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Water Industry Specification

SPECIFICATION FOR BLACK POLYETHYLENE PRESSURE PIPES FOR POTABLE WATER ABOVE GROUND OR SEWERAGE (NOMINAL SIZES 90 TO 1000)

FOREWORD

This specification has been prepared by the Water Research Centre (WRc) under the direction of the WSA/FWR Sewers and Water Mains Committee and in consultation with the Water Industry and the British Plastics Federation to define the properties required for black polyethylene pressure pipe having a derived density range between 931 and 944kg/m^3 at 23°C. It has been issued to satisfy the needs of users and manufacturers for a national specification for larger diameter pipes and to reflect advances in technology gained as a result of the operation of Water Industry Specification No. 4-32-03 for blue polyethylene pipe. It specifies pipes in sizes 90 up to a maximum of 1000, and contains three parts: Part 0 for general requirements, Part 1 covering the specific requirements for sizes from 90 to 315, and Part 2 for sizes from 355 to 1000. (Where possible, the clauses are numbered according to their relevant Part so do not run consecutively between Parts 1 and 2.)

Attention is drawn to BS 6730 which specifies black PE pipe up to size 63 for above ground use, WIS No. 4-32-05 for black non-pressure pipe, WIS Nos. 4-32-04 and 4-32-06 for fusion jointing of fittings and to WIS No. 4-32-08 which specifies fusion jointing procedures. The WSA/WRc "Manual for MDPE pipe systems for water supply" is also relevant as a reference document and offers guidance to the UK Water Industry on the practical design, installation and operation of PE water pipeline systems.

Pipes are designated by their nominal size and are available in two series of wall thicknesses namely SDR 11 and SDR 17.6 (previously SDR 17.6 has commonly been referred to as SDR 17 pipes, but true SDR 17 pipes have different wall thicknesses).

The minimum outside diameters and wall thicknesses of the SDR 11 range of pipes are in accordance with BS 5556. SDR 17.6 is not included in BS 5556, and therefore the wall thicknesses of the SDR 17.6 pipes in this specification are calculated from a maximum working stress of 5.0MPa and a nominal pressure of 6 bar. The marked nominal maximum sustained working pressures of pipes in Part 1 are 10 and 6 bar for SDRs 11 and 17.6 respectively. Whilst these marked pressure ratings will remain as 10 bar and 6 bar, research and experience of use indicates that it is now acceptable, at the discretion of the Water Engineer, to use size 90 - 180 pipes at 12 bar (SDR 11) and 7.5 bar (SDR 17.6) except under main roads (see note to clause 12). The pipes in Part 2 are subject to special design considerations depending upon the technical data generated by the manufacturer, together with the factor of safety acceptable to the specifier. Guidance on this is given in Appendix A of this specification.

A supplementary specification for polyethylene pipes in the size range 90 to 180 supplied as coils or on drums has been included. Requirements for pipe ovality and dimensions of coils and drums are included as well as for acceptance testing and marking.

Polyethylenes are manufactured by different processes and contain a range of, and varying quantities of, co-monomers which can result in substantially different basic properties, e.g. melt flow rate, density and creep resistance. The different materials known to be suitable for the manufacture of pipe to this specification may not be compatible for fusion jointing, and therefore the guidance of the manufacturer should be sought before jointing dissimilar materials by such processes.

Compliance with this specification does not of itself confer immunity from legal obligations.

The specification does not purport to include all the necessary provisions of a contract. Users of this specification are responsible for its correct application. Reference to a British Standard, Water Industry Specification or any other specification applies equally to any equivalent specification.

Purchasers are reminded that this specification requires that the manufacturer shall operate a quality system relating to the manufacture of pipe to this specification in compliance with BS 5750: Part 2 (EN 29002), which ensures that products claimed to comply with this specification consistently meet the required level of quality. Enquiries regarding the availability of third party certification should be addressed to an appropriate NACCB or equivalent accredited third party certification body.

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This specification calls for the use of substances and/or 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.

It has been assumed in the drafting of this specification that the execution of its provisions is entrusted to appropriately qualified and experienced people.

Information contained in this specification is given in good faith but neither the Water Services Association, the Foundation for Water Research, nor the Water Research Centre can accept any responsibility for actions taken as a result.

CONTENTS

1. SCOPE

This document specifies the general and quality assurance requirements for black pigmented polyethylene (PE) pipe for the conveyance under pressure of sewerage, or cold potable water above ground. The pipes are specified in nominal sizes 90 to 1000, with the sizes 90 to 315 covered in Part 1 and sizes 355 to 1000 in Part 2. The working pressures of the pipes in Part 1 are 10 bar and 6 bar for SDRs 11 and 17.6 respectively (see also the note in Clause 12). Those in Part 2 may be used at pressures relating to the technical data generated by the manufacturer during testing, together with the safety factor acceptable to the Water Engineer.

The general requirements include material quality, dimensions, effect on water quality and marking. Quality assurance, type test and quality control test requirements common to both Parts 1 and 2 are included in Part 0.

Coiling and drumming of pipes of nominal sizes 90 to 180 are also specified.

NOTE The titles of the publications referred to in this document are listed in Clause 11 - References.

2. DEFINITIONS

For the purpose of this specification, the following definitions apply:

Ovality - The difference between the measured maximum and minimum outside diameter taken at the same cross-section of the pipe.

SDR - Standard Dimension Ratio: The ratio of minimum mean outside diameter to minimum wall thickness.

3. QUALITY ASSURANCE

Manufacturers shall operate a quality system relating to this specification in compliance with BS 5750: Part 2 (EN 29002).

4. MATERIAL

4.1 Base polymer

The base polymer shall be a single grade of polyethylene with a derived density in the range 931 to 944kg/m^3 at 23°C, when determined in accordance with BS 3412. This includes copolymers of ethylene and higher olefins, in which the higher olefin content does not exceed 10% by mass.

4.2 Compound composition

The base polymer shall be blended with additives (anti-oxidants, carbon black, ultraviolet stabilisers, etc.) that are necessary for the manufacture, storage and use of pipes to this specification.

The base polymer and the compounds made therefrom shall conform to Clauses 4, 5, 9 and 10 of BS 3412: 1976 in respect of density, melt flow rate, colour variation, impurities and carbon black characterisation. The compound supplier shall certify that the carbon black has an iodine adsorption number of ≥ 110 when tested according to BS 5293: Part 10, a maximum toluene extract of 0.10% by mass when tested according to ISO 6209 and has a maximum extinction coefficient of 0.1 when tested according to Appendix C of BS 6730: 1986. The moisture content of the carbon black shall not exceed 2% when tested according to BS 5293: Part 5.

The black compound shall be class W as defined in BS 3412: 1976 (except if in conflict with this specification).

4.3 Anti-oxidants

Only anti-oxidants listed in Table 2 of BS 3412: 1976 amended (excluding 6,6'ditertbutyl-4,4'thiodi-m-cresol) shall be used, provided they comply with Clauses 8.1 and 8.2 of BS 3412: 1976, and the final pipe satisfies this specification.

4.4 Rework material

Clean rework material generated from a manufacturer's own production of pipe to this specification, rework generated from a manufacturer's own production of pipe to BS 6730, and black fittings made to WIS No. 4-32-04, may be used providing the base material used for fittings manufacture is the same as the material used for pipe manufacture and that they are reground under the manufacturer's supervision. Pipe containing rework material shall be traceable from its coding system.

No rework material shall be used for pipes size greater than 315.

4.5 Thermal stability

The material in pipe form shall have an oxidation induction time (OIT) of at least 20 minutes when tested according to Appendix B.

4.6 Pigment dispersion

The colour of the pipe shall be black. When tested according to BS 2782: Method 823B, the carbon black dispersion shall be equivalent to photomicrographs 4 or less of that standard.

5. DIMENSIONS

5.1 Diameter and wall thickness

Pipe shall conform to the outside diameter and wall thickness for the corresponding nominal size and SDR value as specified in Parts 1 and 2 of this specification, when measured according to BS 2782: Method 1101A.

The mean diameter of the pipe at a distance of 0.1 × diameter from the ends may be less than that required by the appropriate table but shall not be less than 98% of the diameter measured one pipe diameter away from the ends.

5.2 Ovality

The ovality of the pipes up to and including nominal size 250 shall not exceed 0.020 × the nominal size in mm. The ovality of pipes greater than nominal size 250 shall not exceed 0.030 × the nominal size in mm.

5.3 Cut end tolerance

The ends of the pipes shall be cut cleanly and square to the axis of the pipe to within the tolerances given in Table 1.

Table 1 - Tolerances for cut ends

Nominal size	Maximum tolerance (mm)
90	2
125	3
180	4
230 - 315	5
355 - 500	7
560 - 1000	10

5.4 Length

5.4.1 Standard lengths of pipes shall be 6, 9 and 12m.

5.4.2 No length of pipe shall be shorter than the nominal length agreed between the manufacturer and the purchaser. In any case of dispute pipes shall be measured at a reference temperature of 23 ± 2°C.

6. QUALITY CONTROL TESTS

6.1 General

The test requirements given in 6.2, 6.3, 6.4, 6.5 and 6.6 are necessary in order to demonstrate a continuing satisfactory level of product quality. The required sampling frequency for quality control tests will be as agreed with the certifying authority and given in the quality schedule/sampling plan.

6.2 Appearance and surface condition

The internal and external surfaces of the pipe shall be smooth and free from defects which shall otherwise impair its properties. There shall be no obvious flat regions on the bore, irrespective of the wall thickness tolerances applied.

6.3 Dimensions

The outside diameter, wall thickness, ovality and out-of-squareness of each sample shall be measured and shall meet the requirements of 5.1, 5.2 and 5.3.

Outside diameters shall be measured according to BS 2782: Method 1101A, at a distance of 0.1 × diameter from the end of the pipe, as well as at a point at least one diameter away from the same pipe end.

The wall thickness at any point around the circumference shall be measured according to BS 2782: Method 1101A or by an alternative method of at least equivalent accuracy.

6.4 Thermal stability

The oxidation induction time shall be determined in accordance with Appendix B and comply with the requirements of 4.5.

6.5 Elongation at break

When tested in accordance with Appendix C, the value of elongation at break for each test piece shall be not less than 450%.

6.6 Hydrostatic pressure test at 80°C

The manufacturer shall establish a system, agreed by the certification body, whereby, on a rotational basis, pipe samples of all sizes and SDRs manufactured shall be tested until failure as follows:

Test pieces, notched as specified in Appendix D, shall be subjected to an internal pressure of 8.0 bar for SDR 11 or 5.0 bar for SDR 17.6 at 80 ± 1°C until failure. The time to failure shall be not less than 1000 hours.

7. TYPE TEST REQUIREMENTS

The type tests shall have been satisfactorily completed before pipes can be claimed to have met this specification. They shall be performed on pipes taken from a production run which has already complied with 6.2, 6.3, 6.4, 6.5 and 6.6. For audit purposes or if there is a change in process technique or introduction of a new or modified compound, type tests may be required to be repeated.

In this specification there are certain tests which may be carried out on a size representative of the manufacturer's range of production. In these circumstances the ranges concerned are given in Table 2.

Table 2 - Size ranges for tests

Range number	Nominal pipe sizes
1	90 - 180
2	250 - 315
3	355 - 500
4	560 - 1000

NOTE Ranges 1 and 2 are covered in Part 1, and ranges 3 and 4 in Part 2 of this specification.

7.1 Effect of materials on water quality

For use in public water supply in the UK 7.1.1 and 7.1.2 shall be complied with.

7.1.1 Basic requirement

When used under the conditions for which they are designated, non-metallic products in contact with or likely to come into contact with potable water shall comply with the requirements of BS 6920: Part 1: 1990.

NOTE 1 Non-metallic products for installation and use in the United Kingdom which are verified and listed under the UK Water Fittings Byelaws Scheme are deemed to satisfy the requirements of this clause. Details of the Scheme are obtained from the WRc Byelaws Advisory Service, 660 Ajax Avenue, Slough SL1 4BG.

7.1.2 *DoE-CCM requirement*

Non-metallic products approved by the Department of the Environment Committee on Chemicals and Materials of Construction for use in Public Water Supply and Swimming Pools are considered free from adverse health effects for the purposes of compliance with this clause.

NOTE 2 A list of approved chemicals and materials and details of the approvals scheme is available from the Secretary of the Committee at the Department of the Environment, Water Division, Romney House, 43 Marsham Street, London SW1P 3PY.

7.2 Resistance to fracture in impact

When tested in accordance with Appendix E, the critical strain energy release rate (G_C) shall be 6.0kJ/m^2 or greater. The determination shall be performed on a minimum of one representative size from each of the manufactured ranges shown in Table 2.

