

Information and Guidance Note

SPECIFICATION FOR BLUE POLYETHYLENE (PE) PRESSURE PIPE FOR COLD POTABLE WATER (NOMINAL SIZES 90 TO 1000 FOR UNDERGROUND OR PROTECTED USE)

FOREWORD

This specification has been prepared by the Water Research Centre under the direction of the WAA Sewers and Water Mains Committee and in consultation with pipe manufacturers to define the properties required for blue polyethylene pipe having a derived density range between 931 and 944 kg/m³ at 23°C. It has been issued to satisfy the need of users and manufacturers for a national specification for larger diameter pipes and to reflect advances in technology since the previous issue. Further issues can be expected as requirements and test methods are refined. It specifies pipes in sizes from 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. (The clauses are numbered according to their relevant Part so do not run consecutively between Parts 1 and 2).

Attention is drawn to BS 6572 which is equivalent to IGN No. 4-32-02 but is now regarded as the lead specification. It specifies blue PE pipe up to and including size 63. BS 6730 specifies black PE pipe up to and including size 63 for above ground use. Large diameter black pipes are no longer specified in this specification but it is intended to produce an equivalent specification for black PE pipes for above ground water or pressure sewer use.

Attention is drawn to the WRC/WAA Manual for MDPE pipe systems for water supply which has been prepared to offer 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 but true SDR 17 pipes have different wall thicknesses).

The minimum outside diameters and the wall thicknesses of the SDR 11 range of pipes are in accordance with BS 5556. SDR 17.6 is not included in the standard series and the wall thicknesses of the SDR 17.6 pipes in this specification are calculated from a maximum working stress of 5.0 MPa and a nominal pressure of 6 bar. The maximum sustained working pressures of pipes in Part 1 are 10 and 6 bar for SDRs 11 and 17.6 respectively, whilst those for

pipes in Part 2 are subject to special hydraulic 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.

Coils have been excluded from this specification due to difficulties encountered in handling and welding. However, if coils are required for special purposes, Issue 2 of this specification may still be cited for dimensional purposes only.

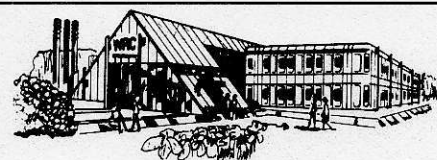
Polyethylenes are manufactured by different processes and contain a range of, and varying quantities of, co-monomers which can result in substantially different basic properties, e.g. melt flow rate, density, creep resistance, etc. Materials known to be suitable for the manufacture of pipe to this specification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

A separate specification is available (No. 4-32-04) which identifies the requirements for polyethylene joints and fittings suitable for fusion jointing to pipes complying with this specification. A specification for electrofusion couplers for sizes up to 180 is also in preparation.

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.

Purchasers are reminded that this specification requires that the manufacturer shall operate an acceptable quality system relating to the manufacture of pipe to this specification in compliance with BS 5750: Part 2, 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 WRC Engineering. 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 Authorities Association nor the Water Research Centre can accept any responsibility for actions taken as a result.

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1. SCOPE

This document specifies the general requirements for blue pigmented polyethylene (PE) pipe for the conveyance of cold potable water in two series of wall thickness. This blue pipe should be restricted to use underground or where protected from direct sunlight. 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, whilst 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. Type test and quality control test requirements common to both Parts 1 and 2 are included in Part 0.

NOTE The titles of the publications referred to in this document are listed under clause 10 – 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. MATERIAL

3.1 Base polymer

The base polymer shall be a single grade of polyethylene with a derived density in the range 931 to 944 kg/m³ at 23°C, when determined in accordance with BS 3412. This includes copolymers of ethylene and higher olefins, in which the higher olefin constituent does not exceed 10% by mass.

3.2 Compound composition

The base polymer shall be blended with additives (antioxidants, pigment, UV 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 in respect of density, melt flow rate, colour variation and impurities.

The blue compound shall be class N as defined in BS 3412: 1976.

3.3 Antioxidants

Only antioxidants as listed in Table 2 of BS 3412

as amended (excluding 6,6'-diterbutyl-4,4'-thiodim-cresol) shall be used, provided that they comply with 8.1 and 8.2 of BS 3412, and the final pipe produced satisfies this specification.

3.4 Approval of formulation

The compound formulation used for the manufacture of pipes to this specification shall have been approved on health grounds for use with potable water by the Department of the Environment Committee for Chemicals and Materials of Construction for use in Public Water Supply and Swimming Pools.

NOTE Clearance obtained from the DoE by the compound supplier is acceptable.

3.5 Rework material

Clean rework material, of the appropriate colour, generated from a manufacturer's own production of pipe to this specification, and rework generated from a manufacturer's own production of pipe to BS 6572, to specification No. 4-32-02 and/or fittings to specification No. 4-32-04, may be used provided that 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 sized greater than 315.

3.6 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.

3.7 Pigmentation

The colour of the pipe shall be blue within the range 18 E 51 and 18 E 53 of BS 4901: 1976. When tested across the pipe wall by the method described in BS 2782: Method 1106A: 1983, the pigment dispersion shall be at least as uniform in appearance as that shown in photomicrograph 2 of Figure 1 of BS 2782: Method 1106A: 1983, i.e. appearances similar to those shown in photomicrographs 3 to 6 of that figure are unacceptable.

