minimum 50year design life. This standard is applicable to all combinations of PE80 and PE100 materials i.e. unimodal and bimodal, plus the PE100 core material used for peelable pipes.
In conjunction with other parts of GIS/PL2, it is applicable to polyethylene pipes, fittings, valves and their joints and to joints with components in other materials.

2. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

2.1 British and European standards

BS 5252, *Framework for colour co-ordination for building purposes.*

BS EN ISO 472, *Plastics — Vocabulary.*

BS EN 728*, Plastics piping and ducting systems — Polyolefin pipes and fittings — Determination of oxidation induction time.*

BS EN ISO 1043-1*, Plastics — Symbols and abbreviated terms — Part 1: Basic polymers and their special characteristics.*

BS EN 1056*, Plastics piping and ducting systems — Plastics pipes and fittings — Method for exposure to direct (natural) weathering.*

BS EN ISO 1133, *Plastics — Determination of the melt mass-flow rate (MFR) and the melt volume-flow rate (MVR) of thermoplastics – Standard method.*

BS EN ISO1167-1, *Thermoplastics pipes, fittings and assemblies for the conveyance of fluids. Determination of the resistance to internal pressure - General method*

BS EN ISO 1167- 2, *Thermoplastics pipes, fittings and assemblies for the conveyance of fluids. Determination of resistance to internal pressure – Preparation of pipe test pieces.*

BS EN ISO 1183-1, Plastics — *Methods for determining the density and relative density of non-cellular plastics — Part 1: Immersion method, liquid pyknometer method and titration method.*

BS EN ISO 1183-2, *Plastics — Methods for determining the density of non-cellular plastics — Part 2: Density gradient column method.*

BS EN ISO 1183-3, *Plastics — Methods for determining the density of non-cellular plastics — Part 3: Gas pyknometer method.*

BS EN ISO 1872-1*, Polyethylene (PE) moulding and extrusion materials — Part 1: Designation system and basis for specifications.*

BS EN ISO 6259-1*, Thermoplastics pipes — Determination of tensile properties — Part 1: General test method.*

BS EN ISO 6259-3*, Thermoplastics pipes — Determination of tensile properties — Part 3: Polyolefin pipes.*

BS ISO 6964*, Polyolefin pipes and fittings — Determination of carbon black content by calcination and pyrolysis — Test method.*

BS EN ISO 9080*, Plastics piping and ducting systems — Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation.*

BS EN ISO 11357-6, *Plastics. Differential scanning calorimetry (DSC) - Determination of oxidation induction time (isothermal OIT) and oxidation induction temperature (dynamic OIT)*

BS ISO 11413: 1996*, Plastic pipes and fittings – Preparation of test piece assemblies between a polyethylene (PE) pipe and electrofusion fitting.*

BS ISO 11414:1996*, Plastics pipes and fittings — Preparation of polyethylene (PE) pipe/pipe or pipe/fitting test piece assemblies by butt fusion.*

BS EN 12099, *Plastics piping systems — Polyethylene piping materials and components — Determination of volatile content.*

BS EN 12106, *Plastics piping systems — Polyethylene (PE) pipes — Test method for the resistance to internal pressure after application of squeeze off.*

BS EN 12107, *Plastics piping systems — Injection-moulded thermoplastics fittings, valves and ancillary equipment — Determination of the long-term hydrostatic strength of thermoplastics materials for injection-moulding of piping components*.

BS EN 12118, *Plastics piping systems — Determination of moisture content in thermoplastics by coulometry.*

BS EN ISO 12162*, Thermoplastics materials for pipes and fittings for pressure applications — Classification and designation and design coefficient.*

BS EN ISO 13478*, Thermoplastics pipes for the conveyance of fluids — Determination of resistance to rapid crack propagation (RCP) — Full scale test (FST).*

BS EN ISO 13479*, Polyolefin pipes for the conveyance of fluids — Determination of resistance to crack propagation — Test method for slow crack growth on notched pipes.*

BS EN ISO 13686*, Natural gas — Quality designation.*

BS ISO 13953*, Polyethylene (PE) pipes and fittings — Determination of the tensile strength and failure mode of test pieces from a butt-fused joint.*

BS ISO 13954, *Plastics pipes and fittings Peel decohesion test for polyethylene (PE) electrofusion assemblies of nominal outside diameter greater than or equal to 90 mm.*

BS ISO 18553*, Method for the assessment of the degree of pigment or carbon black dispersion in polyolefin pipes, fittings and compounds.*

ISO 3, *Preferred numbers – Series of referred numbers.*

ISO 497, *Guide to the choice of series of preferred numbers and of series containing more rounded values of preferred numbers.*

ISO 760*, Determination of water — Karl Fischer method (General method).*

ISO 13477*, Thermoplastics pipes for the conveyance of fluids — Determination of resistance to rapid crack propagation (RCP) — Small-scale steady-state test (S4 test).*

2.2 Gas Industry Standards

GIS/PL2-1, *Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas — Part 1: General and polyethylene compounds for use in polyethylene pipes and fittings.*

GIS/PL2-2, *Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas — Part 2: Pipes for use at pressures up to 5.5 bar.*

GIS/PL2-3*, Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas — Part 3: Butt fusion machines and ancillary equipment.*

GIS/PL2-4*, Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas — Part 4: Fusion fittings with integral heating element(s).*

GIS/PL2-5*, Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas — Part 5: Electrofusion ancillary tooling.*

GIS/PL2-6*, Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas — Part 6: Spigot end fittings for electrofusion and/or butt fusion purposes*

GIS/PL2-3*, Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas — Part 7: Squeeze-off tools and equipment*

GIS/PL2-8*, Specification for polyethylene pipes and fittings for natural gas and suitable manufactured gas — Part 8: Pipes for use at pressures up to 7 bar.*

3. Terms and Definitions

3.1 For the purposes of this standard the terms and definitions, symbols, abbreviations and units given in BS EN ISO 472 and BS EN ISO 1043-1 and the following apply

3.2 Geometrical Definitions

3.2.1 nominal size (DN)

numerical designation of the size of a component, other than a component designated by thread size, which is a convenient round number, approximately equal to the manufacturing dimension in millimetres (mm)

3.2.2 nominal size (DN/OD)

nominal size, related to the outside diameter

3.2.3 nominal outside diameter, d_n

specified outside diameter, in millimetres, assigned to a nominal size DN/OD

3.2.4 outside diameter (at any point), d_e

value of the measurement of the outside diameter through its cross-section at any point of the pipe, rounded to the next greater 0.1 mm

3.2.5 mean outside diameter, d_{em}

value of the measurement of the outer circumference of the pipe or spigot end of a fitting in any cross-section divided by π (= 3.142), rounded to the next greater 0.1 mm

3.2.6 minimum mean outside diameter, $d_{em, min}$

minimum value for the mean outside diameter as specified for a given nominal size

3.2.7 maximum mean outside diameter, $d_{em, max}$

maximum value for the mean outside diameter as specified for a given nominal size

3.2.8 ovality

difference between the maximum and the minimum outside diameter in the same cross-section of a pipe or spigot, rounded to the nearest 0.1 mm

3.2.9 nominal wall thickness, e_n

numerical designation of the wall thickness of a component, which is a convenient round number, approximately equal to the manufacturing dimension in millimetres (mm)

NOTE: For thermoplastics components, the value of the nominal wall thickness, en, is identical to the specified minimum wall thickness, e_{min}.

3.2.10 wall thickness (at any point), e

wall thickness at any point around the circumference of a component

3.2.11 minimum wall thickness (at any point), e_{min}

minimum value for the wall thickness around the circumference of a component, as specified

3.2.12 maximum wall thickness (at any point), e_{max}

maximum value for the wall thickness around the circumference of a component, as specified

3.2.13 mean wall thickness, e_m

arithmetical mean of a number of measurements of the wall thickness, regularly spaced around the circumference and in the same cross-section of a component, including the measured minimum and the measured maximum values of the wall thickness in that cross-section

3.2.14 tolerance

permitted variation of the specified value of a quantity, expressed as the difference between the permitted maximum and the permitted minimum value

3.2.15 wall thickness tolerance

permitted difference between the wall thickness at any point, e, and the nominal wall thickness, en

NOTE $e_n = e_{min.}$

3.2.16 standard dimension ratio (SDR)

numerical designation of a pipe series, which is a convenient round number, approximately equal to the dimension ratio of the nominal outside diameter, dn, and the nominal wall thickness, en

3.3 Material Definitions

3.3.1 virgin material

material in a form such as granules/pellets that has not been subjected to use or processing other than that required for its manufacture and to which no reprocessable or recyclable materials have been added

3.3.2 own reprocessable (rework) material

material prepared from clean rejected unused pipes, fittings or valves, including trimmings from the production of pipes, fittings or valves that will be reprocessed in a manufacturer's plant after having been previously processed by the same manufacturer in the production of components by, for example injection moulding or extrusion

3.3.3 compound

homogenous mixture of base polymer (polyethylene) and additives, i.e. antioxidants, pigments, UV-stabilizers and others, at a dosage level necessary for the processing and use of components conforming to the requirements of this standard

3.3.4 campaign batch

uninterrupted base polymer production run by the resin manufacturer

NOTE It should not exceed 1 month’s production by the plant.

3.3.5 compound batch

clearly identifiable quantity of a given homogeneous compound manufactured under uniform conditions

NOTE: The compound batch is defined and identified by the compound manufacturer. It should not exceed 700 tonnes.

3.3.6 batch

number of pipes, all of them of the same nominal outside diameter, wall thickness and marking, extruded from the same compound on the same machine. A batch of pipe should not exceed 7 days continuous production.

Note: An extrusion equipment breakdown lasting >14hrs constitutes a new pipe batch.

3.3.7 peelable pipe

pipe made with polyethylene PE100 core material over which is an outer skin, which is removed locally with the aid of simple tools, prior to fusion jointing

NOTE: The skin allows protection of the core pipe during installation, but does not contribute to the specified wall thickness or to the mechanical strength of the pipe. The skin carries all marking and colour identification of the pipe.

3.3.8 core pipe

polyethylene pipe PE100 without skin

3.4 Material Properties

3.4.1 lower predicted limit (LPL), σ_{LPL}

quantity, with the dimensions of stress in megapascals (MPa), which can be considered as a property of the material, and represents the 97.5 % lower predicted limit of the mean long term strength at 20 °C for 50 years with internal water pressure

3.4.2 minimum required strength (MRS)

value of σ_{LPL}, rounded down to the next smaller value of the R10 series or of the R20 series depending on the value of σ_{LPL}

NOTE: R10 and R20 series are the Renard number series according to ISO 3 and ISO 497.

3.4.3 overall service (design) coefficient or safety factor, C

Allowable hoop or circumferential stress C should have a minimum value/safety factor of 2.0, which takes into consideration service conditions as well as properties of the components of a piping system other than those represented in the lower confidence limit.