NOTE Due to its greater wall thickness, size 180 should be used to represent range 1 (see Tables 2 and 6).

7.3 Hydrostatic pressure testing

All tests shall be performed by the method described in BS 4728 except that the test pieces shall have a minimum unrestrained length between the end closures as defined in 15.2 of Part 1 and 24.2 of this specification.

The end closures should be of a type shown in Figure 1 of BS 4728, and securely attached to the ends of the test pieces to allow full end loads to be applied to the pipe.

NOTE For the purpose of this specification, devices such as blanked-off fusion welded flanges are considered acceptable.

7.3.1 *Long term hydrostatic strength at 20°C*

The individual requirements for Parts 1 and 2 are given in 15.2 and 24.2 respectively.

7.3.2 *Short term pressure requirement at 20°C*

Samples of pipe shall be capable of withstanding an internal pressure equivalent to a circumferential stress of 12.0MPa for one hour at 20 ± 1°C. This may be demonstrated by extrapolating the regression line produced for 15.2 and/or 24.2 back to one hour and recording the stress indicated.

NOTE 1 A stress of 12MPa represents an approximate pressure of 24 bar for SDR 11 pipe and 14.5 bar for SDR 17.6 pipe.

7.3.3 *Hydrostatic pressure tests at 80°C on notched pipe and fused assemblies*

Samples of pipe from a size representative of each manufactured range given in Table 2 shall be prepared in each of the following ways:

(a) notched as specified in Appendix D.

In addition to testing representative sizes for initial type test assessment, the manufacturer shall establish a system, agreed by the certification body, to test pipe samples of all sizes and SDRs on a continuous rotational basis.

(b) butt-fusion welded pipe assembly with a radial offset (in one axis) of at least 10% of the wall thickness (to be carried out on the thinnest wall in the manufactured range).

(c) fusion welded assemblies of saddles to pipes as well as pipes to sockets conforming to WIS No. 4-32-04 (if appropriate to size).

The pipe manufacturer shall record the procedures used for welding the test pieces. These procedures shall be available on request.

The test pieces shall be subject to an internal pressure of 8.0 bar for SDR 11, or 5.0 bar for SDR 17.6, at 80 ± 1°C until failure.

The time to failure of assemblies type (a), (b) and (c) shall be not less than 1000 hours.

The modes and positions of failure shall be reported.

NOTE 1 The various elements contained in (a), (b) and (c) may be tested either separately or in combined test pieces.

NOTE 2 The information required for the fusion welding of PE pipes is listed in Appendix F.

7.4 Tensile strength at yield and elongation at break

When tested in accordance with Appendix C, the tensile yield stress and elongation at break of each test piece shall be not less than 15.0MPa and 450% respectively.

7.5 Tensile weld test

When tested in accordance with Appendix G, the failure mode shall be as shown in Figure 13(a). "Flat" fracture in a brittle manner as shown in Figure 13(d) or mixed modes, as in Figures 13(b) and (c) are unacceptable. At least two welds shall be made from at least one pipe size representative of each range given in Table 2. The test pieces shall be retained or examination.

8. CONTROL OF TEST CONDITIONS

8.1 Test conditions

Unless otherwise specified, the test measurements shall be conducted at a standard laboratory temperature of 23 ± 2°C.

8.2 Specimen conditioning during type testing, or in cases of disagreement

In the case of tests in air, test pieces shall be conditioned prior to test by being kept at 23 ± 2°C in air for not less than 12 hours for pipes of wall thickness up to and including 12.7mm or not less than 24 hours for pipes of wall thickness over 12.7mm, unless otherwise specified.

In the case of hydrostatic tests involving liquid immersion, the test pieces shall be conditioned in the liquid at the test temperature for 24 hours or alternatively for one hour after the samples are within 1°C of the test temperature. The conditioning time necessary to achieve the requirements for any particular size of pipe and test technique may be determined by prior experimentation, the results of which shall be available for inspection.

9. MARKING

9.1 All pipes shall be indelibly and legibly marked at intervals not greater than 1m, along two strips on opposite sides of the pipe. It shall show the following:

(a) the manufacturer's identification;

(b) the letters "PE";

(c) the number of this specification, i.e. WIS 4-32-09 (the use of this mark is a claim by the manufacturer that the product has been manufactured in accordance with the requirements of this specification and the claim is his sole responsibility);

(d) the nominal size and SDR shown in Tables 3 and 4;

(e) identification of the shift, production line and date of manufacture. Coding of this information is permitted providing the meaning of the code is available to purchasers or their representatives on request. This information need only be marked on one side.

(f) third party certification mark, if permissible.

9.2 The marking shall be printed longitudinally in a suitably discriminatory shade of the following colours:

SDR 11 Blue;
SDR 17.6 Red.

9.3 The height of the characters shall be at least 3mm for the pipe size 90 and at least 5mm for size 125 and above.

9.4 The marking shall remain legible under normal handling, storage and installation procedures. Marking by indentation to a depth not greater than 0.15mm on pipes of wall thickness up to 12.7mm or 0.3mm for pipes of wall thickness greater than 12.7mm shall be deemed to comply with this clause without jeopardising the wall thickness requirements of 5.1. Depths greater than this may be used subject to compliance with the basic test requirements of 7.3.3.

10. PROTECTION OF PIPES

10.1 Whilst under the manufacturer's control, the pipes shall be stacked/stored in such a way as to minimise dimensional changes, scratches, etc. and protected from contamination.

10.2 The ends of the pipes shall be plugged or covered.

NOTE The preferred colour for plugs or covers for SDR 11 pipes is blue and for SDR 17.6 pipes is red.

11. REFERENCES

This specification makes reference to the latest edition of the following publications (except where otherwise stated) including all addenda and revisions, which should also be consulted:

BS 1610 Materials testing machines and force verification equipment.
Part 1: Grading of the forces applied by materials testing machines.

BS 2782 Methods of testing plastics.
Methods 320A to 320F: Tensile strength, elongation and elastic modulus.

Method 359: Determination of Charpy impact strength of rigid material (Charpy impact flexural test).

Method 720A: Determination of melt flow rate of thermoplastics.

Method 823B: Method for assessment of carbon black dispersion in polyethylene using a microscope.

Method 930A: Preparation of test specimens by machining.

Method 1101A: Measurement of dimensions of pipes.

BS 3412 Polyethylene materials for moulding and extrusion.

BS 4728 Determination of the resistance to constant internal pressure of thermoplastics pipe.

BS 5214 Testing machines for rubbers and plastics.

BS 5293 Sampling and testing carbon black for use in the rubber industry.
Part 5: Method for determination of loss of mass on heating.
Part 10: Method for determination of iodine adsorption number.

BS 5556 Specification for general requirements for dimensions and pressure ratings of pipe of thermoplastic materials (metric series).

BS 5750 Quality systems.
Part 2: Specification for production and installation.

BS 6730 Specification for black polyethylene pipes up to nominal size 63 for above ground use for cold potable water.

BS 6920 Suitability of non-metallic products for use in contact with potable water intended for human consumption with regard to their effect on the quality of the water.
Part 1: Specification.

EN 29002 (European Standard) Quality systems. Model for quality assurance in production and installation.

ISO 179 Plastics - Determination of Charpy impact strength of rigid materials.

ISO 6209 Rubber compounding ingredients - carbon black - Determination of solvent extractable material.

WSA/FWR Sewers and Water Mains Committee Water Industry Specifications:

No. 4-32-03 Specification for blue polyethylene (PE) pressure pipe for cold potable water (nominal sizes 90 to 1000 for underground or protected use).

No. 4-32-04 Specification for polyethylene socket and spigot fittings, saddles and drawn bends for use with cold potable water PE pressure pipes.

No. 4-32-05 Specification for polyethylene (PE) sewer linings (non-pressure applications).

No. 4-32-06 Specification for polyethylene electrofusion couplers and fittings for cold potable water supply for nominal sizes up to and including 180.

No. 4-32-08 Specification for site fusion jointing of MDPE pipe and fittings.

WSA/WRc Manual for MDPE pipe systems for water supply.

SPECIFICATION PART 1

12. SCOPE

This part of this specification details the requirements in addition to those of Part 0 for black pigmented polyethylene (PE) pipe in sizes 90 to 315 inclusive and in two series of wall thickness, namely SDRs 11 and 17.6 for sewerage under pressure or above ground installations used for the conveyance of cold potable water. The nominal maximum working pressure ratings of the pipes are 10 bar and 6 bar for SDRs 11 and 17.6 respectively.

NOTE Although pipe markings will remain the same, for sizes 90 - 180 the Water Engineer may now wish to use SDR 11 and SDR 17.6 pipes at 12 bar and 7.5 bar respectively under normal conditions. This relates to a design stress of 6.3MPa with a safety factor of 1.3.

The use of SDR 17.6 pipes under main roads is not recommended unless special care is given to the quality of the bedding or other appropriate methods are utilised e.g. the use of ducting. SDR 11 pipes for this purpose should remain restricted to 10 bar unless it can be demonstrated that the total design stress (all stresses generated by internal pressure, static soil load and dynamic loads due to traffic) does not exceed 6.3MPa (see also A.1).

13. DIMENSIONS

Pipes shall meet the requirements of clause 5 in Part 0 of this specification, and shall also conform to the outside diameter and wall thickness values given in Table 3.

Table 3 - Dimensions for sizes 90 to 315

Nominal size (DN)	Mean outside diameter (mm)		Wall thickness (mm)			
			10 bar (SDR 11)		6 bar (SDR 17.6)	
	minimum	maximum	minimum	maximum	minimum	maximum
90	90.0	90.6	8.2	9.2	5.1	5.8
125	125.0	125.6	11.4	12.7	7.1	8.0
180	180.0	181.2	16.4	18.2	10.2	11.4
250	250.0	251.5	22.7	25.2	14.2	15.8
315	315.0	316.8	28.6	31.7	17.9	19.9

NOTE 1 The maximum wall thickness is equal to 1.1e + 0.2mm (rounded to the nearest 0.1mm) where "e" is the minimum wall thickness in mm.

NOTE 2 Refer to Appendix A for additional information on size 315 pipes.

14. QUALITY CONTROL TESTS

14.1 General

The pipes shall meet all the requirements of Clause 6 of Part 0 of this specification.

15. TYPE TEST REQUIREMENTS

15.1 General

The pipes shall meet all the requirements of Clause 7 of Part 0 of this specification.

15.2 Long term hydrostaic strength at 20°C

The assessment shall be carried out on samples of the largest size and the thickest wall of the manufactured range chosen from each of the ranges 1 and 2 given in Table 2 of Part 0.

When extending the manufactured range outside the limits of the tested range, the manufacturer shall carry out further testing, agreed by the certification body, to demonstrate that the requirements of this clause are met.

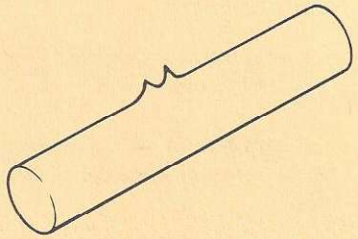
Where rework material conforming to Clause 4.4 is used, or there is a change in material formulation or in pipe manufacture, it is the manufacturer's responsibility to demonstrate compliance with this clause.

Pipe shall be tested in accordance with the general requirements of 7.3 with test pieces having a minimum unrestrained length between the end closures of 400mm or at least three times the outside diameter whichever is greater.

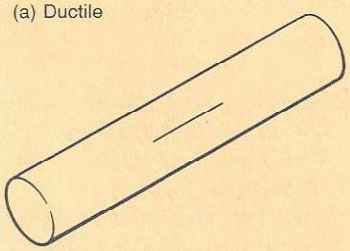
The 97.5% lower confidence limit of the failure time of a stress of 8.0MPa shall be greater than 100 000 hours.

Failure shall be in a ductile mode as illustrated in Figure 1(a). Failure of any test piece in a brittle manner without visible yield deformation (Figure 1(b)) in less than 10 000 hours shall constitute a failure to meet the requirements of this specification.

The method for the analysis of results from the determination of the long term hydrostatic strength of pipe at 20°C shall be determined in accordance with Appendix H.



(a) Ductile



(b) Brittle

Figure 1 - Types of failure

16. POLYETHYLENE PIPES SUPPLIED AS COILS OR ON DRUMS

Coiled or drummed polyethylene pipes in the size range 90 to 180 shall be produced in accordance with the requirements of Appendix I.

SPECIFICATION PART 2

21. SCOPE

This part of this specification details the requirements in addition to those of Part 0 for black pigmented polyethylene (PE) pipe in sizes 355 to 1000 inclusive and two series of wall thickness, namely SDRs 11 and 17.6, for sewerage under pressure or above ground installations used for the conveyance of cold potable water. The nominal maximum working pressures of the pipes are 10 and 6 bar for SDRs 11 and 17.6 respectively, but actual working pressures which the manufacturer shall assign (for a minimum lifetime of 50 years) may depend on additional design considerations and test data together with a safety factor on pressure which is acceptable to the specifier.

NOTE The nominal maximum working pressures of the pipes are calculated from extrapolated results of tests on pipe samples containing only water under constant pressure and temperature to which a safety factor is applied.

Appendix A should be consulted for additional hydraulic design information to assist decisions on pressure ratings for particular circumstances.

22. DIMENSIONS

Pipes shall meet the requirements of Clause 5 in Part 0 of this specification and shall also conform to the outside diameter and wall thickness values given in Table 4.

Table 4 - Dimensions for sizes 355 to 1000

Nominal size (DN)	Mean outside diameter (mm)		Wall thickness (mm)			
			SDR 11 (10 bar)		SDR 17.6 (6 bar)	
	mini-mum	maxi-mum	mini-mum	maxi-mum	mini-mum	maxi-mum
355	355.0	357.1	32.3	35.7	20.1	22.3
400	400.0	402.3	36.4	40.2	22.7	25.2
450	450.0	452.6	41.0	45.3	25.6	28.4
500	500.0	502.9	45.5	50.3	28.3	31.3
560	560.0	563.2	50.8	56.1	31.7	35.1
630	630.0	633.7	57.2	63.1	35.7	39.5
710	710.0	714.0	–	–	40.2	44.4
800	800.0	804.6	–	–	45.3	50.0
900	900.0	905.0	–	–	50.9	56.2
1000	1000.0	1005.0	–	–	56.6	62.5

NOTE The maximum wall thickness is equal to 1.1e + 0.2mm (rounded to the nearest 0.1mm) where "e" is the minimum wall thickness in mm.

23. QUALITY CONTROL TESTS

23.1 General

The pipes shall meet all the requirements of Clause 6 of Part 0 of this specification.

24. TYPE TEST REQUIREMENTS

24.1 General

The pipes shall meet all the requirements of Clause 7 of Part 0 of this specification.

24.2 Long term hydrostatic strength at 20°C

The tests shall be performed according to the general requirements of 7.3; the test pieces shall have a minimum unrestrained length between end closures of 1m.

24.2.1 Manufacturers having full regression data and acceptance for pipe within range 2 (see Table 2 of Part 0) may obtain provisional acceptance for range 3 by following the procedure given in (a) and (b) provided the requirements of (c) are also in progress.

(a) Construct a minimum regression line from four tests on samples from range 3 including the largest size to be registered, to give failure times between 50 and 150 hours. Take the average of the four stresses and failure times and plot them as a single point on a log stress/log time graph. Draw a regression line from this point to 8.3MPa at the 50 year intercept and determine the stresses relevant to 2 500, 5 000, 7 500 and 10 000.

(b) Two samples of one size of pipe representative of the manufactured sizes within range 3 shall be tested at each of the stresses relevant to 2 500 and 5 000 hours determined in (a); these failure times shall be equalled or exceeded by all four samples.

24.2.2 Full acceptance may be achieved by satisfactorily completing (c) within a period agreed by the certification body.

(c) Two samples shall be tested at each of the stresses relevant to 7 500 and 10 000 hours; these failure times must be equalled or exceeded.

24.2.3 Manufacturers may obtain provisional acceptance for range 4 by following (b) (using samples from range 4) and then full acceptance by completing (c) within a period agreed by the certification body. Minimum regression data generated under (a) may be used.

24.2.4 Manufacturers not having full regression data on pipe within range 2 of Table 2 shall comply with the requirements given in Clause 15.2 of this specification using test pieces from ranges 3 or 4 as appropriate.

24.3 Slow crack growth resistance

When tested in accordance with Appendix J, a test piece shall be taken to failure or the test discontinued at 500 hours (representative of ductile failure), whichever is the sooner. It shall not fail in less than 36 hours. Any sign of unstable crack propagation in the failed test piece (e.g. glasslike) is unacceptable.

No additional test is required if the sample survives 500 hours, but if failure occurs between 36 and 500 hours, a test shall be repeated on a production run other than that on which the initial test piece was taken. The second test piece shall not fail in less than 36 hours.

24.4 Residual stress test

Samples of pipe prepared and tested in accordance with Appendix K shall have a maximum tensile residual stress in the pipe wall not exceeding 3.0MPa.

NOTE 1 Residual stresses are known to decay with time after production and it is acceptable for the pipe manufacturer to provide evidence of this decay which gives assurance that the 3.0MPa requirement will be met at the time of the delivery of the pipe.

NOTE 2 Special circumstances may apply if delivery is required immediately after production.

APPENDIX A - DESIGN CONSIDERATIONS

A.1 CONSTANT PRESSURE RESISTANCE AND SAFETY FACTOR

Stress rupture tests are performed as required by the specification on completely water-filled pipe samples under various internal pressures to produce the regression line. This is extrapolated from 10 000+ hours to pass the 50 year line assuming that the failure mode does not change from ductile to slit type and that a log-log relationship continues to exist over the whole period. An illustration of this is shown in Figure 2.

The relationship between circumferential stress (σ) and pressure for the tests is determined from the formula:

$$\sigma = \frac{P\,(D - t)}{20t}\ \text{MPa} \qquad (1)$$

Where P = internal pressure (bar)
D = mean outside diameter (mm)
t = minimum wall thickness (mm).

The specification requires that a lifetime of 50 years is exceeded at a stress of 8.3MPa. The design stress is determined by the application of a safety factor to this stress, i.e.:

$$\text{Design stress} = \frac{8.3}{\text{safety factor}} \qquad (2)$$

A nominal maximum working pressure of 10 bar for an SDR 11 pipe equates to a design stress of 5MPa which results from the application of a safety factor of 1.66 to 8.3MPa. If the extrapolated stress is somewhat greater than 8.3MPa one may wish to take it into account when considering safety factors.

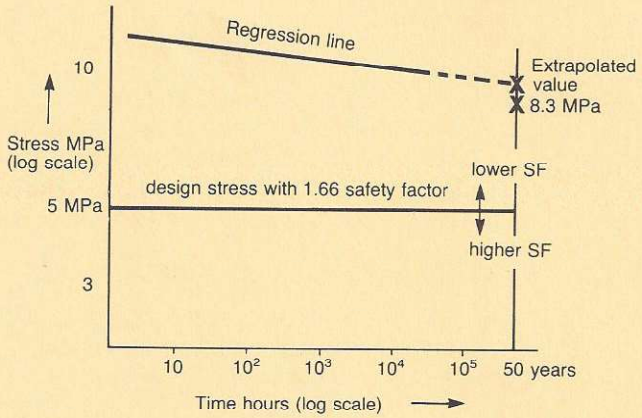


Figure 2 - Typical regression line

A.2 FAST FRACTURE

It is theoretically possible for rapid long linc fracture of a pressurised water filled butt-welded PE pipeline to occur in extremely adverse conditions. It has been produced in air filled pipes under pressure. WRc is unaware of this mode of failure having occurred under practical conditions in the field for the type of pipe passing this specification. Large scale tests have been performed on pipes up to 250mm (see NOTE 2 to Table 5) and it has not been possible to generate a fast fracture in any pipe completely full of water even under arduous conditions of low temperature, high pressure and extreme crack initiation conditions. Neither has fast fracture occurred at 10 bar on a 250mm SDR 11 blue pipe containing 10% air under these conditions.

A derating table of maximum advisable operating pressures for sizes 315 - 500 is given in Table 5.

Table 5 - Maximum advisable operating and test pressures for butt-fusion welded

Nominal size (DN)	Maximum pressure	
	SDR 11	SDR 17.6
315	8.9	5.3
355	8.4	5.0
400	7.9	4.7
450	7.5	4.5
500	7.1	4.2

NOTE 1 No safety factors have been applied.

NOTE 2 These tests have been conducted on pipe extruded from BP Rigidex PC 002-50 R968 blue pipe compound. No information is available on the performance of pipe extruded from any similar material.

A.3 DYNAMIC PRESSURE RESISTANCE

It is suggested that the concept of surge pressure envelopes shown in CP 312: Part 2 is employed. Advice on dynamic operating conditions and an envelope appropriate to SDR 11 pipe is given in the "Manual for MDPE pipe systems for water supply" (this also shows flowcharts, etc.)

A.4 OVERALL SAFETY FACTOR

A.1, A.2 and A.3, together with supporting information from the manufacturer, provide the purchaser with the basis for his judgement as to what overriding safety factor should be applied for his purposes and thus the safe maximum operating pressure for the pipe in use.

A.5 EXCHANGE OF INFORMATION

Whilst not a mandatory part of the specification, it is recommended that this takes place before a contract is placed.

A5.1 Information to be provided by the intending purchaser

(a) Size and SDR of pipe under consideration.

(b) Anticipated laying and operating conditions.

(c) Hydraulic analysis (where available).

A5.2 Information to be provided by the manufacturer

(a) Confirmation that the pipe to be supplied is capable of a maximum continuous working stress of 5.0MPa at 20 ± 3°C.

(b) Safety factor expected for 5.0MPa operation based on the appropriate regression data. (If the safety factor is based on a stress greater than 8.3MPa this should be made clear and the full data supplied.)

(c) Predicted lifetime for the pipe when subjected to constant wall stresses of 5.0MPa and 6.3MPa.

(d) If any decrease in safety factors or lifetime is expected due to operation other than at the test temperature of 20°C, these should be given in graphical form as a function of temperature.

(e) Any limits on cyclic or surge pressures which may be sustained by the pipe during service in pipelines involving pumping, operation of valves, etc.

APPENDIX B - METHOD FOR THE DETERMINATION OF OXIDATION INDUCTION TIME

B.1 INTRODUCTION

This method measures the oxidation induction time of polyethylene in oxygen at elevated temperatures.

B.2 SCOPE

The method provides a means of measuring the oxidative thermal stability of polyethylene pipe and fittings material in oxygen at typical processing and welding temperatures. It may be used for measuring the stability of either raw materials or finished products, and may be taken as an indication of polymer or anti-oxidant performance.

The test temperature is 200°C which is suitable for adequately stabilised pipe and fittings materials.

The thermal stability measured by this method is dependent on specimen mass.

B.3 PRINCIPLE

This test measures the time during which the anti-oxidant present in the sample inhibits oxidation whilst the specimen is held isothermally at 200°C under a flow of oxygen.

The progress of the oxidation is monitored by measuring the difference in temperature between the sample and reference compartments of a thermal analyser and recording this against time. The thermal stability is then derived from this record.

B.4 APPARATUS

The following apparatus is required:

B4.1 Differential scanning calorimeter (DSC) or differential thermal analyser (DTA) capable of:

(a) recording the difference in temperature or energy flow between sample and reference compartments against time.

(b) maintaining the test temperature within ± 0.25°C for the duration of the test.

(c) exposing the sample to a flow of oxygen equal to 50mL/minute.

(d) programming the specimen temperature over the range 150 to 250°C at a rate of 1° C/minute or less.

(e) continuously recording the specimen temperature with a resolution of 0.1°C. If this is not available then B4.2 applies.

B4.2 Temperature measuring apparatus, capable of continuously monitoring the specimen temperature with a resolution of 0.1°C.

A high impedance digital voltmeter with a resolution of 1μV has been found suitable when connected to the specimen thermocouple, and the associated cold junction, or cold junction compensator of the thermal analyser.

B4.3 Analytical balance, capable of weighing the 15 ± 0.5mg test specimen to an accuracy of 0.1mg.

B4.4 Oxygen and high purity nitrogen supplies, able to be switched to give alternative flow. The change-over must be made close to the DSC or DTA cell so that the atmosphere is completely changed within one minute of switchover.

B4.5 Gas flow measuring devices. Rotameters are suitable, but their calibration should be checked against a positive displacement device.

B4.6 High purity metal standards: Indium, tin.

B.5 PREPARATION OF TEST SPECIMENS

A cylindrical disc specimen of a specified weight, with a diameter just less than the inner diameter of the sample pans of the thermal analyser is required.

B5.1 Test specimens from pipe or fittings:

(a) Take two through-wall cores from the top segment of the pipe as extruded by using a core drill of suitable size (or equivalent method e.g. scalpel), ensuring that the sample is not overheated during this operation.

NOTE 1 The sides of the core should be lightly scraped to remove any contamination, etc.

NOTE 2 Any swarf which collects near the inner surface should be carefully lifted away.

(b) Using a scalpel, cut discs from the core samples of an approximate thickness to give specimen weights of 15 ± 0.5mg. Select the two inner and one outer surface as the minimum sample points which are to be tested individually.