3.4.4 design stress, σ_s

allowable stress, in megapascals (MPa) for a given application

NOTE It is derived from the MRS by dividing it by the coefficient C, i.e.:

$$\sigma_s = \frac{\mathrm{MRS}}{C}$$

3.4.5 melt-mass flow rate (MFR)

value relating to the viscosity of the molten material at a specified temperature and load, expressed in grams per 10 min (g/10 min)

3.5 Service Conditions

3.5.1 gaseous fuel

any fuel, which is in gaseous state at a temperature of 15 °C, at atmospheric pressure

3.5.2 maximum operating pressure (MOP)

maximum effective pressure of the fluid in the piping system, expressed in bar, which is allowed in continuous use. It takes into account the physical and the mechanical characteristics of the components of a piping system

NOTE It is calculated using the following equation:

$$\mathrm{MOP} = \frac{20 \times \mathrm{MRS}}{C \times (\mathrm{SDR} - 1)}$$

3.5.3 reference temperature

temperature for which the piping system is designed

NOTE It is used as the base for further calculation when designing a piping system or parts of a piping system for operating temperatures different from the reference temperature.

3.6 Joints

3.6.1 butt fusion joint (using heated tool)

joint made by heating the planed ends of pipes or spigot end fittings

NOTE The surfaces of the joint match by holding them against a flat heating plate until the polyethylene material reaches fusion temperature, removing the heating plate quickly and pushing the two softened ends against one another.

3.6.2 fusion compatibility

ability of two similar or dissimilar polyethylene materials to be fused together to form a joint, which conforms to the performance requirements of this standard

3.7 Packaging

3.7.1 coiled pipe

pipe extruded in a multi-layer coiled configuration with the layers strapped together to provide a stable and self-supporting unit

3.7.2 drummed pipe

pipe extruded on to a rigid framed reel, with a supporting centre core to which the pipe is anchored

3.8 Symbols

C overall service (design) coefficient

d_e outside diameter (at any point)

d_{em} mean outside diameter

$d_{em,max}$ maximum mean outside diameter

$d_{em,min}$ minimum mean outside diameter

d_n nominal outside diameter

e wall thickness (at any point) of a pipe

e_m mean wall thickness

e_{max} maximum wall thickness (at any point)

e_{min} minimum wall thickness (at any point)

e_n nominal wall thickness

σ_{LPL} lower predicted limit (MPa)

σ_s design stress

T_{min} minimum butt joint fusion temperature

T_{max} maximum butt joint fusion temperature

P_c critical pressure

$P_{C_{FS}}$ critical pressure measured in full-scale test (BS EN ISO 13478)

$P_{C_{S4}}$ critical pressure measured in S4 test (ISO 13477)

3.9 Abbreviations

BRT batch release testing

DN nominal size

DN/OD nominal size outside diameter related

LPL lower predicted limit

MFR melt mass-flow rate

MOP maximum operating pressure

MRS minimum required strength

PVT process verification testing

RCP rapid crack propagation

SDR standard dimension ratio

TT type testing

3.10 Contractor

The person, firm or company with whom a Gas Transporter enters into a contract to which this Standard applies, including the Contractor's personal representatives, successors and permitted assigns.

4. Conformance

4.1 Units of measurement

In this standard, for data expressed in both SI and USC units, a dot (on the line) is used as the decimal separator, and no comma or space is used as the thousand’s separator, in order to be consistent with other Gas Transporter specifications.

5. Material

5.1 General

The materials used for the polyethylene gas pipe systems shall be suitable for carrying gaseous fuels and in particular natural gas having a composition specified in BS EN ISO 13686 or suitable manufactured gases.

5.2 Material of the components

The pipes, fittings and valves shall be made of polyethylene compound.

NOTE: The type of material used for the propriety skin on peelable pipes is not specified.

5.3 Polyethylene compound

5.3.1 Additives

The compound shall be made by adding to the polyethylene base polymer only those additives necessary for the manufacture of pipes, fittings, valves as applicable, and for their fuse-ability, storage and use.

All additives, including those used in the peelable skin, shall not contain lead or cadmium. The additives shall be uniformly dispersed.

5.3.2 Colour

The colour of the PE80 compound should be shade 10E55 (yellow) or 00E53 (black) in accordance with BS 5252 or as close as reasonably practicable. The colour of the PE100 compound shall be shade 08E53 (yellow–orange) or 00E53 (black) in accordance with BS 5252 or as close as reasonably practicable.

For pipes with a peelable skin, the skin shall be shade 10E55 (yellow) in accordance with BS 5252 or as close as reasonably practical. In addition, several axial stripes equally spaced around the pipe and continuously along its length shall be incorporated into the skin and shall be coloured Black (00E53) to denote SDR11, Red (04E56) to denote SDR17.6, Brown (08C37) to denote SDR21, Green (12E55) to denote SDR26, and Blue (20E53 to 20E56) to denote SDR33. Stripe colours shall be in accordance with BS5252 or as close as reasonably practicable.

NOTE: For pipes with a peelable skin, the colour of the PE100 core compound is not specified.

NOTE: For pipes being supplied to Gas Networks Ireland the peelable skin colours shall be in accordance with IS EN 1555 1&2 National Annex.

5.3.3 Properties

5.3.3.1 Properties of the compound in the form of granules/pellets

The compound in the form of granules/pellets, used for the manufacture of pipes (including core compounds), fittings and valves, when tested in accordance with Table 1 shall conform to the performance requirements specified in Table 1.

The acceptable MFR range shall depend upon pipes being able to make butt fusion joints with a bead shape and size that meets the requirements of Gas Distribution Networks' mainlaying procedures as these are used in the field for butt joint quality control. Inspection and measurement of beads shall be in accordance with Annex A of this standard.

Table 1 — Properties of the compound in the form of granules/pellets

Properties	Performance requirements	Test parameters		Test method
		Parameter	Value	
Conventional density of compound	Conventional density of the compound with a maximum deviation of ±3 kg/m³ of the declared value [a)]	Test temperature	23 °C	BS EN ISO 1872-1
		No. of test pieces [b)]	Shall conform to BS EN ISO 1183-1, -2 or -3	BS EN ISO 1183-1, -2 or -3
Conventional density of base polymer (uncoloured)	Conventional density of base polymer with a maximum deviation of ±3 kg/m³ of the declared value [a)]	Test temperature	23 °C	BS EN ISO 1872-1
		No of test pieces [b)]	Shall conform to BS EN ISO 1183-1, -2 or -3	BS EN ISO 1183-1, -2 or -3
Oxidation induction time (OIT) (thermal stability)	>20 min	Test temperature	200 °C [c)]	BS EN 728 & BS EN ISO 11357-6
		No. of test pieces [b)]	3	
Melt mass-flow rate (MFR)	Nominated value of MFR [d)] Maximum deviation	Loading mass	5 kg	BS EN ISO 1133 & Annex A of this standard.
		Test temperature	190 °C	
		Time	10 min	

	of ±20 % of the declared value	No. of test pieces [b)]	Shall conform to BS EN ISO 1133	
Volatile content	≤350 mg/kg	No. of test pieces [b)]	1	BS EN 12099
Water content [e)]	≤300 mg/kg	No. of test pieces [b)]	1	BS EN 12118 or ISO 760
Carbon black content [f)]	2.0 % (by mass) to 2.5 % (by mass)	Shall conform to ISO 6964		ISO 6964
Pigment and carbon black dispersion	Grade ≤3.0	Preparation of test pieces	Free [g)]	BS ISO 18553
		No. of test pieces [b)]	Shall conform to BS ISO 18553	
Pellet geometry	Comparison with reference sample	Sample selection	Free	Free

Table 1 — Properties of the compound in the form of granules/pellets (continued)

Properties	**Performance requirements**	**Test parameters**		**Test method**
		Parameter	**Value**	
Colour	Defined in clause 5.3.2 of this standard.	No. of test pieces [b)]	1	BS 5252

[a)] All unpigmented and compound batches to be within the tolerance range throughout production.

[b)] The number of test pieces given indicate the numbers required to establish a value for the characteristic described in the table.

[c)] Test may be carried out at 210 °C providing that there is a clear correlation with the results at 200 °C. In case of dispute the reference temperature shall be 200 °C.

[d)] MFR is the value nominated by the compound manufacturer.

[e)] Only applicable, if the measured volatile content is not in conformity to its specified requirement. In case of dispute the requirement for water content shall apply.

[f)] Only for black compound.

[g)] In case of dispute, the compression method, in accordance with BS ISO 18553, for the preparation of test pieces shall apply.

5.3.3.2 Properties of the compound in the form of pipe

Unless otherwise specified by the applicable test method, the test pieces shall be conditioned at 23 °C ± 2 °C before testing in accordance with Table 2 of this standard. For details on minimum conditioning periods refer to GIS/PL2–2, clause 7.1, Table 2.

The compound in the form of pipe, when tested in accordance with Table 2 of this standard shall conform to the performance requirements specified in Table 2**.**

Table 2 — Properties of the compound in the form of pipe

Properties	Performance requirements	Test parameters: Parameter	Test parameters: Value	Test method
Resistance to gas condensate (d_n 32 mm: SDR11)	No failure during the test period of any test pieces	End caps	Type a	BS EN ISO1167
		Test temperature	80°C	
		No. of test pieces [a]	3	
		Circumferential (hoop) stress	2.0 MPa	
		Type of test	Synthetic condensate [b] inside pipe in water bath	
		Test period	20 h	
		Conditioning period	1500 h in air at 23°C	
Resistance to weathering (one size d_n:110mm to 180mm SDR11) Yellow PE80 and Yellow-Orange PE100 compounds j)	The weathered test pieces shall fulfil the requirements of the following characteristics: -	Weathering: Cumulative solar radiation	≥3.5 GJ/m^2	BS EN 1056
		No. of test pieces [a]	See below	
De-cohesion of an electrofusion joint	>66.7% ductile failure	Test temperature	23°C	ISO 13954 k) ISO 11413 i) Joint Condition 1
		No. of test pieces [a]	3	
80 °C Hydrostatic strength (un-notched)	No failure during the test period of any test piece [c]	End caps	Type a	BS EN ISO1167
		Conditioning time	Shall conform to BS EN ISO1167	
		No. of test pieces [a]	3	
		Type of test	Water-in-water	
		Internal test pressure:		
		PE80	Select from Table 4 c)	
		PE100	Select from Table 4 c)	
		Test period	Select from Table 4 c)	
		Test temperature	80 °C	
Yield strength and elongation at break	PE80 Yield stress ≥15 MPa Elongation ≥500 % PE100 Yield stress ≥20 MPa Elongation ≥500 %	Test piece dimensions	Shall conform to ISO 6259-3	BS EN ISO 6259-1 ISO 6259-3
		Test temperature	23 °C	
		No. of test pieces [a]	Shall conform to BS EN ISO 6259-1	
		Test speed: - e < 13 mm e >= 13 mm	 100 mm/min 25 mm/min	
80 °C Hydrostatic strength after squeeze off	No failure during the test period of any test piece [c]	As above for 80 °C hydrostatic strength	As above for 80 °C hydrostatic strength	BS EN 12106 BS EN ISO1167

Table 2 — Properties of the compound in the form of pipe (continued)

Properties		Performance requirements	Test parameters		Test method
			Parameter	Value	
Resistance to Weathering (continued)	20°C Hydrostatic strength.	No failure during the test period of any test piece	End caps	Type a	BS EN ISO1167
			Conditioning Time	Shall conform to ISO 1167	
			Type of Test	Water in Water	
			Circumferential (hoop) stress for: PE80 pipes PE100 pipes	Stress taken from the appropriate regression curves [h)]	
			Number of test pieces [a)]	3	
			Test Period	1000h	
			Test Temperature	20°C	
	80°C Hydrostatic strength after offset butt fusion	Produce butt weld to conditions in Annex A	Number of test pieces [a)]	3	Annex A in GIS/PL2-2.
		No failure during the test period of any test piece [c)]	As above for 80 °C hydrostatic strength	As above for 80 °C hydrostatic strength	BS EN ISO1167
Resistance to rapid crack propagation (RCP) Full-scale or S4 test [d)] (e ≥15 mm)		Critical pressure, P_c P_{CFS} ≥2.0 MOP [e)] with $P_{CFS} = 3.6\ P_{CS4} + 2.6$ [f)]	Test temperature	0 °C	BS EN ISO 13477
			No. of test pieces [a)]	Shall conform to ISO 13477 or BS EN ISO 13478	BS EN ISO 13478
Resistance to slow crack growth (Notched pipe test) (d_n: 110mm to 180mm SDR11) [g)]		No failure during the test period	Test temperature	80 °C	BS EN ISO 13479
			Internal test pressure:	Table 3	
			Test period	Table 3	
			Type of test	Water-in-water	
			No. of test pieces [a)]	Shall conform to BS EN ISO 13479	

Table 2 — Properties of the compound in the form of pipe (continued)

a) The numbers of test pieces given indicate the numbers required to establish a value for the characteristic described in the Table.
b) 50 % (by mass) n-decane and 50 % (by mass) 1-3-5 trimethylbenzene.
c) Only brittle failures shall be taken into account. If ductile failure occurs, the test shall be repeated at the reference time of 1000 h. Pressures and the associated test periods shall be selected from Table 4.
d) PE100 core grades, as used for peelable pipes, shall be tested without the skin for the RCP test.
e) The maximum operating pressures (MOP) are given in Annex B of this standard. The RCP testing conditions and requirements for PE80, PE100 and peelable pipes are detailed in clause 5.7 and Annex D of this standard.
f) If the S4 requirement is not met or S4 test equipment not available, then (re)testing by using the full scale test shall be performed in accordance with BS EN ISO 13478 in which case the full-scale test results take preference. In this case: $P_C = P_{C_{FS}}$.
g) Core PE100 grades shall be tested for stress crack resistance with the skin intact. Notch depth 20 % of core thickness.
h) F rom the material classification in this standard, the 20°C long-term hydrostatic test shall be conducted using the appropriate hoop stresses obtained from the lower predicted limit applicable to 1000h.
i) ISO 11413:1996 does not take into account peelable pipe. It is intended that its next revision will cover this aspect.
j) Not required for PE100 core compounds used for the manufacturer of peelable pipes (see also PL2-2)
k) ISO 13954 - 3 electro-fusion joint samples, each one cut into 4 test pieces for measurement

Table 3 — Resistance to slow crack growth (notch pipe test).

Applicable to PE80 pipes, peelable (PE100 core) pipes, and PE100 pipes. The notch test shall be performed on non-weathered pipes in all cases.

Pipe size to be selected from the range 110mm SDR11 to 180mm SDR11.

Characteristic	Requirement	Test Temperature	Test Method
Resistance to Slow Crack Growth a) Notch Pipe Test	PE80 = 8.0 bar ≥1000h PE100 = 9.2 bar ≥ 500h	80°C	BS EN ISO 13479
a) See Annex A in BS EN ISO 13479 for test conditions.			

Table 4 — 80 °C Hydrostatic strength test (un-notched). Test pressure at 80 °C and associated test periods (size in the range 110mm to 180mm SDR11 after weathering)

PE80		PE100	
Pressure bar	**Test period** h	**Pressure** bar	**Test period** h
9.0 8.0	165 [a)] 1 000	10.8 10.0	165 [a)] 1 000
[a)] If the sample fails by premature ductile failure, the test shall be automatically repeated at the reference condition for 1000 h.			

5.4 Fusion compatibility

5.4.1 Designation PE80/PE80, PE100/PE100, peelable pipes PE100/PE100 cores: same manufacturer

Compounds of the same designation (see 5.5) from the same manufacturer shall be fusible as follows: PE80 to PE80, PE100 to PE100 and for peelable pipes PE100 core to PE100 core.

For each compound, a butt fusion joint shall be prepared from two pipes each manufactured from that compound, in accordance with ISO 11414:1996, Annex A at an ambient temperature of 23 °C ± 2 °C. When tested in accordance with BS ISO 13953, the tensile strength of the butt fusion joints shall conform to Table 5.

5.4.2 Same designation: compound 1 with compound 2 and same manufacturer

If the compound manufacturer supplies more than one grade of PE80, PE100 (orange) or PE100 (peelable pipe core) for pipe, or replaces a grade by another grade of the same designation, all compound grades of the same designation and colour shall be compatible with each other, as they may be fusion jointed together in the field. Butt fusion joints shall be prepared from pipes manufactured from all compounds of the same designation in accordance with of ISO 11414:1996, Annex A at an ambient temperature of 23 °C ± 2 °C. When tested in accordance with BS ISO 13953 the tensile strength of the butt fusion joints shall conform to Table 5.

Table 5 — Tensile strength of compound in the form of butt fusion joint

Property	**Performance requirement** [a)]	**Test parameters**		**Test method**
		Parameter	**Value**	
Tensile strength for butt fusion d_n: 110mm to 180mm SDR11	Test to failure: ductile: pass brittle: fail	Test temperature	23 °C	BS ISO 13953
		No. of test pieces [b)]	Shall conform to BS ISO 13953	
[a)] The conformity to these requirements shall be proved by the compound producer. [b)] The numbers of test pieces given indicate the numbers required to establish a value for the characteristic described in the table.				

5.5 Classification and designation

Compounds shall be designated by the type of polyethylene material. The level of minimum required strength (MRS) shall conform to Table 6 when tested in the form of pipe.

Table 6 — Classification and designation of compounds

Classification by MRS MPa	**Designation**
8.0	PE80
10.0	PE100

The compound shall be evaluated in accordance with BS EN ISO 9080 where pressure tests are made in accordance with BS EN ISO1167 to find σ_{LPL}. The MRS value shall be derived from σ_{LPL} and the compound shall be classified by the compound producer in accordance with BS EN ISO 12162.

NOTE For the classification of a compound intended only for the manufacture of fittings, it is permissible to produce the pipe test piece by injection-moulding in accordance with BS EN 12107.

5.6 Maximum operating pressures (MOP), overall service (design) coefficient and design stress

PE80 yellow pipes shall be able to operate at temperatures down to -20 °C at pressures up to: -

- 5.5 bar for SDR11
- 4 bar for SDR 13.6 [a)]
- 3 bar for SDR17.6
- 2 bar for SDR21/26

Note a) Fittings fabricated by mitred butt fusion shall be limited to a maximum operating pressure of 2 bar

Due to RCP considerations, the MOPs of PE80 pipes in the larger sizes and lower temperatures have been reduced (see Annex B).

All peelable pipes (SDR21 and SDR26) with a PE100 core shall be able to operate at temperatures down to −20°C and at operational pressures up to a MOP of 2 bar. (see Annex B).

All SDR17.6 peelable pipe with a PE100 core supplied to Gas Networks Ireland shall be able to operate at temperatures down to −20°C and at operational pressures up to a MOP of 4 bar. (see Annex B).

All PE100 (orange) pipes shall be able to operate at a MOP of 7 bar but only for temperatures of 0 °C and above (see Annex B).

NOTE 1 - The relationships between the pipe's SDR, maximum operating pressure (MOP), minimum required strength (MRS), overall service (design) coefficient (C) and the design stress (σ_S) are given in the Table 7 below.

Table No 7 – Maximum Operating Pressures and Design Coefficient and Stress values

Polyethylene Designation	**SDR**	**MOP** **bar**	**MRS** **MPa**	**Service Design Coefficient, C**	**Design Stress, σ_S MPa**
PE80	11	5.5	8.0	2.9	2.75
	13.6	4.0	8.0	3.2	2.5
	17.6	3.0	8.0	3.2	2.5
	21	2.0	8.0	4.0	2.0
	26	2.0	8.0	3.2	2.5
Peelable Pipe	17.6	4.0	10.0	3.0	3.3
	21	2.0	10.0	5.0	2.0
	26	2.0	10.0	4.0	2.5
PE100	11	7.0	10.0	2.9	3.5
see clause 3 for symbols and definitions * Gas Networks Ireland only					

where: -

$$\sigma_S = \frac{MRS}{C}, \text{ MPa}$$

$$MOP = \frac{20 \text{ x } MRS}{C \text{ x } (SDR-1)} = \frac{20\,\sigma_S}{(SDR-1)}, \text{ bar}$$

5.7 Rapid crack propagation requirements for PE80, PE100 and peelable pipes

PE80 pipes operate at temperatures down to -20 °C but the RCP tests are conducted at the reference temperature of 0 °C. The derating of the pipe's MOPs for the larger sizes and operation below 0 °C allows the pipes to be used at these temperatures provided the RCP performance is first demonstrated at 0 °C.

Peelable pipes (SDR21 and 26) also operate down to -20 °C and the RCP performance of the peelable pipes has to be tested at this temperature but by the pipe manufacturer in GIS/PL2-2. In this specification, the RCP performance of the PE100 compound has to be tested as pipe by the compound manufacturer at a temperature of 0 °C.

PE100 orange pipes are only permitted to be used at temperatures of 0 °C and above so the RCP tests are conducted at 0 °C.

The RCP performance of all pipes shall be conducted at the relevant temperature and demonstrate crack arrest at a test pressure of 2 x MOP i.e. a safety factor of 2.

Details of the full-scale and S4 RCP testing procedures and requirements for PE80, peelable and PE100 pipes are given in Annex D of this standard. Further explanations and test details are given in informative Annex E

5.8 Reprocessable and recyclable material

Reprocessable material obtained from external sources and recyclable material shall not be used.

6. Type testing of compound

Type tests shall demonstrate that a compound conforms to all requirements for the characteristics given in Table 8 before pipe is supplied to the gas transporter using this compound.

In case of a change in compound as defined in Annex C, the relevant type test requirements are defined in Annex C and Table C.1, which refer to Tables 1 and 2.