(c) The specimens should be prepared for testing during the same day and should not be unduly handled or left in direct sunlight.

B5.2 Test specimens from raw materials from melt flow rate extrudate:

(a) Prepare a melt flow rate extrudate in accordance with BS 2782: Method 720A.

(b) Cut a cylindrical sample with a diameter just less than the inner diameter of the sample pan.

(c) Using a scalpel, cut specimens from the cylinder to give a specimen weight of 15 ± 0.5mg.

B.6 PROCEDURE

B6.1 Temperature calibration

Establish an oxygen flow of 50mL/minute over the specimen and reference compartments of the apparatus at a temperature of 10°C below the expected melting point of indium or tin.

Heat 2mg specimens of indium or tin in a sealed aluminium pan, using an empty aluminium pan as reference, at a rate not exceeding 1°C/minute until the melting endotherm is recorded. If the apparatus does not automatically do so, the indicated temperature should be marked on the chart at intervals in the region of the endotherm so that the melting point can be determined to a precision of ± 0.1° C. Determine the melting points of both indium and tin.

The melting point of the metal is taken as the temperature given by the intercept of the extended baseline, and the extended tangent to the first slope of the endotherm (see Figure 3).

Adjust the apparatus so that the indicated melting points of indium and tin lie within 156.0 ± 0.5°C and 231.9 ± 0.5° C respectively.

NOTE 1 Unless tin of high purity is used, its melting point can vary considerably.

NOTE 2 In cases where the thermogram exhibits a knee in the trace, the relevant maximum slope is that of the first part.

B6.2 Time calibration

Check that the pen moves along the abscissa at the selected rate using a stopwatch.

B6.3 Oxidation induction time measurement

Establish a nitrogen flow of 50mL/minute through the DSC or DTA cell. Check that when a switchover to oxygen is made, the gas flow will continue at that rate and then revert to a nitrogen flow of 50mL/minute.

Introduce a 15 ± 0.5mg cylindrical PE sample in an open aluminium pan and an empty aluminium reference pan into the cell. Specimens which contain the inner or outer surfaces of a pipe shall be placed in the sample pan with that surface uppermost. Set the instrument to run isothermally at raising the temperature at a rate of 20°C/minute, and allow the temperature to stabilise. Make any minor corrections to the heater voltage to bring the specimen temperature to 200 ± 0.1°C. Start to record the thermogram which is a plot of the temperature differential against time.

When steady conditions exist under nitrogen after 5 minutes, switch over to oxygen and mark this point on the thermogram. The cell should be purged within one minute of atmosphere change-over. Continue to run the thermogram until the oxidation exotherm has occurred, and has reached its maximum.

B.7 INTERPRETATION OF RESULTS

The oxidation induction time of each specimen is the time taken in minutes from the introduction of oxygen to the intercept of the extended baseline and the extended tangent drawn to the exotherm at the point of maximum slope (see Figure 4).

B.8 TEST REPORT

(a) Full identification of the product from which samples were taken.

(b) Sample weights.

(c) Individual oxidation induction times.

(d) sample in pipe wall.

(e) Test temperature.

(f) The date of the test.

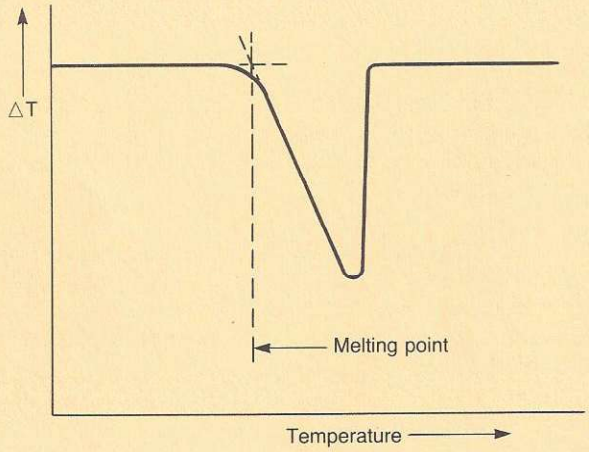


Figure 3 - Metal melting point

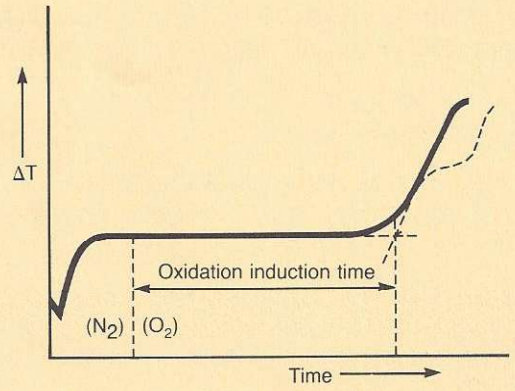


Figure 4 - Example of a thermogram

APPENDIX C - METHOD FOR THE DETERMINATION OF TENSILE YIELD STRESS AND ELONGATION AT BREAK

C.1 APPARATUS

Tensile testing machine accurate to grade A of BS 5214: Part 1: 1975 or grade 1.0 of BS 1610: Part 1: 1985.

C.2 TEST PIECES

Longitudinal samples shall be taken from the full wall thickness at positions equally spaced around the circumference of the pipe. The minimum number required (for each range shown in Table 2) is four for range 1, six for range 2, eight for range 3 and ten for range 4.

For wall thickness greater than 12.7mm and, where possible, for thicknesses below this, the test pieces shall be machined to the profile shown in Figure 5 (see NOTE 5).

Reference lines (gauge marks) shall be perpendicular to the longitudinal axis of the test piece and symmetrically placed along the parallel section. They shall not be scratched, punched or impressed on the test piece.

Heat shall not be applied to the pipe to enable flattening or aid cutting.

C.3 PROCEDURE

Measure the mean width and thickness of the test piece in the gauge length to an accuracy of 0.01mm. Condition the test pieces prior to testing. The test pieces shall be tested individually at a grip separation rate of 10mm/minute ± 10%.

At ultimate break the measured distance between the gauge marks shall be expressed as a percentage of the original gauge length.

The yield stress for each test piece shall be calculated from the force at yield and the original gauge area dimensions.

NOTE 1 The standard of sample production is very important.

NOTE 2 BS 2782: Method 930A should be consulted for guidance on machining.

NOTE 3 Wherever possible a continuous record of force versus displacement shall be retained.

NOTE 4 The measurement of yield stress is not obligatory for quality control tests in this specification.

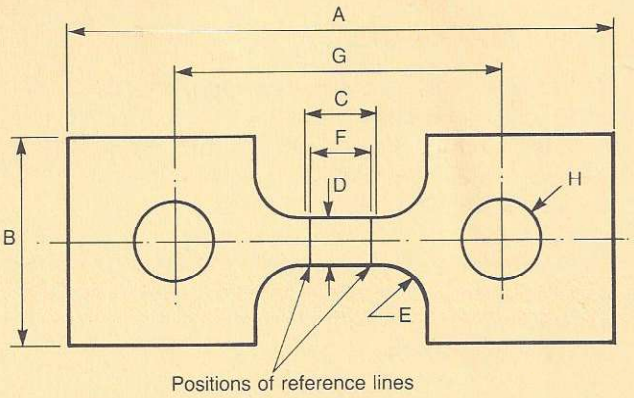
NOTE 5 For wall thicknesses of 12.7mm or less test pieces may be machined to the form shown in BS 2782: Method 320A (with or without radius F) and tested at 100mm/minute ± 10%.

NOTE 6 Alternative test methods for determining yield strength and elongation at break may be used provided that equivalence to specified methods can be demonstrated.

C.4 REPORT

The report shall include the following information:

(a) The full identification of the pipe from which samples were taken.
(b) Type of test specimen.
(c) Rate of grip separation.
(d) Test temperature.
(e) Individual results of elongation at break and/or tensile yield stress.
(f) Make and model of test instrument used.
(g) The date of the test.



A - overall length, minimum	250	
B - width at ends (recommended)	100	± 3
C - length of narrow parallel portion	25	± 1
D - width of narrow parallel portion	25	± 1
E - minimum radius	25	
F - distance between reference lines	20	± 1
G - initial distance between grips or centres of loading pins (recommended)	165	± 5
H - holes for loading pins if required (recommended diameter)	25 - 35	

(all dimensions in mm)

Figure 5 - Tensile test piece

APPENDIX D - METHOD FOR 80°C HYDROSTATIC TESTS ON NOTCHED TEST PIECES

D.1 PRINCIPLE

Pipe specimens with four external longitudinal notches are end capped and then placed in a hot water tank. The specimens are hydrostatically pressurised at constant pressure throughout the duration of the test. The test time is recorded.

D.2 APPARATUS

D2.1 Milling machine with a horizontal mandrel rigidly fixed to the bed on which the pipe can be securely clamped to give a straight specimen. The mandrel supports the pipe bore beneath and along the length of the notch. The milling cutter on a horizontal arbor shall be a 60° included angle "V" cutter, 12.5mm wide having a cutting rate of 0.010 ± 0.002 (mm/rev)/tooth. For example a cutter with 20 teeth rotating at 700rpm, traversed at a speed of 150mm/min has a cutting rate of 150/(20 × 700) = 0.011 (mm/rev)/tooth.

D2.2 Equipment as defined in BS 4728 including:

D2.2.1 Hydrostatic pressure source capable of maintaining a constant pressure of water for long periods. A method of detecting failure of individual specimens and noting the elapsed time from the start of the test, yet permitting any other specimens to continue undisturbed.

D2.2.2 A thermostatically controlled water tank maintained at 80 ± 1°C.

D.3 NOTCHING

D3.1 Pipe measurement

A pipe specimen shall be taken and the mean pipe outside diameter measured with a Pi-tape in accordance with BS 2782: Method 1101A. The minimum pipe wall thickness shall be located and marked for machining the initial notch.

The positions shall be marked for machining three additional notches equally spaced around the pipe circumference at the same longitudinal position as the initial notch (see Figure 6).

The average wall thickness shall be recorded from measurements taken at either end of the specimen in line with the positions for each of the four notches.

D3.2 Machining

A notch shall be machined by climb milling to a depth so as to produce a pipe wall ligament of thickness between 0.80 and 0.81 times the measured minimum wall thickness of the specimen, Figure 7.

In order to machine notches in thick walled pipe (wall thickness 50mm) the material shall be machined away with a 15 - 20mm diameter slot drill to leave 10mm to be removed by the "V" cutter.

The length of the notch, at full depth, shall be equal to the pipe outside diameter.

Three other notches at the positions indicated shall be machined to give the identical ligament thickness of the initial notch (Figures 6 and 8).

The milling cutter shall be carefully protected against damage at all times. It must not be used for any other material or purpose and shall be replaced after 100m of notching.

D.4 PIPE TEST SPECIMENS

Pipe specimens shall be end capped to ensure that any longitudinal internal pressure load is fully reacted by the pipe (see BS 4728: Figure 1: 1971).

The minimum free length of pipe between the end caps shall be 3 × pipe outside diameter.

D.5 CONDITIONING

The pipe specimens shall be filled with water and immersed in the 80°C water tank and allowed to condition for a period of 24 hours for pipes of wall thickness up to 25mm and 48 hours for greater wall thicknesses.

D.6 TEST PROCEDURE

D6.1 The test temperature of the water bath shall be 80 ± 1°C.

D6.2 The specimen shall be pressurised with water at a steady rate within 30 to 40 seconds to the test pressure. This pressure shall be maintained throughout the duration of the test period.

D6.3 The test time (hours) and in the case of failure, the location of failure shall be recorded for each specimen.

D6.4 The specimens shall be retained for completion of the test report in accordance with clause D.8.

D.7 NOTCH DEPTH

D7.1 Measurement

At the completion of the pressure test a section of pipe shall be cut out from around the position of each notch.

The notch shall be opened up to give clear access to one of the machined surfaces of the notch. The width of the machined surface of the notch, L, shall be measured to an accuracy of ± 0.1mm, figure 8. If required by the specification the depth of crack penetration should be measured.

D7.2 Calculation

The notch depth shall be calculated from the formula:

$$n = 0.5\ [d_e - \sqrt{(d_e^2 - L^2)}] + 0.866L$$

n = notch depth (mm)
L = width of machined surface of notch (mm)
d_e = measured mean pipe outside diameter (mm).

The percentage notch depth shall be calculated using the individual average wall thickness at each notch.

D.8 TEST REPORT

The report on this test shall include as a minimum:

(a) A complete identification of the pipe (manufacturer, type of pipe, production date).

(b) The date of the test.

(c) Cutter size and number of teeth.

(d) Cutter speed (rpm) and traverse speed (mm/min).