Table 8 — Properties of the compound that require type testing (TT) by the compound manufacturer

Properties		Shall conform to:	Sampling procedure	No. of samples [a)]	No. of measurements per sample
Granules/Pellets	Conventional density of base (uncoloured, unfilled) polymer [b)]	**5.3.3.1**	Once/compound	3	1
	Conventional density of compound	**5.3.3.1**	Once/compound	3	1
	Oxidation induction time (thermal stability)	**5.3.3.1**	Once/compound	3	1
	Melt mass-flow rate (MFR)	**5.3.3.1**	Once/compound	3	1
	Volatile content	**5.3.3.1**	Once/compound	1	1
	Water content [c)]	**5.3.3.1**	Once/compound	1	1
	Carbon black content [d)]	**5.3.3.1**	Once/compound	1	1
	Colour	**5.3.2**	Once/compound	3	1
	Pigment dispersion [e)]	**5.3.3.1**	Once/compound	1	6
Pipe	Resistance to gas condensate	**5.3.3.2**	Once/compound	3	1
	Resistance to weathering	**5.3.3.2**	Once/compound	3/3/3/3/3/3 [f)]	4/1/5/1/1/1 [f)]
	Resistance to rapid crack propagation (e ≥15 mm)	**5.3.3.2**	Once/compound	Shall conform to ISO 13477 or BS EN ISO 13478	
	Resistance to slow crack growth (d_n: 110mm to 180mm SDR11)	**5.3.3.2**	Once/compound	3	1
	Fusion compatibility: Tensile strength for butt fusion (d_n: 110mm to 125mm SDR11)	**5.4.1**	Once/compound	3	Shall conform to BS ISO 13953
		5.4.2 [g)]	Once/compound	3	
	Classification	**5.5**	Once/compound	Shall conform to BS EN ISO 12162	Shall conform to BS EN ISO 12162

Table 8 — Properties of the compound that require type testing (TT) by the compound manufacturer (continued)

a) The number of samples specified in the table shall be the minimum. All samples shall pass the relevant test(s).
b) Base polymer measured on the granule/pellet i.e. uncoloured, un-compounded polyethylene.
c) Only applicable if the requirement for volatile content is not conformed to. In case of dispute the requirement for water content shall apply.
d) Only applicable for black compound.
e) Applicable to black, yellow and orange compounds. Not required for natural compound.
f) Three samples for de-cohesion of an electro-fusion joint with four measurements per sample. Three samples for 80 °C hydrostatic strength (un-notched) with one measurement per sample. Three samples for tensile yield stress and elongation at break with five measurements per sample. Three samples for 80 °C hydrostatic strength after squeeze off with one measurement per sample. Three samples for 20°C Long-Term Hydrostatic test for 1000hrs with one measurement per sample. Three samples for 80°C hydrostatic strength incorporating an offset butt fused joint with one measurement per sample.
g) Only required if the compound manufacture supplies or has supplied more than one PE80 or PE100 grade for pipe and/or fittings to the gas transporter.

7. Batch Release Testing (BRT) & Process Verification Testing (PVT) of compounds

Compounds shall be subject to batch release tests (BRT) and process verification tests (PVT) in accordance with Table 9. The minimum sampling frequencies shall be in accordance with Table 9.

Table 9 — Properties and minimum sampling frequencies for BRT/PVT

Properties		Shall conform to:	Minimum sampling frequency	No. of samples a)	No. of measurements per sample
Granules	Conventional density of base polymer b)	**5.3.3.1**	Once/campaign	1	1
Granules	Conventional density of compound b)	**5.3.3.1**	Once/batch	1	1
Granules	Oxidation induction time (OIT) (thermal stability)	**5.3.3.1**	Once/batch	1	1
Granules	Melt mass-flow rate (MFR)	**5.3.3.1**	Once/batch	1	1
Granules	Water content d)	**5.3.3.1**	Once/batch	1	1
Granules	Pellet geometry	**5.3.3.1**	Once/batch	1	1
Granules	Carbon black content	**5.3.3.1**	Once/batch	1	1
Granules	Pigment dispersion	**5.3.3.1**	Once/batch	1	6
Granules	Colour change / drift	**5.3.2**	Once/year	1	1
Pipe	Rapid crack propagation resistance (RCP) e)	**5.3.3.2**			
Pipe	PE80: S4 or [full-scale] test	**5.3.3.2**	Once/year	3 [1] c)	1 [1] c)
Pipe	PE100: S4 or [full-scale] test	**5.3.3.2**	Once/year	3 [1] c)	1 [1] c)

a) The number of samples specified in the table shall be the minimum. All samples shall pass the relevant test(s).

b) All powder/granule/pellet and compound batch results to fall within the range ±3 kg/m^3 of the declared value.

c) Three pipe samples for S4 test or 1 pipe sample for the full-scale test

d) May be replaced by volatile content test (≤350 mg/kg) to BS EN 12099 (see Table 1).

e) RCP test pipes, with a wall thickness greater to or equal 15 mm, to be produced using commercial extrusion conditions.

Annex - A Butt Fusion beads (normative)

The butt welding equipment and procedure shall conform to GIS/PL2-3.

After the butt fusion joint has been completed and the butt fusion bead formed, the bead shall be visually inspected for evenness (same bead size from each pipe end). The weld bead width shall be measured using an appropriate gauge. If satisfactory, the bead shall then be removed with an approved tool, the width shall be checked again using the gauge, and finally the underside of the bead shall be inspected for offsets and for contamination and slit defects by the bend-back technique.

Consequently, the melt mass-flow rate (MFR) of the polyethylene shall be within reasonably strict limits or the bead widths will not be correct and the joints will then be rejected during installation.

NOTE 1: The width of the bead depends upon the butt welding procedure and the melt properties of the polyethylene material, which are largely governed by the melt mass-flow rate (MFR).

NOTE 2: Acceptance of the polyethylene grade depends upon being able to produce butt fusion bead widths that meet the current range of bead gauges using the agreed butt fusion procedures.

NOTE 3: This primary level of inspection is carried out on all butt fusion joints and is an essential part of the in-field quality control to ensure high quality joints.

NOTE 4: If poor butt joints are produced, the weld interface may fracture leading to a full-bore pipe failure and the loss of large quantities of uncontrolled gas.

Annex - B Maximum operating pressures (MOP) for PE80, peelable (PE100 core) and PE100 pipes (normative)

Table B.1 – Diameters and maximum operating pressures for PE80 polyethylene pipe

Pipe DN/OD	Maximum operating pressure Bar																			
	Pipe SDR (class)																			
	11				13.6				17.6				21				26			
mm	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C
16	5.5	5.5	5.5	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	5.5	5.5	5.5	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	5.5	5.5	5.5	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	5.5	5.5	5.5	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	5.5	5.5	5.5	5.5	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
55	5.5	5.5	5.5	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
63	5.5	5.5	5.5	5.5	-	-	-	4.0	-	-	-	-	-	-	-	-	-	-	-	-
75	5.5	5.5	5.5	5.5	-	-	-	4.0	-	-	-	-	-	-	-	-	-	-	-	-
90	5.5	5.5	5.5	5.5	-	-	-	-	3.0	3.0	3.0	3.0	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	3.0	3.0	3.0	3.0	-	-	-	-	-	-	-	-
125	4.4	4.7	5.1	5.5	-	-	-	-	3.0	3.0	3.0	3.0	-	-	-	-	-	-	-	-
140	4.1	4.4	4.8	5.5	-	-	-	-	3.0	3.0	3.0	3.0	-	-	-	-	2.0	2.0	2.0	2.0
160/162	-	-	-	-	-	-	-	-	3.0	3.0	3.0	3.0	-	-	-	-	2.0	2.0	2.0	2.0
180	3.5	3.7	4.1	4.7	-	-	-	-	2.9	3.0	3.0	3.0	-	-	-	-	2.0	2.0	2.0	2.0
200	3.3	3.5	3.8	4.4	-	-	-	-	2.7	2.8	3.0	3.0	-	-	-	-	2.0	2.0	2.0	2.0
213	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.0	2.0	2.0
225	-	-	-	-	-	-	-	-	-	-	-	3.0	-	-	-	-	2.0	2.0	2.0	2.0

TABLE B.1 - (concluded)

Pipe DN/OD	Maximum operating pressure Bar																			
	Pipe SDR (class)																			
	11				13.6				17.6				21				26			
mm	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°-C	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C
250	2.9	3.0	3.3	4.0	-	-	-	-	2.3	2.5	2.7	3.0	-	-	-	-	2.0	2.0	2.0	2.0
268	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.9	2.0	2.0	2.0
280	2.7	2.8	3.1	3.8 *	-	-	-	-	2.2	2.3	2.5	2.9	-	-	-	-	1.8	2.0	2.0	2.0
315	2.5	2.6	2.9	3.4 *	-	-	-	-	2.0	2.1	2.3	2.7	-	-	-	-	1.7	1.8	2.0	2.0
355	2.3	2.4	2.7	3.1	-	-	-	-	1.9	2.0	2.2	2.5	1.7	1.8	2.0	2.0	-	-	-	-
400	2.1	2.3	2.5	2.9	-	-	-	-	1.7	1.8	2.0	2.3	1.6	1.7	1.9	2.0	-	-	-	-
450	2.0	2.1	2.3	2.7	-		-	-	1.6	1.7	1.9	2.2	1.5	1.6	1.7	2.0	-	-	-	-
469	-	-	-	-	-	-	-	-	1.6	1.7	1.8	2.1	1.5	1.6	1.7	2.0	-	-	-	-
500	1.9	2.0	2.2	2.5	-	-	-	-	1.5	1.6	1.8	2	1.4	1.5	1.6	2.0	-	-	-	-
560	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-
630	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
710	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-
800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-

1. SDR 21 and SDR 26 pipe for traditional insertion/close fit insertion only.
2. Pipe sizes of 355mm and above use SDR 21 instead of SDR 26, as the thicker wall gives additional support from ground loading.
3. Pipe sizes indicated by a dash (-) are not normally available.
4. The higher operating pressures apply to the overlapping temperatures of –10°C, -5°C and 0°C.
5. The operating temperature range for the UK under normal conditions is in the range of 0°C to 20°C.
6. The maximum test pressure for PE is 1.5 times the maximum operating pressure.

* 4 Bar in Gas Networks Ireland

TABLE B.2 - Diameters and maximum operating pressures for Peelable (PE100 core) polyethylene pipe

Pipe DN/OD	Maximum operating pressure bar								
	Pipe SDR (class)								
	17.6	**21**				**26**			
mm	0°C to 20°C	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C	-20°C to -10°C	-10°C to -5°C	-5°C to 0°C	0°C to 20°C
63	-	2	2	2	2	2	2	2	2
75	-	2	2	2	2	2	2	2	2
90	-	2	2	2	2	2	2	2	2
110	-	2	2	2	2	2	2	2	2
125	4 *	2	2	2	2	2	2	2	2
140	-	2	2	2	2	2	2	2	2
160	-	2	2	2	2	2	2	2	2
180	4 *	2	2	2	2	2	2	2	2
200	4 *	2	2	2	2	2	2	2	2
225	4 *	2	2	2	2	2	2	2	2
250	4 *	2	2	2	2	2	2	2	2
280	4 *	2	2	2	2	2	2	2	2
296	4 *	2	2	2	2	2	2	2	2
315	4 *	2	2	2	2	2	2	2	2
355	4 *	2	2	2	2	2	2	2	2
400	4 *	2	2	2	2	2	2	2	2
450	-	2	2	2	2	2	2	2	2
500	-	2	2	2	2	2	2	2	2
560	-	2	2	2	2	2	2	2	2
630	-	2	2	2	2	2	2	2	2
800	-	2	2	2	2	-	-	-	-

Notes

The operating temperature range for the UK under normal conditions is in the range 0°C to 20°C.

The test pressure for PE 100 SDR 21 & 26 is 1.5 times the maximum operating pressure (3 bar gauge).

* Gas Networks Ireland only

TABLE B.3 - Diameters and maximum operating pressures for PE100 orange polyethylene pipe

Pipe DN/OD mm	Maximum operating pressure bar
	Pipe (class) SDR 11
	0ºC to 20ºC
63	7
75	7
90	7
110	7
125	7
180	7
200	7
225	7
250	7
315	7
355	7
400	7
450	7
500	7
560	7
630	7
800	7
Notes The operating temperature range for the UK under normal conditions is in the range 0ºC to 20ºC. The maximum air pressure test for PE100 SDR 11 is 7 bar gauge	

Annex - C Change in compound (normative)

C.1 Major changes in compound formulation

If the base polymer is changed or a change is made to the chemical nature or colour of pigment then type testing shall be carried out in accordance with Tables 1 and 2. Change of polymer manufacturer, polymerization process or chemical nature of co-monomer shall be deemed to be a change of base polymer.