(e) Mean pipe diameter.

(f) Minimum pipe wall thickness.

(g) Ligament thickness.

(h) Notch depth and percentage notch depth for each notch.

(i) If applicable, identification of failed notch and position along the notch.

(j) Duration of test (hours).

(k) If required by product specification the report shall also include depth of crack penetration.

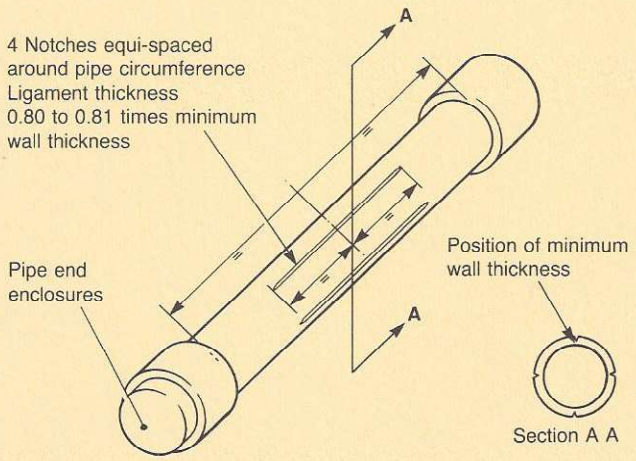


Figure 6 - Test specimen

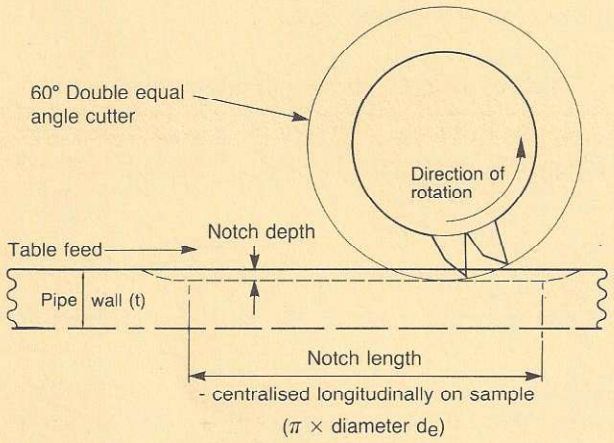


Figure 7 - Notching method

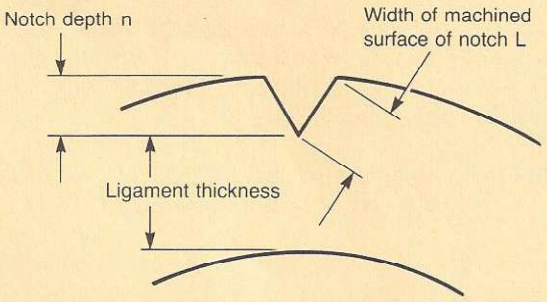


Figure 8 - Measurement to calculate notch depth

APPENDIX E - METHOD FOR THE DETERMINATION OF CRITICAL STRAIN ENERGY RELEASE RATE (G_C)

E.1 APPARATUS

E1.1 Charpy pendulum test machine as described in Clause 5.1 of BS 2782: Method 359: 1984 or ISO 179.

NOTE The absorbed energy should be recorded preferably using a digital display or chart recorder.

E1.2 Means of producing notches of variable depth across the test specimen. The resulting notch profile shall be 45 ± 15° included angle and have a notch root radius of 10μm or less.

E1.3 Measuring apparatus for the determination of depth, thickness and crack depth to an accuracy of 0.01mm.

E.2 PROCEDURE

E2.1 Test piece preparation

Without heating or moulding, prepare a minimum of 15 impact test pieces cut from the longitudinal direction of the pipe (see Figures 9 and 10) having the dimensions specified in Table 6.

Table 6 - Charpy specimen dimensions (mm)

Nominal pipe size	Thickness (or width) B (± 0.2)	Depth D (± 0.15)	Length L (± 2)	Test span S (± 0.2)
180 and above	12	12	100	70

Internal stress in the pipe may cause test pieces to curve when cut. If this occurs cut strips from the full wall thickness and machine flat to the final dimensions after the stress has been relieved e.g. 24 hours or longer elapsed time.

Machine the inside surface of each test piece first, to produce a flat smooth surface with the minimum removal of material, followed by the opposing surface. Trim the remaining surfaces to give the appropriate widths and approximate length.

NOTE Woodworking planing machines have been found to given an adequate finish.

A band saw shall not be used unless followed by linishing. Circular sawing is preferable.

Machine a notch across the centre of the "internal bore" surface of each impact test piece to produce a series of test pieces such that a range of Charpy calibration factor Φ of approximately 0.12 to 0.6 is covered in approximately equal steps (see Figure 10 and Table 7).

Condition the specimens at 23 ± 2°C for 24 hours prior to testing.

Measure the average thickness B and depth D of each test piece adjacent to the notch, also the depth of the notch itself, measured from the side.

E2.2 Impact test procedure

Ensure that the test apparatus is level and correctly aligned for the test span (see Table 6). By performing preliminary tests ensure that the tup to be used provides the appropriate impact energy for the material (within 20 - 60% of the indicated range) and that the impact machine produces accurate readings within permissible error limitations specified in BS 2782: Method 359.

The test velocity should be chosen to maintain the strain rate of the test within a range of 30 to 100 reciprocal seconds (over which G_C has been found to be essentially independent of strain rate) calculated from the following formula:

$$E = 6\,\frac{DV}{S^2} \qquad (5)$$

where E = strain rate (s^{-1})
D = test piece depth (m)
S = test span (m)
V = velocity of tup at impact (m/s).

For the specimen dimensions given in Table 6 a velocity of 2.90m/s is appropriate.

Place the test pieces in turn centrally on the supports with the notch facing away from the tup and centre the notch (see Figure 11). It is essential that uniform contact is achieved between the test piece and the vertical supports.

Release the tup and record the impact energy absorbed in breaking each test piece, applying corrections for frictional losses, etc. as necessary.

If necessary, check the mean notch depth from the face of each fractured test piece.

NOTE A convenient method is to use a binocular microscope fitted with either a calibrated eyepiece or moving table

E.3 CALCULATION OF RESULTS

Calculate the value of a/D for each test piece from the measurements, and from Table 7, obtain the accuracy value of Charpy calibration factor Φ.

Table 7 - Charpy calibration factor (Φ) for S/D = 5.833

a/D	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.20	0.6180	0.6155	0.6130	0.6106	0.6081	0.6057	0.6033	0.6010	0.5986	0.5963
0.21	0.5940	0.5917	0.5894	0.5871	0.5849	0.5827	0.5805	0.5783	0.5761	0.5740
0.22	0.5719	0.5698	0.5677	0.5656	0.5635	0.5615	0.5594	0.5574	0.5554	0.5534
0.23	0.5515	0.5495	0.5476	0.5456	0.5437	0.5418	0.5399	0.5381	0.5362	0.5344
0.24	0.5325	0.5307	0.5289	0.5271	0.5253	0.5236	0.5218	0.5201	0.5184	0.5166
0.25	0.5149	0.5132	0.5115	0.5099	0.5082	0.5066	0.5049	0.5033	0.5017	0.5001
0.26	0.4985	0.4969	0.4953	0.4937	0.4922	0.4906	0.4891	0.4876	0.4861	0.4845
0.27	0.4830	0.4816	0.4801	0.4786	0.4771	0.4757	0.4742	0.4728	0.4714	0.4700
0.28	0.4685	0.4671	0.4657	0.4644	0.4630	0.4616	0.4602	0.4589	0.4575	0.4562
0.29	0.4549	0.4535	0.4522	0.4509	0.4496	0.4483	0.4470	0.4457	0.445	0.4432
0.30	0.4419	0.4407	0.4394	0.4382	0.4369	0.4357	0.4345	0.4333	0.4321	0.4308
0.31	0.4296	0.4285	0.4273	0.4261	0.4249	0.4237	0.4226	0.4214	0.4203	0.4191
0.32	0.4180	0.4168	0.4157	0.4146	0.4134	0.4123	0.4112	0.4101	0.4090	0.4079
0.33	0.4068	0.4057	0.4046	0.4036	0.4025	0.4014	0.4004	0.3993	0.3982	0.3972
0.34	0.3961	0.3951	0.3941	0.3930	0.3920	0.3910	0.3900	0.3889	0.3879	0.3869
0.35	0.3859	0.3849	0.3839	0.3829	0.3819	0.3809	0.3800	0.3790	0.3780	0.3770
0.36	0.3761	0.3751	0.3741	0.3732	0.3722	0.3713	0.3703	0.3694	0.3685	0.3675
0.37	0.3666	0.3656	0.3647	0.3638	0.3629	0.3620	0.3610	0.3601	0.3592	0.3583
0.38	0.3574	0.3565	0.3556	0.3547	0.3538	0.3529	0.3520	0.3512	0.3503	0.3494
0.39	0.3484	0.3476	0.3468	0.3459	0.3450	0.3442	0.3433	0.3424	0.3416	0.3407
0.40	0.3399	0.3390	0.3382	0.3373	0.3365	0.3357	0.3348	0.3340	0.3332	0.3323
0.41	0.3315	0.3307	0.3298	0.3290	0.3282	0.3274	0.3266	0.3257	0.3249	0.3241
0.42	0.3233	0.3225	0.3217	0.3209	0.3201	0.3193	0.3185	0.3177	0.3169	0.3161
0.43	0.3153	0.3145	0.3138	0.3130	0.3122	0.3114	0.3106	0.3099	0.3091	0.3083
0.44	0.3075	0.3060	0.3060	0.3052	0.3045	0.3037	0.3029	0.3022	0.3014	0.3007
0.45	0.2999	0.2992	0.2984	0.2977	0.2969	0.2962	0.2954	0.2947	0.2939	0.2932
0.46	0.2925	0.2917	0.2910	0.2903	0.2895	0.2888	0.2881	0.2873	0.2866	0.2859
0.47	0.2852	0.2844	0.2837	0.2830	0.2823	0.2816	0.2808	0.2801	0.2794	0.2787
0.48	0.2780	0.2773	0.2766	0.2759	0.2752	0.2745	0.2738	0.2731	0.2724	0.2717
0.49	0.2710	0.2703	0.2696	0.2689	0.2682	0.2675	0.2668	0.2662	0.2655	0.2648
0.50	0.2641	0.2634	0.2628	0.2621	0.2614	0.2607	0.2601	0.2594	0.2587	0.2581
0.51	0.2574	0.2567	0.2561	0.2554	0.2547	0.2541	0.2534	0.2528	0.2521	0.2515
0.52	0.2508	0.2501	0.2495	0.2489	0.2482	0.2476	0.2469	0.2463	0.2456	0.2450
0.53	0.2444	0.2437	0.2431	0.2425	0.2418	0.2412	0.2406	0.2399	0.2393	0.2387
0.54	0.2381	0.2374	0.2368	0.2362	0.2356	0.2350	0.2344	0.2337	0.2331	0.2325
0.55	0.2319	0.2313	0.2307	0.2301	0.2295	0.2289	0.2283	0.2277	0.2271	0.2265
0.56	0.2259	0.2253	0.2248	0.2242	0.2236	0.2230	0.2224	0.2218	0.2213	0.2207
0.57	0.2201	0.2195	0.2190	0.2184	0.2178	0.2172	0.2167	0.2161	0.2155	0.2150
0.58	0.2144	0.2139	0.2133	0.2128	0.2122	0.2117	0.2111	0.2106	0.2100	0.2095
0.59	0.2089	0.2084	0.2078	0.2073	0.2068	0.2062	0.2057	0.2052	0.2046	0.2041
0.60	0.2036	0.2021	0.2025	0.2020	0.2015	0.2010	0.2005	0.2000	0.1994	0.1989
0.61	0.1984	0.1979	0.1974	0.1969	0.1964	0.1959	0.1954	0.1949	0.1944	0.1939
0.62	0.1934	0.1929	0.1925	0.1920	0.1915	0.1910	0.1905	0.1900	0.1896	0.1891
0.63	0.1886	0.1882	0.1877	0.1872	0.1868	0.1863	0.1858	0.1854	0.1849	0.1845
0.64	0.1840	0.1835	0.1831	0.1826	0.1822	0.1818	0.1813	0.1809	0.1804	0.1800
0.65	0.1796	0.1791	0.1787	0.1783	0.1778	0.1774	0.1770	0.1766	0.1761	0.1757
0.66	0.1753	0.1749	0.1745	0.1741	0.1736	0.1732	0.1728	0.1724	0.1720	0.1716
0.67	0.1712	0.1708	0.1704	0.1700	0.1696	0.1692	0.1689	0.1685	0.1681	0.1677
0.68	0.1673	0.1669	0.1666	0.1662	0.1658	0.1654	0.1651	0.1647	0.1643	0.1640
0.69	0.1636	0.1632	0.1629	0.1625	0.1622	0.1618	0.1615	0.1611	0.1608	0.1604
0.70	0.1601	0.1597	0.1594	0.1591	0.1587	0.1584	0.1580	0.1577	0.1574	0.1571
0.71	0.1567	0.1564	0.1561	0.1558	0.1554	0.1551	0.1548	0.1545	0.1542	0.1539
0.72	0.1535	0.1532	0.1529	0.1526	0.1523	0.1520	0.1517	0.1514	0.1511	0.1508
0.73	0.1505	0.1502	0.1500	0.1497	0.1494	0.1491	0.1488	0.1485	0.1483	0.1480
0.74	0.1477	0.1474	0.1472	0.1469	0.1466	0.1463	0.1461	0.1458	0.1455	0.1453
0.75	0.1450	0.1448	0.1445	0.1443	0.1440	0.1438	0.1435	0.1433	0.1430	0.1428
0.76	0.1425	0.1423	0.1420	0.1418	0.1416	0.1413	0.1411	0.1408	0.1406	0.1404
0.77	0.1402	0.1399	0.1397	0.1395	0.1393	0.1390	0.1388	0.1386	0.1384	0.1382
0.78	0.1379	0.1377	0.1375	0.1373	0.1371	0.1369	0.1367	0.1365	0.1363	0.1361
0.79	0.1359	0.1357	0.1355	0.1353	0.1351	0.1349	0.1347	0.1345	0.1343	0.1341
0.80	0.1340	0.1338	0.1336	0.1334	0.1332	0.1331	0.1329	0.1327	0.1325	0.1323
0.81	0.1322	0.1320	0.1318	0.1317	0.1315	0.1313	0.1312	0.1310	0.1308	0.1307
0.82	0.1305	0.1304	0.1302	0.1300	0.1299	0.1297	0.1296	0.1294	0.1293	0.1291
0.83	0.1290	0.1288	0.1287	0.1285	0.1284	0.1283	0.1281	0.1280	0.1278	0.1277
0.84	0.1276	0.1274	0.1273	0.1272	0.1270	0.1269	0.1268	0.166	0.1265	0.1264
0.85	0.1263	0.1261	0.1260	0.1259	0.1258	0.1257	0.1255	0.1254	0.1253	0.1252
0.86	0.1251	0.1250	0.1248	0.1247	0.1246	0.1245	0.1244	0.1243	0.1242	0.1241
0.87	0.1240	0.1239	0.1238	0.1237	0.1236	0.1235	0.1234	0.1233	0.1232	0.1231
0.88	0.1230	0.1229	0.1228	0.1227	0.1226	0.1225	0.1224	0.1224	0.1223	0.1222
0.89	0.1221	0.1220	0.1219	0.1218	0.1218	0.1217	0.1216	0.1215	0.1214	0.1214
0.90	0.1213	-	-	-	-	-	-	-	-	-