C.2 Minor changes in compound

If the following changes are made to the compound then type testing shall be carried out in accordance with Table C.1:

a) increase nominated MFR (190 °C, 5 kg) more than 20 % or 0.1 g/10min;
b) change of nominated density more than 3 kg/m^3;
c) production of the same compound at a different site;
d) production of the same base polymer with a new production line at the same site.

C.3 Change of pigment

If the pigment level is increased by more than 30 % then type testing shall be carried out in accordance Table C.1.

C.4 Changes in additives other than pigments

The following changes in additives shall necessitate type testing in accordance with Table C.1:

a) change of chemical nature or addition or deletion of any additive;
b) change of any additive (other than stabilizers) level by more than 30 %;
c) decrease of UV-stabilizers by more than 30 % or increase by more than 50 %.

Table C.1 — Type testing required for re-evaluation (minor changes)

Properties	Change						
	C.2a) and C.2b)	C.2c)	C.2d)	C.3	C.4a)	C.4b)	C.4c)
Physical [a)]	+	+	+	+	+	+	+
Resistance to slow crack growth (80 °C)	+	+	+	+	+	+	+
Resistance to rapid crack propagation	+	+	+	+	+	—	—
Tensile strength for butt fusion	+	—	—	+	+	+	+
Resistance to weathering [b)]	—	—	—	—	+	—	+
Hydrostatic strength (20 °C) [c)]	+	+	+	—	+	—	—
Hydrostatic strength (80 °C) [d)]	+	+	+	+	+	+	+

Key

“ + ” denotes test to be carried out.

“ — ” denotes test not required.

a) As defined in Table 1 (conventional density, oxidation induction time, MFR, volatile content, water content (if required), carbon black content, pigment and carbon black dispersion, colour, pellet geometry).

b) Tests specified in Table 2, i.e. de-cohesion, 80 °C hydrostatic strength (un-notched), yield strength and ductility, 80 °C hydrostatic strength after squeeze-off, 20 °C hydrostatic strength,.80 °C hydrostatic strength offset butt fusion.

c) Test shall be performed on pipe sizes 110mm – 180mm. Check two stress levels at 20 °C taken from the predicted LPL curve of the original classification dataset, corresponding to at least 100 h and 2,500 h respectively. Test three test pieces at each stress level. The corresponding times shall be exceeded without failure.

d) Test shall be performed on pipe size 110mm –180mm. Two stress levels shall be checked at 80 °C taken from the predicted LPL curve of the original classification dataset, corresponding to at least 100 h and 2 500 h respectively. Test three test pieces at each stress level. The corresponding times shall be exceeded without failure.

Annex - D RCP Testing Procedures (normative)

D.1 RCP Testing of PE80 yellow Pipes

PE80 yellow pipes have to be able to operate at temperatures down to -20 °C at pressures up to: -

- 5.5 bar for SDR11
- 4 Bar for SDR 13.6
- 3 bar for SDR17.6
- 2 bar for SDR21 and SDR26

Due to RCP considerations, the maximum operating pressures (MOPs) of PE80 pipes in the larger sizes and lower temperatures have already been reduced (see Table B.1). Consequently, RCP tests are conducted at a temperature of 0 °C.

The correlation equation proposed by the ISO TC138/SC4 committee in producing ISO 13477 is: -

$P_{fs} = 3.6P_{s4} + 2.6$ bar (1)

where

P_{FS} – full-scale pressure, bar

P_{S4} – S4 pressure, bar

For GIS/PL2 Part 1, the RCP test shall be conducted by the compound manufacturer on one pipe size provided the wall thickness is 15 mm or greater.

A full-scale RCP test (BS EN ISO 13478) or an S4 RCP test (ISO 13477) shall be conducted.

The full-scale RCP test shall be conducted at a temperature of 0°C and pressure of 2 x MOP. The MOP is selected for the appropriate pipe size, SDR and 0°C temperature.

The S4 test shall be conducted at a temperature of 0°C and a pressure (P_{S4}) calculated from equation 1 using a full-scale pressure (P_{FS}) of 2 x MOP for the appropriate pipe size, SDR and 0°C temperature.

If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

D.2 RCP Testing Peelable (PE100) yellow Pipes

All peelable pipes (SDR21 and SDR26) with a PE100 core shall be able to operate at temperatures down to −20 °C and at operational pressures up to a MOP of 2 bar (see Table B.2).

For GIS/PL2 Part 1, the RCP test shall be conducted by the compound manufacturer on one pipe size **without the skin**, provided the wall thickness is 15 mm or greater.

A full-scale RCP test (BS EN ISO 13478) or an S4 RCP test (ISO 13477) shall be conducted.

The full-scale test for all sizes shall be conducted at a temperature of 0°C and pressure of 14 bar for SDR11 pipe.

The S4 test for all sizes shall be conducted at a maximum temperature of 0°C and a pressure (P_{S4}) of 3.2 bar for SDR11 pipe.

If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedent, as the full-scale test is the reference test.

D.3 RCP testing PE100 (orange) Pipes

All PE100 (orange) pipes shall be able to operate at a MOP of 7 bar but only for temperatures of 0 °C and above (see Tables B.1, B.2 & B.3).

For GIS/PL2 Part 1, the RCP test shall be conducted by the compound manufacturer on one pipe size, provided the wall thickness is 15mm or greater.

A full-scale RCP test (BS EN ISO 13478) or an S4 RCP test (ISO 13477) shall be conducted.

The full-scale test for all sizes shall be conducted at a temperature of 0°C and a pressure of 14 bar (SDR11).

The S4 test for all sizes shall be conducted at a maximum temperature of 0°C and a pressure (PS4) of 3.2 bar (SDR11).

If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

Annex - E Rapid Crack Propagation (RCP) - Discussion and Requirements (Informative)

E.1 Summary

E.1.1 General

Rapid crack propagation (RCP) is the name used to describe a brittle crack travelling down a pipeline at very high speeds. RCP is more likely to occur with large diameter polyethylene (PE) pipes operating at high pressures and low temperatures when crack speeds of up to 1000 km/hr. (300 m/s) are produced. Consequently, the PE pipeline system has to be designed to ensure this failure mode cannot occur either during pressure testing or later in service.

The two RCP test methods – full-scale (BS EN ISO 13478) and S4 (ISO 13477) are described, together with the correlation between the test pressures derived from these two methods.

Yellow PE80 pipes are operated at pressures up to 5.5 bar but the maximum operating pressures (MOP) are derated for larger pipe sizes and lower operating temperatures.

Peelable pipes have a yellow skin over a black or natural PE100 core. These are operated down to -20 °C at maximum operating pressures up to 2 bar for all sizes and temperatures.

Yellow-orange PE100 pipes are operated at pressures up to 7 bar for all sizes but must always be operated at temperatures of 0 °C and above.

The detailed RCP testing requirements are given and discussed for Gas Industry Specifications: -

GIS/PL2 Part 1 [PE compounds]
GIS/PL2 Part 2 [yellow PE80 and peelable pipes (PE100 core)]
GIS/PL2 Part 8 [PE100 yellow-orange pipes]

The full-scale test at the appropriate temperature and pressure should be conducted. Alternatively, the S4 test may be used at the same or lower temperature but with the reduced test pressure calculated from the correlation equation (E.4.2). If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful, takes precedence, as the full-scale test is the reference test.

E.1.2 PE80 yellow Pipes – SDR 11, 13.6, 17.6, 21 & 26

For GIS/PL2-1 compliance, the full-scale RCP test shall be conducted on one pipe size (wall thickness, t ≥15mm) at 0 °C and a pressure of 2 x maximum operating pressure (MOP) for the appropriate pipe size, SDR and 0°C temperature.

For GIS/PL2 -2, the full-scale RCP test shall be conducted on the manufacturer’s maximum pipe size (t ≥15mm) at 0 °C and a pressure of 2 x maximum operating pressure (MOP) for the appropriate pipe size, SDR and 0°C temperature. If successful, approval is also given to any smaller pipe size, provided the wall thickness is not greater than that tested.

In both cases, the S4 test method at 0 °C may be used instead and at the reduced test pressure calculated from the correlation equation (E.4.2).

E.1.3 Peelable Pipes (PE100 core) – SDR 21 & 26

For GIS/PL2-1, the full-scale RCP test shall be conducted on one pipe size (t ≥15mm) **without the skin** at 0 °C and a pressure of 14 bar for SDR11 pipe (2 x MOP for PE100 pipes).

For GIS/PL2 -2, the full-scale RCP test shall be conducted on 250 mm, 315 mm and the manufacturer’s maximum pipe size at -20 °C and a pressure of 4 bar (2 x MOP). The skin is left intact. If successful, approval is given to any smaller and intermediate pipe sizes and further to any SDR26 pipe if the SDR21 pipe has RCP approval.

In both cases, the S4 test method may be used instead at maximum temperatures of 0 °C or -20 °C, as appropriate, and at the test pressure calculated from the correlation equation (E.4.2) i.e. GIS/PL2-1 at 3.2 bar; GIS/PL2 -2 at 0.4 bar.

E.1.4 PE100 yellow-orange Pipes – SDR11

For GIS/PL2-1, the full-scale RCP test shall be conducted on one pipe size (t ≥15mm) at 0 °C and a pressure of 14 bar (2 x MOP).

For GIS/PL2-8, the full-scale RCP test shall be conducted on the manufacturer's maximum pipe size (t ≥15mm) at 0 °C and a pressure of 14 bar (2 x MOP). If successful, approval is also given to any smaller pipe size.

In both cases, the S4 test method may be used instead at a maximum temperature of 0 °C and at the reduced test pressure of 3.2 bar calculated from the correlation equation (E.4.2).

E.2 Introduction

Rapid crack propagation (RCP) is the name used to describe a brittle crack travelling down a pipeline at very high speeds, **Figure E.1**. RCP is more likely to occur with large diameter polyethylene (PE) pipes operating at high pressures and low temperatures when crack speeds of up to 1000 km/hr (300 m/s) are produced. Once RCP conditions are produced, then the whole section of the pipeline may be lost. It could occur without warning and the results could be catastrophic. Consequently, the PE pipeline system has to be designed to ensure this failure mode cannot occur either during air pressure testing (commissioning) at 1.5 times maximum operating pressure (MOP) or later in service, carrying gas.

The pipeline's maximum operating pressures (MOP) are given in Annex B.1.

E.3 RCP Initiation & Arrest

Even if the conditions for RCP are present in the PE pipeline, a high speed crack first has to be initiated in the pipe wall to produce RCP. Normally, PE is very tough and cracks are difficult to initiate under normal conditions. A high speed crack may initiate by impact by heavy machinery e.g. back-hoe excavator, particularly if the teeth or bucket are sharp, however, the most likely cause of initiation is the sudden brittle failure of a defective butt fusion joint. Under axial bending loads, the crack can initiate at one small part of the weld's circumference. The crack then rapidly travels around the weld interface, but as it does so, the hoop stress in the pipe wall (due to the internal pressure) deflects the circumferential high speed crack to run along the length of the pipe. Whether this axial high-speed crack arrests within a few metres or continues to propagate depends entirely on the pipeline conditions.

Once RCP conditions are established the crack will continue to run down the pipeline as the pipe in front of the crack tip is under exactly the same conditions as the section it has just cracked. The high speed crack will propagate through any butt fusion joints. Naturally, the crack will be stopped by mechanical joints - at valves for example. It is believed that an electrofusion fitting will also stop the crack and although there is some evidence for this, it has not yet been demonstrated conclusively.

E.4 RCP Test Methods

E.4.1 Full-Scale Test

E.4.1.1 Normal Full-Scale Technique

Test methods have been developed to assess the resistance of plastic pipes to RCP and are described in detail in BS EN ISO 13478 (full-scale) (1) and ISO 13477 (S4) (2).

The full-scale method simulates what could happen in service by testing a long length of PE pipe at the expected minimum below ground temperature. From historical information, it is assumed that a temperature of 0 °C is reached below ground at the normal pipe burial depth of 750 mm once in every 50 years in the UK.

The test method requires that at least 14 m of PE pipe at 0 °C is be used for the test. This is connected to a steel pipe reservoir, at least 28 m long, to simulate a longer PE pipeline

Figure E.1 RCP in 315 mm SDR 17.6 PE80 pipe

As the gas exhausts down the pipe during RCP, the crack tip generally lags behind the gas decompression wave front that spreads down the pipe (see **Annex E.9**). Consequently, the gas pressure at the crack tip, which is driving the crack forward, is less than the original pipe pressure. Each full-scale test determines whether RCP will occur under the pipe's particular conditions i.e. pressure, pipe size, temperature, etc. However, from a series of tests, the full-scale critical pressure (P_{cFS}) between arrest and RCP under practical operating conditions can be measured at a temperature, normally of 0 °C. The critical pressure is conservatively taken as the highest arrest pressure; it is not an average of the highest arrest pressure and the lowest propagation pressure. If the critical pressure for a particular pipe size is higher than that required by the gas utility, then all smaller diameter pipes of the same standard dimension ratio (SDR) will also be satisfactory. Smaller diameter pipes of the same SDR always have higher critical pressures.
GIS/PL2 Parts 2 & 8 require the crack to arrest at a full-scale test pressure of 2 x MOP.

E.4.1.2 Modifications to Full-Scale Test Technique for PE100 Pipes

The full-scale test method is also used for PE100 pipes, though the technique is usually slightly modified for these high RCP resistant PE100 pipes by first initiating a high-speed crack in a length of PE80 pipe before crossing a butt weld into the PE100 test section. The details are given in EN ISO 13478.

E.4.2 S4 Test Technique & Correlation Equation

A Small-Scale Steady-State (S4) laboratory test (ISO 13477) was developed as a cheaper and quicker alternative to the full-scale test method. The test uses pipe lengths of $7d_n$ (e.g. 1.75 m for

250 mm pipe), which are very much shorter than the 14 m (minimum) used in the full-scale tests. A system of internal baffles are also fitted inside the pipe bore that effectively stop axial gas exhaustion throughout the test, thus maintaining gas pressure at the crack tip at the initial test pressure, Annex E.9.
Again, the test measures the critical pressure (P_{cS4}) between arrest and RCP but, because of the higher crack tip pressure during the test, P_{cS4} will always be lower than the equivalent P_{cFS}. A correlation between the full-scale and S4 results is therefore necessary in order to enable the S4 results to be recalculated to an equivalent full-scale critical pressure. A correlating equation has been developed for PE materials, but in cases of dispute or when the S4 test is not available for the larger sizes, the full-scale test is recognised as the reference test.
The correlation equation proposed by the ISO TC138/SC4 committee in producing ISO 13477 (Appendix B) is: -

$$P_{cFS} = 3.6P_{cS4} + 2.6 \text{ bar} \qquad (1)$$

Any pressure in the S4 test can be converted the equivalent pressure in the full-scale test using the equation but it is generally used for converting the S4 critical pressure (P_{cS4}), derived from a series of S4 tests, to the equivalent full-scale critical pressure (P_{cFS}).

All decisions on the suitability of the PE pipe for operational use are based upon the full-scale pressure (P_{FS}) or the equivalent full-scale pressure recalculated from the S4 pressure (P_{S4}). GIS/PL2 Parts 2 & 8 require the crack to arrest at a full-scale test pressure of 2 x MOP (see **Annex E.9**). When the S4 test is used, the full-scale test pressure requirements in the specifications are back-calculated to the equivalent S4 test pressure before conducting the S4 test (E.4.2).

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E.5 RCP Testing of PE80 Yellow Pipes

Gas Industry Specifications require PE80 yellow pipes to be able to operate at temperatures down to -20 °C at pressures up to: -

5.5 bar for SDR11
4 bar for SDR 13.6
3 bar for SDR17.6
2 bar for SDR21 and SDR26

Due to RCP considerations, the MOPs of PE80 pipes in the larger sizes and lower temperatures have been reduced by Gas Distribution Networks. The maximum operating pressures (MOP) are given in Annex B. Consequently, RCP tests are conducted at a “spot-check” temperature of 0 °C to ensure they have at least the same RCP resistance as the original PE80 pipes from which the de-rated MOPs were obtained. The full-scale test pressures are 2 x MOP.

Alternatively, the S4 test at 0 °C can be used for PE80 yellow pipes.
Note the test pressure (P_{S4}) that the pipe must pass in the S4 test is calculated from the ISO/CEN correlation equation (E.4.2, equation 1) using 2 x MOP
e.g. 250mm SDR11 PE80

Test Temperature = 0 °C
MOP = 4 bar (see Annex B)
Therefore, P_{FS} = 2 x MOP = 8 bar

$$P_{S4} = \frac{(P_{FS} - 2.6)}{3.6} = 1.5\text{bar}$$

Consequently, the S4 test would have to demonstrate crack arrest at a minimum test pressure of 1.5 bar at 0 °C.

If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

For **GIS/PL2 Part 1**, the RCP test has to be conducted by the compound manufacturer only on one pipe size, provided the wall thickness is 15 mm or greater.

For GIS/PL2 Part 2, the RCP test is conducted on the manufacturer's maximum pipe size (≥15mm). If successful, approval is given to any smaller pipe size, provided the wall thickness is not greater than that tested (see GIS/PL2 Part 2: Table 13).
Extracts from the detailed specification requirements from GIS/PL2-1, GIS/PL2-2 and GIS/PL2-8 are given in Annex E.10.

E.6 RCP Testing Peelable (PE100) Yellow Pipes

Gas Industry Specifications require all peelable pipes (SDR21 and SDR26) with a PE100 core to be able to operate at temperatures down to −20 °C and at operational pressures up to a MOP of 2 bar.

Consequently, the RCP test for all sizes must be conducted at -20°C. For all sizes, the full-scale test pressure will be 4 bar and for the S4 test, a pressure of 0.4 bar. Either the full-scale or S4 test can be used. Again, if the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

Although the temperature of -20 °C is quite severe for the PE100 core pipe, the test pressures are also low.

It has been observed that the grade of the polypropylene skin, its thickness and the adhesion to the PE100 core pipe, all have a complex effect on the RCP performance. Consequently, the polypropylene grade, thicknesses and adhesion levels (and tolerances where appropriate) need to be declared by the pipe manufacturer in seeking Type Testing approval. Modifications to the current GIS/PL2 Part 2 will be necessary, together with additional test method(s).

For GIS/PL2 Part 1, there are no RCP test requirements for peelable pipes because the skin has an effect on the results and this is controlled by the pipe manufacturer. However, it is still necessary to demonstrate the RCP performance of the PE100 core pipe (≥15mm), without any skin, meets the basic RCP requirements for PE100 yellow-orange pipe at 0 °C by either the full-scale or S4 test methods (see E.7). It is only in GIS/PL2 Part 2 that the peelable pipe, with its skin, is tested for RCP resistance down to -20 °C.

Therefore, for GIS/PL2 Part 1, the RCP test has to be conducted by the compound manufacturer only on one pipe size provided the wall thickness is 15mm or greater. For all sizes the test temperature is 0°C, with a full-scale test pressure of 14 bar for an SDR11 pipe or an equivalent S4 test pressure of 3.2 bar. In principle, a higher SDR (thinner-walled) pipe is acceptable but the wall thickness must still be 15 mm or greater but then the MOP is unknown.

The RCP test in GIS/PL2 Part 2 is conducted on a range of sizes: 250mm, 315mm and the manufacturer's maximum size e.g. 630mm. The polypropylene skin at low temperatures is generally more brittle than the PE100 and so may result in crack initiation that can jump across the interface into the PE100 pipe core. Though the skin thicknesses are controlled in the Specification (Table 5), they are almost constant across the entire diameter range and the current tolerances are relatively wide. It will not become clear until further research is completed on effect of the skin, whether a relatively thick skin on a smaller diameter pipe is more likely to reduce the RCP resistance than a relatively thin skin on a larger diameter, thicker-walled pipe. Hence at this stage, it cannot be assumed that smaller pipe sizes would have higher critical pressure, so testing a range of sizes is currently required.

For GIS/PL2 Part 2, either the full-scale or S4 RCP test can be used. The full-scale test for all sizes is conducted at -20 °C at a test pressure of 4 bar using a PE80 SDR21/26 pipe as the initiation pipe if necessary (see E.4.1.2). The S4 test for all sizes is also conducted at -20 °C with a test pressure of 0.4 bar, as calculated from equation 1. Coincidentally, an S4 test temperature of approximately -20 °C is necessary to obtain the correct initiation conditions (see E.7)

If successful, approval is given to any smaller and intermediate pipe size, and is also conferred on any SDR26 pipe if the SDR21 pipe of equivalent OD has RCP approval (see GIS/PL2 Part 2: Table 13).

E.7 RCP Testing PE100 (Yellow-Orange) Pipes

Gas Industry Specifications require that all PE100 (yellow-orange) pipes (which are all SDR11) are able to operate at a MOP of 7 bar but, only at temperatures of 0 °C and above (see Annex B).

Consequently, the RCP test for all sizes must be conducted at 0 °C. For all sizes the full-scale test pressure will be 14 bar and for the S4 test, a pressure of 3.2 bar. Either the full-scale or S4 test can be used. Again, if the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

The full-scale method uses a PE80 crack initiation pipe length, butt welded onto the end of the PE100 test length (see E.4.12).

The S4 test can also be used for testing PE100 pipes. However, for the test to be valid it is necessary to prove the S4 initiation conditions can produce the start of a high speed crack into the test length (see ISO 13477). Otherwise, any crack arrest may have resulted from inadequate crack initiation rather than the pipe's test conditions (pressure, temperature, etc.). At 0 °C, suitable initiation conditions cannot be produced with modern PE100 compounds due to their high toughness, but it is possible to produce the required conditions at lower temperatures e.g. -20 °C. If, whilst using the same initiation conditions at the same low temperature, the S4 pipe test demonstrates crack arrest for the 3.2 bar test pressure, then the pipe would also show crack arrest at higher temperatures e.g. 0 °C. The RCP critical pressure never decreases on raising the temperature from -20 °C to 0 °C. Consequently, satisfactory RCP performance of the pipe would have been demonstrated for this pressure at 0 °C. Although the test is more severe than actually required, it is an effective way of addressing the problem of creating suitable crack initiation conditions. In practice, this test method works well with modern PE100 pipe compounds.