Calculate the value of the produce BDΦ (m^2) for each test piece and plot a graph of impact energy W (Joules) against BDΦ. Plot a regression line using the method of least squares (this line will always have a positive intercept on the energy axis).

Obtain a value of Gc (kJ/m^2) from the slope W/BDΦ of this line.

E.4 TEST REPORT

The report shall include the following:

(a) Identification of the pipe under test.

(b) Average thickness, width and length of the impact test pieces (mm).

(c) The critical strain energy release rate Gc (kJ/m^2).

(d) Impact energy of tup used (J).

(e) Velocity of tup at impact (m/s).

(f) Strain rate of test (s^{-1}).

(g) Date of test.

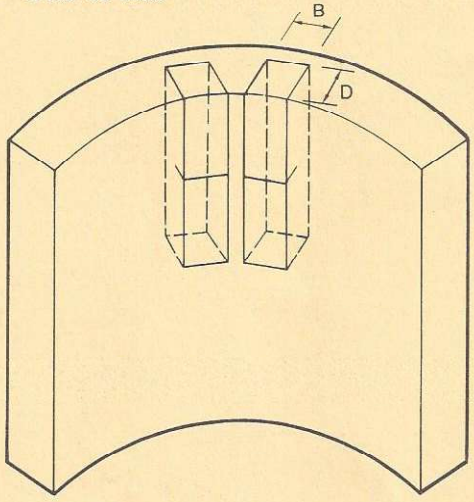
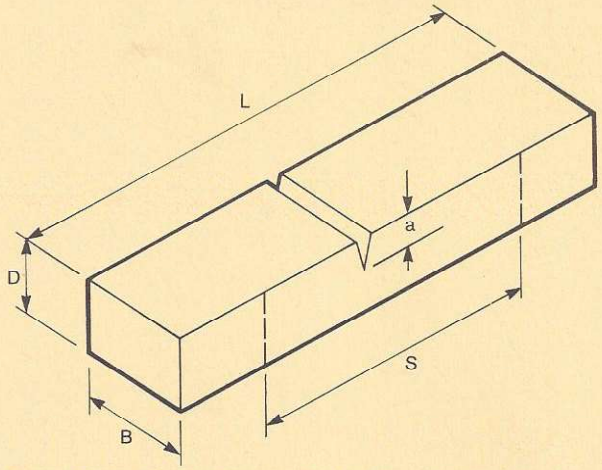


Figure 9 - Dimensions of impact specimens relative to pipe geometry



D is the depth of the impact specimen taken from the radial thickness of the pipe wall
B is the impact specimen thickness
L is specimen length
S is the span used in the pendulum impact test
a is the notch depth

Figure 10 - Charpy impact test piece

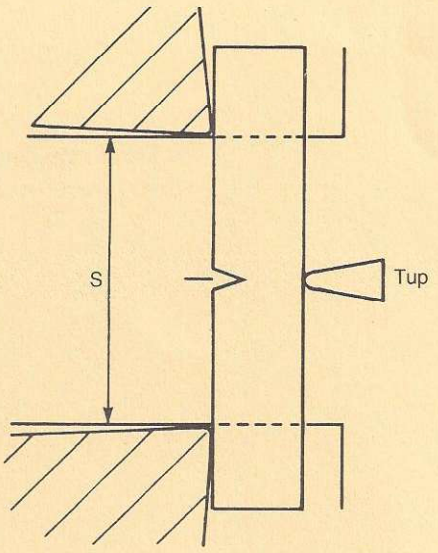


Figure 11 - Test geometry

APPENDIX F - BUTT-FUSION WELDING CONDITIONS

This appendix does not form a mandatory part of the specification but is included for the guidance of both purchasers and manufacturers.

Pipe sizes up to and including 250 should be welded in accordance with WIS No. 4-32-08. For sizes above 250 the purchaser is recommended to request from the manufacturer, welding instructions including details of the following as a function of the ambient temperature where appropriate:

(a) Heater plate temperature and acceptable limits.

(b) Pressure cycle for initial beading and/or bead size.

(c) The soak time and pressure at soak.

(d) Maximum heater plate removal/pipe contact time.

(e) The welding pressure and limits (appropriate to particular welding machines). Where machine gauge pressure for a particular welding machine are not available from the pipe manufacturer than the force per unit area of pipe wall necessary for the appropriate operation should be provided.

(f) The weld cooling time and pressure conditions during cooling.

(g) The finished bead size limits.

(h) Any debeading limitation.

G.1 APPARATUS

Tensile testing machine (see Clause C.1).

G.2 TEST PIECES

Cut longitudinal rectangular samples across the weld from the full wall thickness of pipes butt-fusion welded together using the manufacturer's recommended technique. The distribution and number of samples shall be as in Clause C.2. Prepare test pieces of the form shown in Figure 12. This may conveniently be performed by first drilling or milling holes at 45mm centres along the weld then cutting towards the holes from the edges. The radiused portions of the test pieces shall be smooth but the finish of the remaining edges is not critical.

Alternatively, for pipes in excess of 25.2mm thickness, the following procedure may be used:

Cut longitudinal rectangular samples across the weld from the full wall thickness of pipes, butt-fusion welded, using the manufacturer's recommended technique. The distribution and number of samples shall be as in Clause C.2. Half the samples shall be machined from the outside, the other half from the inside, to produce samples half the original thickness. Prepare test pieces of the form shown in Figure 12.

The test pieces shall then be tested in accordance with the procedure specified in clause G.3.

NOTE 1 A "spade" type wood drill have been found to give satisfactory results.

NOTE 2 To minimise the possibility of contamination it is recommended that the cold heater plates are thoroughly cleaned using water (or if necessary a suitable solvent) and a clean lint-free cloth or tissue. For optimum results an initial weld should be made and discarded.

G.3 METHOD

Condition the test pieces and test them in tension at a grip separation rate of 5mm/min^{-1} ± 10%. Allow the tests to continue until the test piece breaks and observe the failure modes e.g. ductile tearing, flat brittle failure. Figure 13 shows examples of the tensile failure modes of welds.

NOTE Where a force/deflection trace is available, it would be expected to appear as in Figure 14 prior to acceptable failure.

G.4 REPORT

The report shall include the following information:

(a) The identification of the pipes.

(b) Full description of the welding conditions including type of machine used.

(c) The failure modes.

(d) The date of the test.

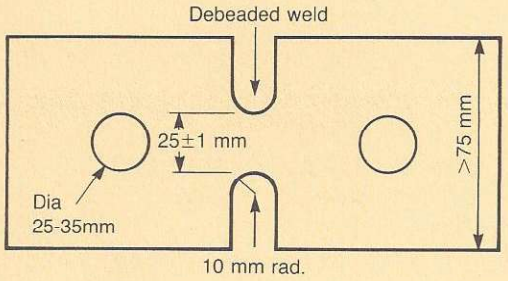


Figure 12 - Tensile specimen geometry for welds

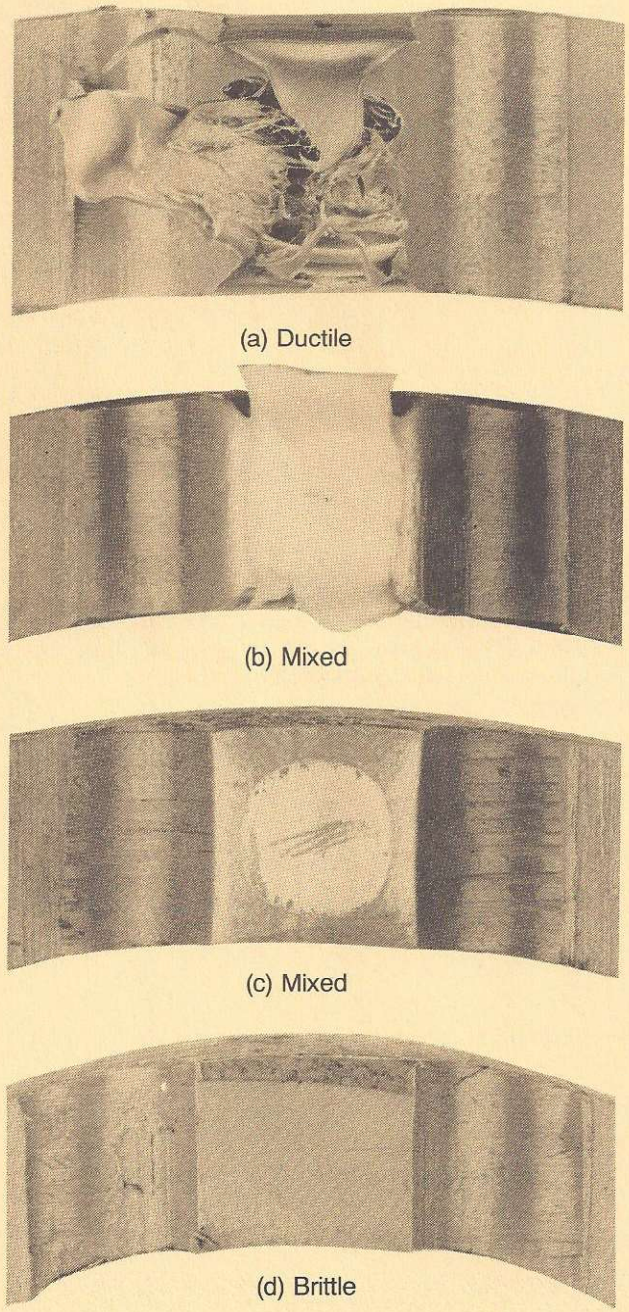


Figure 13 - Examples of tensile failure modes

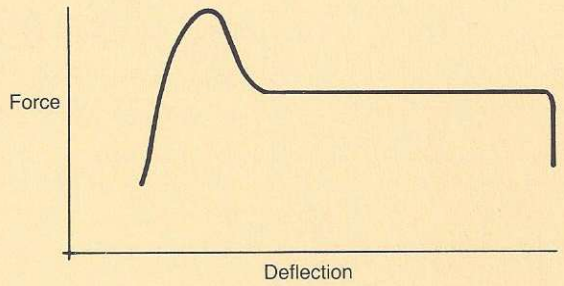


Figure 14 - Example of force/deflection trace for ductile failure

APPENDIX H - METHOD FOR THE ANALYSIS OF RESULTS FROM THE DETERMINATION OF THE LONG TERM HYDROSTATIC STRENGTH OF PIPE AT 20°C

H.1 PROCEDURE

Obtain at least 18 test results for the calculation of the log (time) versus log (stress) regression line with failure point distribution as given in Table 8. Include as failures, at the time of testing, those test pieces that have not failed after being under test for more than 10 000 hours if they increase the value of the extrapolated time (see H2.4 and H2.5).