For GIS/PL2 Part 1, the RCP test has to be conducted by the compound manufacturer only on one SDR11 pipe size provided the wall thickness is 15mm or greater. For all sizes the test temperature is 0°C, with a full-scale test pressure of 14 bar or a S4 test pressure of 3.2 bar.

For GIS/PL2 Part 8, the RCP test is conducted on the manufacturer's maximum pipe size, provided it has a wall thickness of 15mm or greater. For all sizes the test temperature is 0°C, with a full-scale test pressure of 14 bar or an S4 test pressure of 3.2 bar. If successful, approval is given to any smaller pipe size (see GIS/PL2 Part 8: Table 12).

E.8 Application of the Critical Pressure Data

The critical pressure obtained from full-scale tests (or converted from S4 critical pressures) on a particular PE pipe size and SDR is not normally used to predict the RCP performance of larger pipe sizes and/or different SDRs. All that can be inferred is that the critical pressures of the larger sizes will be not be higher for the same SDR. Conversely, if the critical pressure is known for a PE pipe size and SDR, then the critical pressure of a smaller pipe size, but of the same compound and SDR will be higher. Naturally, this assumes the intrinsic RCP resistance of the PE compound/pipe batch is unchanged.

PE80 and peelable pipes are designed to operate down to -20 °C, though the probability of operating at this temperature is not high. It has been estimated that a PE main buried at the normal burial depth of 750 mm may only reach 0 °C once in 50 years in the UK, though the reference data for this is now unknown.

However, downstream of a pressure reduction station (PRS) the gas expansion will decrease the temperature by approximately 0.5 °C per bar pressure reduction. For example, a pressure reduction from 19 bar to 4 bar will cause the temperature to drop by 7.5 °C. In winter, periods the gas may already be at a temperature of +4 °C (for example), therefore the de-pressurised gas will be entering the downstream pipework at -3.5 °C. Naturally, the gas will warm as it travels along the pipeline so only a section will be affected by the subzero temperatures. The length of the section can be estimated and so could be replaced by a length of cross-linked polyethylene (PE-X) pipe, which has very high RCP resistance down to -60 °C. The gas can also be preheated to avoid the problem but this is expensive in energy, and requires automatic back-up systems and long-term maintenance.

Low temperature gas can also occur in liquid petroleum gas (LPG) systems in winter. The gas is normally stored in tanks above ground which tend to attain the air temperature and this can be reduced further to well below zero, as vaporisation of the gas cools the gas and remaining liquid.

The effect on the pipe's RCP performance due to variability of the PE compound between batches is not known. In addition, the effects of different pipe manufacturers' production techniques (e.g. different extrusion conditions) on RCP performance have also not been evaluated. However, significant pipe-to-pipe RCP variability in PE80 compounds has not been reported.

E.9 Decompression in Full-Scale and S4 RCP Tests

E.9.1 Pressure at the crack tip

The internal "gas" pressure at the crack tip is driving the crack forward, partly because of the hoop stress in the pipe wall but more importantly the "gas" exhausting radially is acting on the two flaps of pipe behind the crack tip so wedging open the crack. The crack tip pressure does not depend upon the pipe material and size, but only on the initial pressure, crack speed and some physical properties of the "gas". The formula gives the theoretical crack tip pressure for an infinitely long pipe line in any material. Measurements of the crack speed in the full-scale tests in PE pipes have shown that they have never exceeded the "gas" decompression speed.

$$\frac{p_t}{p_0} = \left[1 - \frac{\gamma - 1}{\gamma + 1}\left(1 - \frac{a}{c_0}\right)\right]^{\frac{2\gamma}{\gamma-1}} \quad \textbf{when } a < C_0 \qquad (2)$$

$$\frac{p_t}{p_0} = 1 \quad \textbf{when } a \geq C_0$$

where: -

P_t = absolute pressure at the crack tip

P_0 = initial pressure in the pipe

γ = ratio of specific heats of the "gas" (heat capacity ratio)

a = crack speed

C_0 = velocity of sound at 0 °C

In using equation 2, the crack path is assumed to be axial and the speed constant but in reality, the crack is usually wavy with a variety of speeds along its path, Figure E.1. Nevertheless, if the crack speed is constant, the pressure at the crack tip, though reduced from the original test pressure, is also constant (see Figure E.3 & equation 2). These "constant conditions" of crack tip pressure, pipe dimensions and properties continue to drive the crack forward indefinitely i.e. RCP conditions are produced.

As the crack speed slows and eventually stops, the ratio of a/c_0 tends to zero, however, the pressure in the pipe never falls below 28% of the original pressure for an infinitely long pipeline using a "gas" with a specific heat ratio, γ, of 1.4 i.e. air or nitrogen, Figure E.2.

$$\frac{p_t}{p_0} \Rightarrow 0.28 = \frac{1}{3.6} \qquad (3)$$

E.9.2 Correlation equation

The full-scale RCP test simulates the fractured PE pipe in service during which the pressure at the crack tip is lower than originally set because the pipe pressure has reduced ahead of the crack tip, Figure E.3. The internal baffles in the S4 test method effectively stop axial decompression. Consequently, the pressure at the crack tip in the S4 test is always at the initial test pressure, whereas, for the Full-scale test, the pressure is reduced. As a result, the critical pressure measured in the S4 test will always be lower than the critical pressure in the full-scale test. A correlation between the two pressures is necessary.

As explained in the Full-scale test (ISO/FDIS 13477: 2007 Appendix D), the crack speed slows and momentarily arrests (slip-stick) at test pressures near the critical pressure. The crack tip pressure will therefore fall almost instantaneously to the minimum value of 28% of the initial pressure i.e. the ratio of **a/c₀** approaches zero (equation 3). In the S4 test, the full test pressure will always be present. Consequently, the ratio of the critical pressures (absolute values) is given by: -

$$\frac{P_{cFS}}{P_{cS4}} = \frac{1}{0.28} = 3.6 \quad \text{absolute pressures}$$

$$\frac{P_{cFS}+1}{P_{cS4}+1} = 3.6 \quad \text{pressures in barg}$$

$$P_{cFS} = 3.6P_{cS4} + 2.6 \quad \text{barg} \qquad (4)$$

Equation 4 does not depend upon the pipe material, size or SDR, but only on γ - ratio of specific heats Cp/Cv (Heat capacity ratio) of the “gas”. The formula therefore only applies to nitrogen or air as the pressurising test “gas” because they have the same γ ratio of 1.40.

Several round-robin testing programmes to validate the formula have been completed (1). Typically, measured values of P_{cS4} on 250mm PE80 SDR11 pipes were in the range 1.0 - 1.5 barg so that on using the equation the calculated P_{cFS} range was 6.2 - 8.0 barg. This produced a direct correlation factor in the range 5.3 - 6.2. Typical measured P_{cFS} on the same pipes are 7 barg to 9.6 barg, which are in reasonable agreement with the calculated range.

It seems that this correlation equation can be used with a reasonable degree of assurance, however, it must be pointed out that all the RCP data on which the correlation factors have been verified were obtained using 250mm SDR11 pipes and two very similar PE80 resins.

In practice, critical pressures from full-scale tests have generally exceeded the calculated “full-scale pressures” from the S4 method i.e. the correlation equation is conservative in predicting the actual critical pressures.

E.9.3 Testing using air/nitrogen instead of natural gas

Normally air or nitrogen is used for test purposes for which the decompression speeds at 0°C are 334m/s and 337m/s respectively. In comparison, natural gas (methane) has a higher decompression speed of 430m/s, though a lower heat capacity ratio, γ, of 1.31. Generally, the pressure at the crack tip in air/nitrogen is higher than for natural gas, though at speeds at 25-75m/s as the crack arrests (slip-stick) the differences are negligible, Figure E.4.

Consequently, the critical pressure, P_{cFS} measured in the full-scale test using air/nitrogen is not significantly different to that when using natural gas. Practical tests to demonstrate that there are no differences have not been conducted.

E.9.4 Reference

J M Greig, Rapid crack propagation in polyethylene gas pipes, Plastic Pipes IX Conference, Edinburgh, September 1995 (British Gas R&T Report No E949, August 1995).

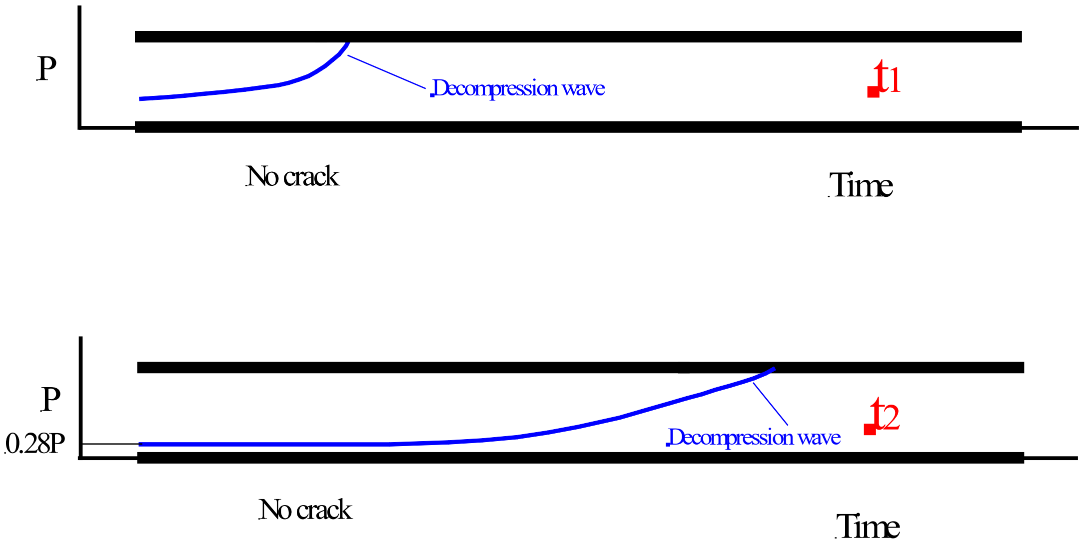

Figure 2 A schematic of the pressure profile of a decompression wave travelling down a pipeline. For an infinitely long pipeline the pressure never reduces below 28% of the initial pressure for test gases nitrogen or air.

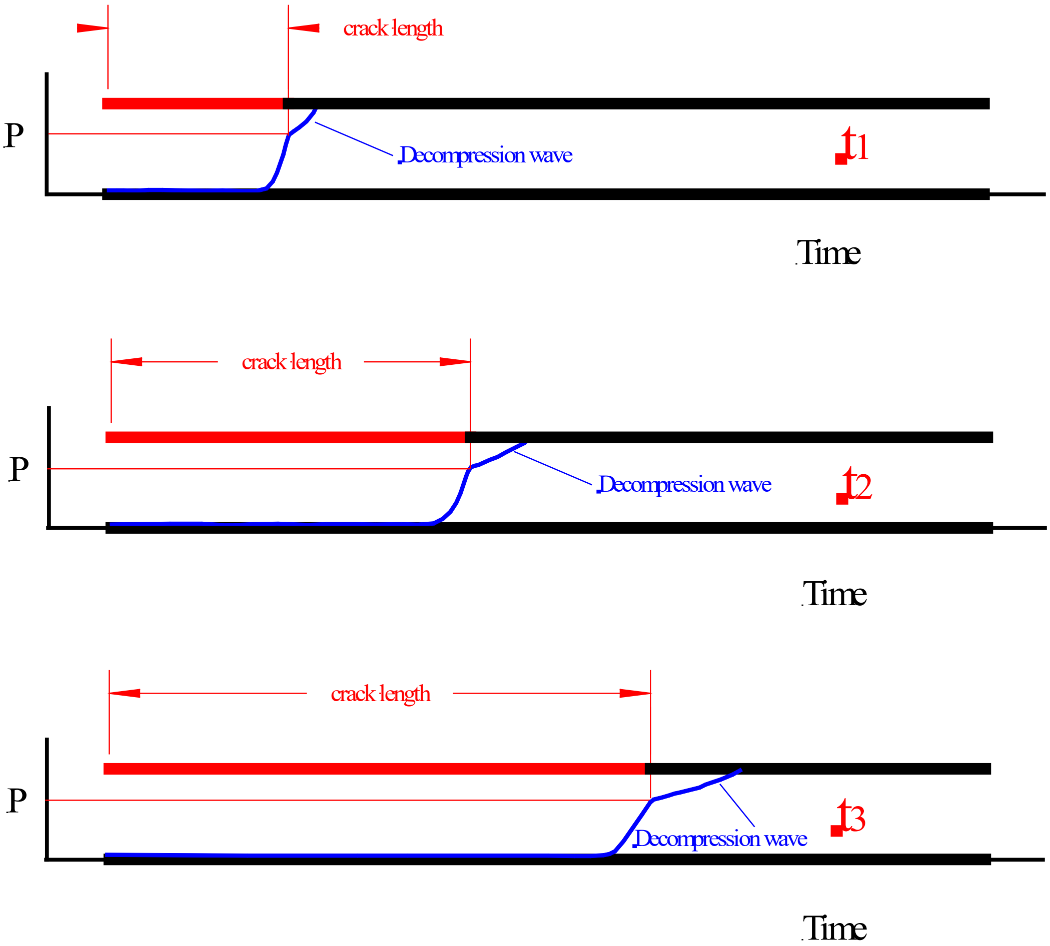

Figure 3 A schematic of the pressure profile of a decompression wave travelling down a pipeline followed by a crack. For constant crack speed, the pressure at the crack tip is constant.

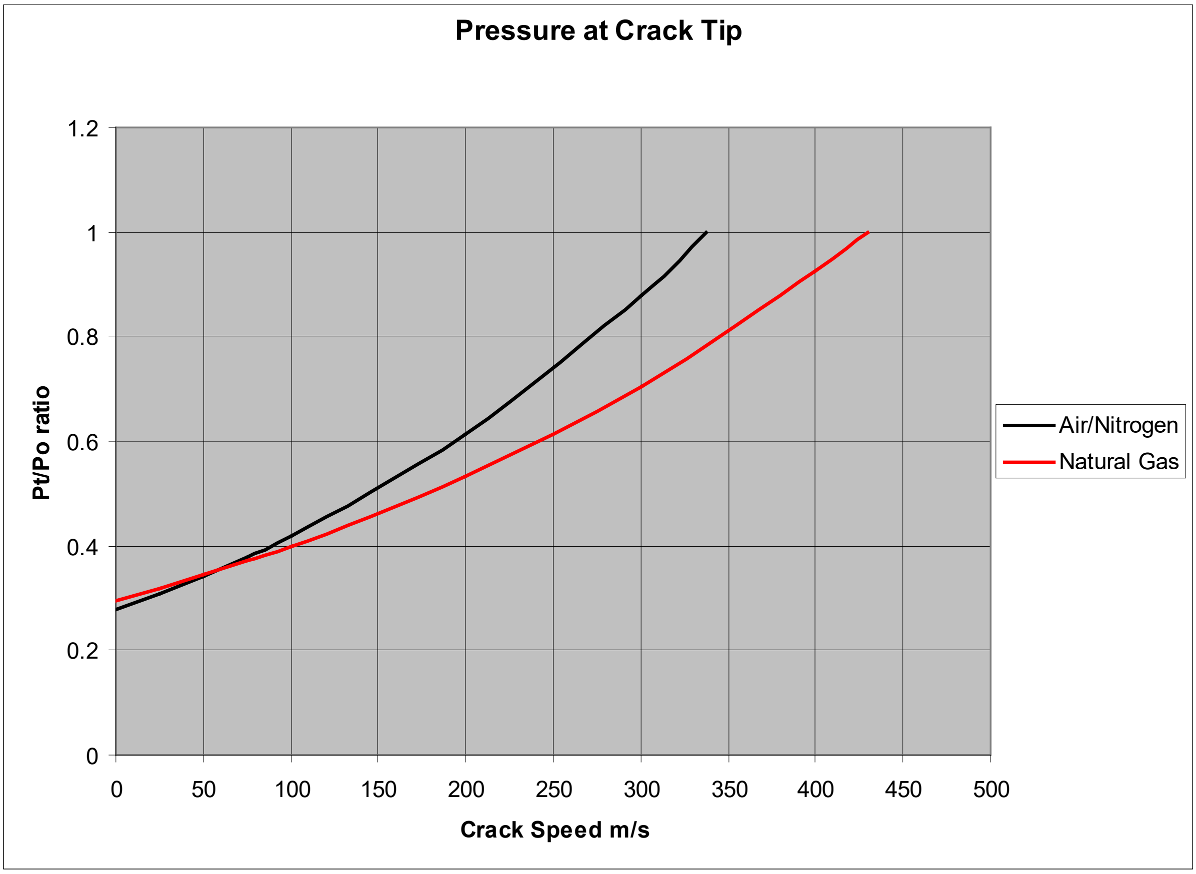

Figure 4 The pressure at the crack tip depends upon the crack speed but as the crack slows completely and starts to go into a slip–stick mode, the pressure differences are negligible between air/nitrogen and natural gas (plotted using equation 2).

E.10 Detailed GIS/PL2 Pipe Specification Requirements (GIS/PL2 Parts 1, 2 & 8)

E.10.1 RCP Testing PE80 Yellow Pipes

PE80 yellow pipes have to be able to operate at temperatures down to -20 °C at pressures up to: -

5.5 bar for SDR11

4 bar for SDR 13.6

3 bar for SDR17.6

2 bar for SDR21 and SDR26

Due to RCP considerations, the maximum operating pressures (MOPs) of PE80 pipes in the larger sizes and lower temperatures have already been reduced (see Annex B. Consequently, RCP tests are conducted at a temperature of 0 °C.

The correlation equation proposed by the ISO TC138/SC4 committee in producing ISO 13477 is: -

$$P_{FS} = 3.6P_{S4} + 2.6 \quad bar \qquad (1)$$

where:

P_{FS} – full-scale pressure, bar

P_{S4} – S4 pressure, bar

E.10.1.1 GIS/PL2 Part 1

For GIS/PL2 Part 1, the RCP test shall be conducted by the compound manufacturer on one pipe size provided the wall thickness is 15 mm or greater.

A full-scale RCP test (BS EN ISO 13478) or an S4 RCP test (ISO 13477) shall be conducted.

The full-scale test shall be conducted at a temperature of 0°C and pressure of 2 x MOP. The MOP is selected for the appropriate pipe size, SDR and 0°C temperature.

The S4 test shall be conducted at a temperature of 0°C and a pressure (P_{S4}) calculated from Equation 1 using a full-scale pressure (P_{FS}) of 2 x MOP for the appropriate pipe size, SDR and 0°C temperature.

If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

E.10.1.2 GIS/PL2 Part 2

For GIS/PL2 Part 2, the RCP test shall be conducted on the manufacture's maximum pipe size provided the wall thickness is 15mm or greater.

A full-scale RCP test (BS EN ISO 13478) or an S4 RCP test (ISO 13477) shall be conducted.

The full-scale test shall be conducted at a temperature of 0°C and pressure of 2 x MOP for the appropriate pipe size, SDR and 0°C temperature.

The S4 test shall be conducted at a temperature of 0°C and a pressure (P_{S4}) calculated from equation 1 using a full-scale pressure (P_{FS}) of 2 x MOP for the appropriate pipe size, SDR and 0°C temperature.

If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

If successful, approval is given to any smaller pipe size, provided the wall thickness is not greater than that tested.

E.10.2 RCP Testing Peelable (PE100) Yellow Pipes

All peelable pipes (SDR21 and SDR26) with a PE100 core shall be able to operate at temperatures down to −20 °C and at operational pressures up to a MOP of 2 bar (see Annex B).

E.10.2.1 GIS/PL2 Part 1

For GIS/PL2 Part 1, the RCP test shall be conducted by the compound manufacturer on one pipe size **without the skin**, provided the core wall thickness is 15mm or greater.

A full-scale RCP test (BS EN ISO 13478) or an S4 RCP test (ISO 13477) shall be conducted.

The full-scale test shall be conducted at a temperature of 0°C and pressure of 14 bar for SDR11 pipe.

The S4 test shall be conducted at a maximum temperature of 0°C and a pressure (P_{S4}) of 3.2 bar for SDR11 pipe.

If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

E.10.2.2 GIS/PL2 Part 2

For GIS/PL2 Part 2, the RCP test shall be conducted on 250mm, 315mm and the manufacturer's maximum pipe size. The skins shall be present.

A full-scale RCP test (BS EN ISO 13478) or an S4 RCP test (ISO 13477) shall be conducted.

The full-scale test shall be conducted at a temperature of -20°C and pressure of 4 bar for SDR21/26 pipe.

The S4 test shall be conducted at a temperature of -20°C and a pressure (P_{S4}) of 0.4 bar for SDR21/26 pipe.

If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

If successful, approval is given to any smaller and intermediate pipe sizes and further to any SDR26 pipe if the SDR21 pipe has RCP approval.

E.10.3 RCP Testing PE100 (Yellow-orange) Pipes

All PE100 (yellow-orange) SDR11 pipes shall be able to operate at a MOP of 7 bar but only for temperatures of 0 °C and above (see Annex B).

E.10.3.1 GIS/PL2 Part 1

For GIS/PL2 Part 1, the RCP test shall be conducted by the compound manufacturer on one pipe size, provided the wall thickness is 15mm or greater.

A full-scale RCP test (BS EN ISO 13478) or an S4 RCP test (ISO 13477) shall be conducted.

The full-scale test shall be conducted at a temperature of 0°C and pressure of 14 bar (SDR11).

The S4 test shall be conducted at a maximum temperature of 0°C and a pressure (P_{S4}) of 3.2 bar (SDR11).

If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

E.10.3.2 GIS/PL2 Part 8

For GIS/PL2 Part 8, the RCP test shall be conducted on the manufacture's maximum pipe size, provided it has a wall thickness of 15mm or greater

A full-scale RCP test (BS EN ISO 13478) or an S4 RCP test (ISO 13477) shall be conducted.

The full-scale test shall be conducted at a temperature of 0°C and pressure of 14 bar (SDR11).

The S4 test shall be conducted at a maximum temperature of 0°C and a pressure (P_{S4}) of 3.2 bar (SDR11).

If the pipe fails the S4 test, it is permitted to re-test using the full-scale test, which if successful takes precedence, as the full-scale test is the reference test.

If successful, approval is given to any smaller pipe size, provided the wall thickness is not greater than that tested.