Table 8 - Failure point distribution

Failure time range (hours)	Minimum data point distribution	Recommended* data point distribution
>10 but <50	2	≥ 4
≥ 50 but <2 500	3	≥ 5
≥ 2 500 but <6 500	3	≥ 4
≥ 6 500 but <10 000	2	≥ 4
≥ 10 000	1	≥ 1
TOTAL	11 + 7 others	≥ 18

* Whilst 18 data points, distributed as shown in column 2, is the minimum pattern required, it is recommended that sufficient data points be obtained so that 18 data points distributed as shown in column 3 are included.

H2.1 The following symbols are used:

n is the number of observations;

f_i is the log of stress (in MPa) of observation i; $i = 1, \ldots, n$;

h_i is the log of time (in h) of observation i; $i = 1, \ldots, n$;

$\bar{f}$ is the arithmetic mean of all f_i values

$$= \frac{1}{n} \sum_{i=1}^{n} f_i \qquad (6)$$

$\bar{h}$ is the arithmetic mean of all h_i values

$$= \frac{1}{n} \sum_{i=1}^{n} h_i \qquad (7)$$

The regression equation of log time (h) on log stress (f) is:

$$h = a + bf \qquad (8)$$

H2.2 Calculate the following three quantities:

$$S_{ff} = \sum_{i=1}^{n} f_i^2 - n(\bar{f})^2 \qquad (9)$$

$$S_{hh} = \sum_{i=1}^{n} h_i^2 - n(\bar{h})^2 \qquad (10)$$

$$S_{fh} = \sum_{i=1}^{n} f_i h_i - n\bar{f}\bar{h} \qquad (11)$$

H2.3 Calculate b and a from the following equations:

$$b = \frac{S_{fh}}{S_{ff}} \qquad (12)$$

$$a = \bar{h} - b\bar{f} \qquad (13)$$

If the slope of the regression line, b, is not negative, the results shall be rejected.

H2.4 Calculate the mean failure time (in h) at a stress of 8.3 MPa from equation (8).

H2.5 Calculate the lower 97.5% confidence limit as follows:

(a) Determine the residual variance about the regression line s_r^2, from the following equation:

$$s_r^2 = \frac{1}{n-2}\left[S_{hh} - \frac{S_{fh}^2}{S_{ff}}\right] \qquad (14)$$

(b) Calculate the lower 97.5% confidence limit for one future observation at a given stress 8.0 MPa from the following equation:

$$h_0 = a + bf_0 - t_v s_r \left[1 + \frac{1}{n} + \frac{(f_0 - \bar{f})^2}{S_{ff}}\right]^{1/2} \qquad (15)$$

where:

t_v is Student's t for $v = n - 2$ degrees of freedom, as given in Table 9 which gives the upper $2^1/_2\%$ points;

h_0 is the estimated log time before failure (in h);

f_0 is the log of the stress (in MPa) (in this case, log 8.0).

H2.6 Calculate the mean failure stress at a time of 50 years.

H.3 TEST REPORT

The report shall include the following:

(a) The identification of the test pieces.

(b) The mean failure time (in hours) at stress equal to 8.3MPa.

(c) The lower 97.5% confidence limit at stress equal to 8.0MPa.

(d) The mean failure stress at 50 years.

(e) The period of the test.

Table 9 - Percentage points of student's "t" distribution (upper $2^1/_2$% points)

v	t_v	v	t_v	v	t_v
1	12.7062	46	2.0129	91	1.9864
2	4.3027	47	2.0117	92	1.9861
3	3.1824	48	2.0106	93	1.9858
4	2.7764	49	2.0096	94	1.9855
5	2.5706	50	2.0086	95	1.9853
6	2.4469	51	2.0076	96	1.9850
7	2.3646	52	2.0066	97	1.9847
8	2.3060	53	2.0057	98	1.9845
9	2.2622	54	2.0049	99	1.9842
10	2.2281	55	2.0040	100	1.9840
11	2.2010	56	2.0032	102	1.9835
12	2.1788	57	2.0025	104	1.9830
13	2.1604	58	2.0017	106	1.9826
14	2.1448	59	2.0010	108	1.9822
15	2.1315	60	2.0003	110	1.9818
16	2.1199	61	1.9996	112	1.9814
17	2.1098	62	1.9990	114	1.9810
18	2.1009	63	1.9983	116	1.9806
19	2.0930	64	1.9977	118	1.9803
20	2.0860	65	1.9971	120	1.9799
21	2.0796	66	1.9966	122	1.9796
22	2.0739	67	1.9960	124	1.9793
23	2.0687	68	1.9955	126	1.9790
24	2.0639	69	1.9949	128	1.9787
25	2.0595	70	1.9944	130	1.9784
26	2.0555	71	1.9939	132	1.9781
27	2.0518	72	1.9935	134	1.9778
28	2.0484	73	1.9930	136	1.9776
29	2.0452	74	1.9925	138	1.9773
30	2.0423	75	1.9921	140	1.9771
31	2.0395	76	1.9917	142	1.9768
32	2.0369	77	1.9913	144	1.9766
33	2.0345	78	1.9908	146	1.9763
34	2.0322	79	1.9905	148	1.9761
35	2.0301	80	1.9901	150	1.9759
36	2.0281	81	1.9897	200	1.9719
37	2.0262	82	1.9893	300	1.9679
38	2.0244	83	1.9890	400	1.9659
39	2.0227	84	1.9886	500	1.9647
40	2.0211	85	1.9883	600	1.9639
41	2.0195	86	1.9879	700	1.9634
42	2.0181	87	1.9876	800	1.9629
43	2.0167	88	1.9873	900	1.9626
44	2.0154	89	1.9870	1000	1.9623
45	2.0141	90	1.9867	INF	1.9600

APPENDIX I - SUPPLEMENTARY SPECIFICATION FOR POLYETHYLENE PIPE SUPPLIED AS COILS OR ON DRUMS

I.1 SCOPE

This specification applies to polyethylene pipe in the size range 90 to 180 supplied as coils or on drums. It specifies requirements for acceptable levels of pipe ovality and the dimensions of coils and drums for both SDR 17.6 and SDR 11 pipes. Requirements for acceptance testing and marking are also specified.

I.2 DEFINITIONS

I.2.1 Coiled pipe

Pipe extruded in a multi-layer coiled configuration with the layers strapped together to provide a stable unit without a supporting centre core.

I.2.2 Drummed pipe

Pipe extruded onto a rigid framed reel with a supporting centre core to which the pipe is anchored. The pipe shall be dispensed from a trailer or low loader.

I.3 GENERAL REQUIREMENTS

I.3.1 All pipes shall be constrained in a stable configuration which permits the safe and controlled dispensing of the pipe. Restraining and dispensing methods shall not damage the pipe e.g., kinking, scoring, etc. The requirements of 6.2 of this specification shall also apply.

I.3.2 The maximum external surface temperature of the pipe at the time of coiling shall not exceed 35°C (measured using an agreed method, e.g. contact thermometer probe) at a distance as near as practical to the centre axis of the coiling machine.

I.3.3 The ovality of the pipe shall not exceed 0.15D for SDR 17.6 and 0.6D for SDR 11 pipe where D is the minimum specified outside diameter as given in Table 3.

I.3.4 The ovality shall be determined as follows: The coiled or drummed pipe (50m minimum) shall be stored at ambient temperature for 7 days and then unwound. Three 1m test sections shall be cut from the pipe. The first section shall be cut from the inner roll at a position of not more than 10m from the pipe end. The other two sections shall be cut at a distance of approximately 20m and 40m respectively from the first section.

These samples shall be stored for 1 hour at 23 ± 2°C and their ovality measured.

No measurement shall exceed the values specified in I.3.3.

I.3.5 Any open ends on coils or drums shall be plugged or covered. The requirements of Clause 10 of this specification shall also apply.

I.4 COILED PIPE

I.4.1 Coiled pipe shall be supplied in a minimum length of 50m and multiples of 25m thereafter. However, any length may be supplied by agreement between manufacturer and user.

I.4.2 Dimensions of pipe coils shall be in accordance with Table 10.

Table 10 - Dimensions of coiled pipes

Nominal size	Internal coil diameter* (m)	
	SDR 11	SDR 17.6
90	1.8	2.5
125	2.5	2.5 or 3.0
180	3.0	3.0
* The tolerances on internal diameter shall be +100mm – 0.		

I.4.3 The maximum external diameter of any coil shall be 4.0m.

I.4.4 The maximum width of any coil shall be 1.0m.

I.4.5 Coiled pipe shall be constrained in a stable configuration by strapping. The strapping shall permit the removal of one layer of the coil without the remainder of the coil being unravelled. The strapping arrangement shall ensure that individual layers are clearly discriminated (see Figure 15) and shall not be impaired by transport and handling.

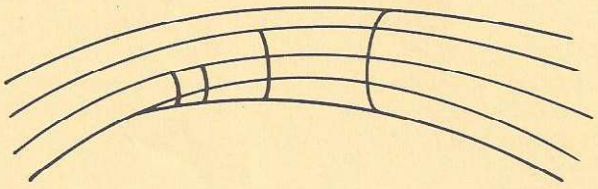


Figure 15 - Typical strapping arrangement for coils

I.4.6 The ends of the coil shall be straight for a distance of at least 2 pipe diameters excluding any anchorage holes.

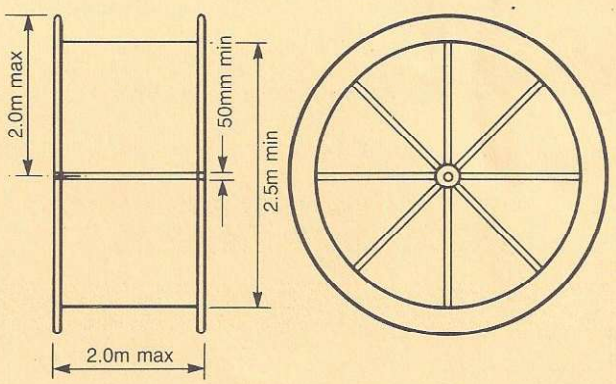
I.4.7 Instructions for uncoiling shall be provided.

WARNING: There may be a risk of injury if correct uncoiling procedures are not followed.

I.5 DRUMMED PIPE

I.5.1 Pipe shall be wound onto drums having the principal dimensions as shown in Figure 16.

I.5.2 Drums shall be of such construction as to withstand normal site handling.



Distance from centre axis to outer rim: 2.0 m max
Outside width: 2.0 m max
Bore of axle: 80mm minimum

Figure 16 - Principal dimensions of drums

I.5.3 The core diameter of the drum shall be not less than 2.5m.

I.5.4 The maximum diameter of any drum shall not exceed 4.0m. The PE pipe shall not stand proud of the drum outer guardrail.

I.5.5 The maximum weight of the drum plus maximum length of PE pipe shall not exceed 2 500kg. The pipe manufacturer shall declare the maximum length of pipe (for a given diameter and SDR rating) that is compatible with the weight and drum dimension criteria.

I.5.6 Where drums are supplied by the manufacturer for direct use from a low loader, the weight limits of I.5.5 shall not apply and the system shall incorporate a braking device.

I.6 ACCEPTANCE TESTING

I.6.1 Ovality

The manufacturer shall demonstrate compliance with this specification by meeting the requirements of I.3.3 using the procedure specified in I.3.4 on each of 2 coils of each size and SD rating on both coils and drummed pipe.

I.6.2 Reroundability

The manufacturer shall demonstrate compliance with this specification by meeting the requirements of maximum and minimum pipe outside diameter given in Table 3, using rerounding clamps, for each size and SD rating manufactured on both coils and drummed pipe.

I.7 MARKING

Pipes shall be marked in accordance with Clause 9 of this specification. In addition, each coil and drum shall be clearly and indelibly labelled with the following:

(a) Nominal weight (kg) of coiled pipe or loaded drum, as applicable.

(b) Requirements for safe handling and pipe dispensing.

J.1 APPARATUS

(a) A tool capable of cutting a notch of less than 90° included angle of uniform depth with a notch tip radius not exceeding 10μm.

(b) Equipment capable of applying a calculated load accurate to within 50g to the test piece and an adjustable counter-balance.

(c) Rigid curved supports extending the full length of the test piece (see Figure 17) are recommended for SDR 17.6 pipe to ensure that a controlled bending moment is applied to the notched section.

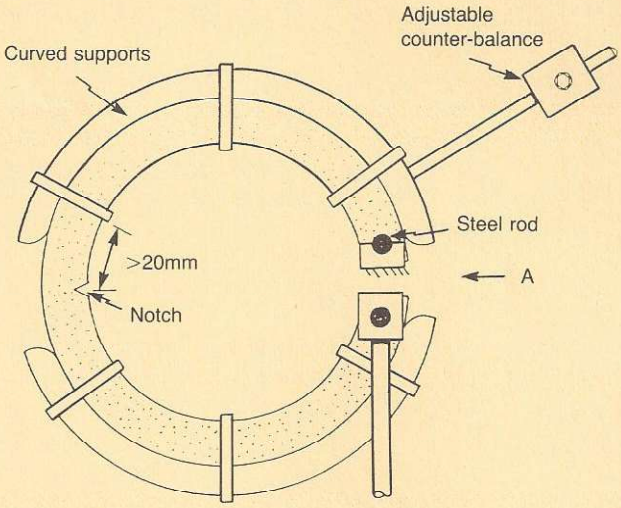


Figure 17 - Test piece assembly

J.2 TEST SPECIMEN

The test specimen shall be a section of pipe of length 95 ± 5mm cut in such a manner that the cut surfaces are perpendicular to the longitudinal axis of the pipe.

A reference line shall be marked along the length of the specimen and the wall thickness (t) and mean pipe diameter ($D_m = {}^1/_2$ (OD + ID)) measured at this section. If any possible sources of weakness are visible on the pipe, e.g. spider lines, the reference line shall be marked at this position.

Cut a notch in the bore of the test specimen at the marked section. The notch shall be cut across the complete width of the specimen to a depth of 25% of the wall thickness (the use of a shaping machine is recommended).

Cut a section from the pipe ring at 180° to the notch such that the distance between the "arms" of the slit ring is approximately 20mm. Drill longitudinal holes of a suitable diameter through the pipe wall, close to the tip of each arm. By inserting metal rods through these holes a fulcrum and weight carrier may be attached to the upper and lower arms of the specimen respectively (see Figure 18).

If curved supports are used ensure that these are not clamped to the specimen within 20mm of the notch and that there are no sharp points of contact between the specimen and support (see Figure 18).

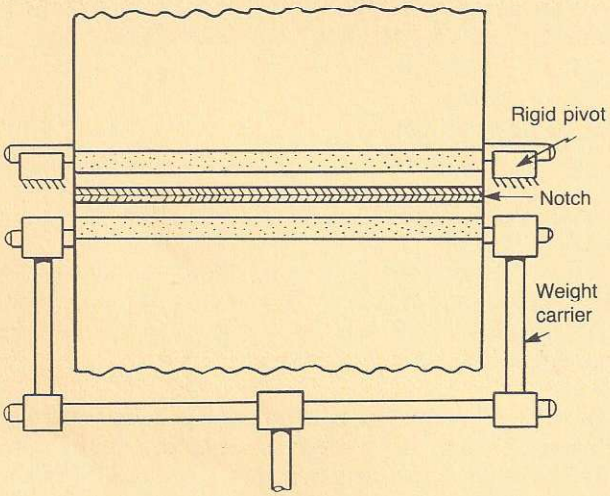


Figure 18 - Side view from A (diagrammatic)

J.3 PROCEDURE

J.3.1 Weigh the lower curves support and clamps if used and the weight carried.

J.3.2 Condition the test specimen.

J.3.3 Mount the upper arm of the specimen on a rigid fulcrum and adjust the counter-balance (attached to the upper curved support or the pipe itself) until the ends of the upper and lower arms are aligned vertically.

J.3.4 Carefully add the test mass calculated by the method given in Clause J.4. The loading time shall be less than one minute. The ambient temperature shall be maintained at 23 ± 1°C throughout the test.

J3.5 At specified times additional weights shall be added to the test specimen to compensate for any reduction in the length of the moment arm (see J.4 below).

If curved supports are not used, this operation must be performed at one hour intervals during the first 5 hours of the test and thereafter at 5 hour intervals.

If curved supports are used, a single correction shall be made at one hour from the beginning of the test.

J.4 CALCULATION OF THE TEST WEIGHT

Read off from Figure 19 the value of fracture toughness K_c corresponding to the measured wall thickness. A value of $K_{IC} = 1.5MN\ m^{-3/2}$ has been used to construct this graph which compensated for plasticity effects in test specimens of different dimensions.

Using a value of K_c calculate the bending moment M to be applied to the test specimen using the equation:

$$M = \frac{K_c l t^{3/2}}{181.6} \; Nm \qquad (16)$$

where l is the length f the pipe ring (mm)

t is the pipe wall thickness (mm).

Assuming the mean diameter to be the initial moment arm, the total test mass W may be calculated:

$$W = \frac{101.9M}{D_m} \; Nm \qquad (17)$$

where D_m is the mean diameter (mm).

In order to calculate the initial mass to be added to the test specimen, half the weight of the lower curved support plus the total weight of the carrier must be subtracted from the value of W.

To correct for any change in the moment arm occurring during the test, the horizontal distance between the mid-point of the section containing the notch and the vertical plane through which the force acts should replace the dimension D_m in equation (17).

J.5 REPORT

The report shall include the following information:

(a) The full identification of the pipe from which the test piece was prepared.

(b) Test temperature.

(c) The mass applied.

(d) The time to failure.

(e) The date of the test.

APPENDIX K - METHOD FOR THE DETERMINATION OF RESIDUAL STRESS

K.1 TEST PIECES

Cut adjacent sections of pipe of length equal to the outside diameter immediately after extrusion and maintain them at 23 ± 2°C laying on their sides.

Mark each one in line with one of the marking strips.

K.2 PROCEDURE

K.2.1 Recommended preliminary experiment to establish optimum size of pipe section to be removed

The day following production (but less than 23 hours elapsed time), by sawing longitudinally in the vicinity of the marked line, remove a section of pipe (from one or more test pieces) covering an arc of between 30° and 60° . Lay the test piece(s) on its side and observe the closure of the gap in the pipe ring for 60 minutes. If the ring is near to closing completely within this period remove a further segment. From this experiment, estimate the amount of material which would be required to be removed to allow closure of the gap to 8mm after 60 minutes.

K.2.2 Determination

Take an uncut test piece and determine the mean wall thickness around the circumference near one end. Measure the outside diameter at the centre of the test piece using a steel OD tape (D_1).

24 hours after original sampling, remove the necessary section of pipe in the vicinity of the marked line and immediately commence timing; lay the test piece on its side. After 60 minutes, measure the outside diameter at the centre of the test piece altered by closure (D_2).

NOTE The experiment in K2.1 should allow the gap almost to close after 60 minutes during the determination. However, it must not close completely and if, for any reason, this appears imminent a further small section will need to be removed.

K.3 CALCULATION

Assuming a linear stress distribution across the pipe wall, the residual circumferential stress (O_R) may be determined from curved beam theory using the following equation:

$$\sigma_R = \frac{2Et\,(D_1 - D_2)}{(D_2 - t)(D_1 + D_2 - 2t)} \; \text{MPa} \qquad (18)$$

Where t is the mean wall thickness (mm)
D_1 is the original outside diameter (mm)
D_2 is the reduced outside diameter (mm)
E is the time dependent modulus (MPa).

Since conventionally extruded and cooled PE pipe normally has a parabolic stress profile across the wall rather than a linear profile, the maximum tensile stress on the bore is approximately two-thirds of the apparent value O_R. For the purposes of this specification the residual stress (σ_R) shall be calculated from the following:

$$\sigma_R = \frac{4Et\,(D_1 - D_2)}{3(D_2 - t)(D_1 + D_2 - 2t)} \; \text{MPa} \qquad (19)$$

The modulus of the material (E MPa) shall be taken as the one hour creep value from a constant stress (4MPa) three-point bending test on compression moulded sheet of the pipe material. The preferred method is given in Appendix D of WIS No. 4-32-05: Issue 1. Complying certificated results from the pipe manufacturer's polymer supplier will be acceptable.

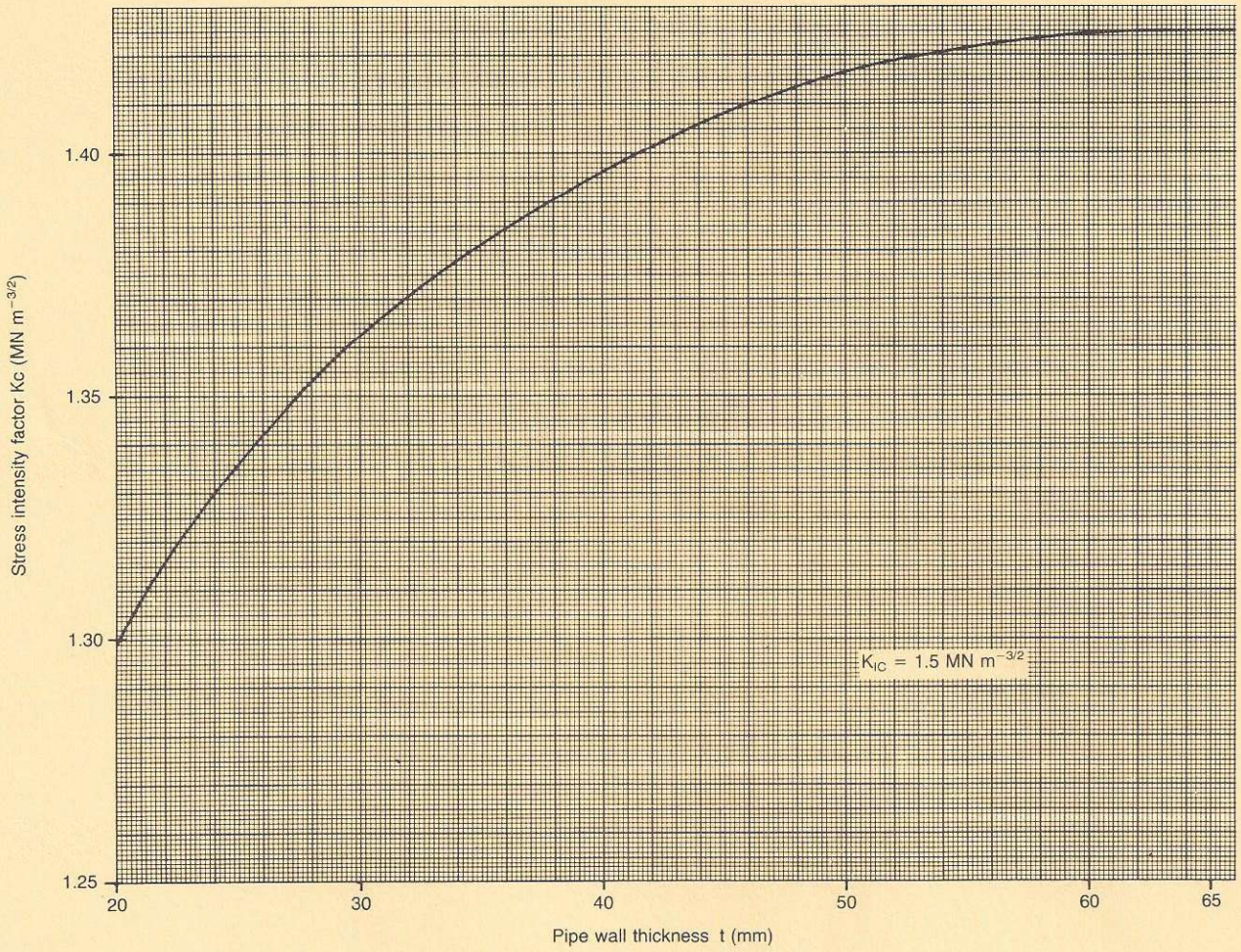


Figure 19 - Calibration curve for split ring test piece

K.4 REPORT

The report shall include the following information:

(a) The full identification of the pipe from which the test pieces were taken.

(b) Test temperature.

(c) Calculated residual stress value σ_R.

(d) The value of E used, the test method and source.