4. DIMENSIONS

4.1 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 outside diameter of the pipe at a distance of 0.1 x diameter from the ends may be

less than that required in the appropriate table but shall not be less than 98% of the diameter measured at least one pipe diameter away from the ends.

4.2 Ovality

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

4.3 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
250 – 315	5
355 – 500	7
560 – 1000	10

4.4 Length

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

4.4.2 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 $23 \pm 2^\circ\text{C}$.

5. QUALITY CONTROL TESTS

5.1 General

The test requirements given in 5.2, 5.3, 5.4, 5.5 and 5.6 are necessary in order to demonstrate a continuing satisfactory level of product quality. The required sampling frequency for quality control tests will be given in the third party assessment scheme.

5.2 Appearance and surface condition

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

5.3 Dimensions

The outside diameter, wall thickness, ovality and out-of-squareness of each sample shall be measured and shall meet the requirements of 4.1, 4.2 and 4.3.

Outside diameters shall be measured according to BS 2782: Method 1101A, at a distance of 0.1 x

diameter from the end of the pipe, and at a point at least one diameter away from the 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.

5.4 Thermal stability

The oxidation induction time shall be determined and comply with the requirements of 3.6.

5.5 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%.

5.6 Hydrostatic pressure test at 80°C

The manufacturer shall establish a system, agreed by the certification body and WRc, 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 $80 \pm 1^\circ\text{C}$ until failure. The time to failure shall be not less than 1,000 hours.

The depth of the notches shall be such that, when pressurised as required above, a stress of 4.6 MPa or greater is developed across the notch (see Appendix D for formulae).

NOTE 1 See 6.4 for general test method.

NOTE 2 If a calculated notch depth of greater than 20% of the wall thickness is indicated, then an actual depth of 20% need not be exceeded.

6. 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 5.2, 5.3 and 5.4. 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.

6.1 Effect on water quality

When used under the conditions for which they are designed, materials in contact with or likely to come into contact with potable water shall not constitute a toxic hazard, shall not support microbial growth and shall not give rise to unpleasant taste or odour, cloudiness or discolouration of the water.

Concentrations of substances, chemicals and biological agents leached from materials in contact with potable water, and measurements of organoleptic/ physical parameters shall not exceed the maximum values recommended by the World Health Organisation in its publication "Guidelines for drinking water quality", Volume 1, "Recommendations" (WHO, Geneva 1984), or as required by the EC Directive of 15 July 1980 relating to the quality of water intended for human consumption (Official Journal of the European Communities L229 pp11-29), whichever in each case is the more stringent.

NOTE 1 Requirements for the testing of materials in these respects are set out in the UK Water Fittings Byelaws Scheme Information and Guidance Note No. 5-01-02, ISSN 0267-0313.

NOTE 2 Pending the determination of suitable means of characterising the toxicity of leachates from materials in contact with potable water, materials 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 toxic hazard for the purpose of compliance with this clause. A list of approved chemicals and materials is available from the Technical Secretary of that Committee at the Department of the Environment, Water Division, Romney House, 43 Marsham Street, London SW1P 3PY.

NOTE 3 Products manufactured for installation and use in the United Kingdom which are verified and listed under the UK Water Fittings Byelaws Scheme administered by the Water Research Centre are deemed to satisfy the requirements detailed in this clause.

6.2 Resistance to fracture in impact

When tested in accordance with Appendix E the critical strain energy release rate (G_c) shall be 7.5kJ/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).

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6.3 Resistance of pipe to weathering

6.3.1 General

Following outdoor exposure for 1 year, performed in accordance with BS 2782: Method 550A with exposure at 45° facing south in the United Kingdom, of three 1m long samples of pipe having the manufacturer's least nominal wall thickness from each of the ranges given in Table 2, the weathered samples, or test pieces taken therefrom as appropriate, shall meet the requirements of 6.3.2 and 6.3.3 after having been washed with clean water free from any detergent.

NOTE 1 12 months' exposure in the manner specified approximates to a total radiation energy of 3.5GJ/m^2 .

NOTE 2 Provisional compliance with this clause may be accepted providing that testing is carried out on samples that have been weathered for a minimum continuous period of 3 "summer" months in the United Kingdom between the months of March and September, or to a total radiation energy of at least 1GJ/m^2 and that sufficient extra samples are under test to enable full testing to be completed. After this period of exposure, a maximum change of appearance equivalent to GS4 (BS 1006: Section A02) is acceptable.

6.3.2 Physical requirements

- There shall be no cracking or crazing visible under $\times 10$ magnification.
- Test pieces taken from the weathered side of exposed samples shall comply with the requirements of 6.5.
- Samples from the inside surface of the weathered side shall comply with the requirements of 3.6. Weathered surfaces shall have a minimum residual oxidation induction time of 10 minutes.

NOTE 1 For the determination of oxidation induction time of weathered surfaces it is permissible to remove up to 0.2mm of the surface prior to testing by lightly scraping it. Scraped pipes should be retained for examination.

NOTE 2 See 6.4.3(d) for 80°C hydrostatic pressure test requirements for weathered pipe.

6.3.3 Appearance requirements

Either:

- the colour requirements of 3.7 shall be met, or:

(b) when exposed samples are placed next to an unexposed reference sample, which has been stored in the dark below 30°C, on a neutral background and viewed normally with natural North light (or an artificial equivalent) incident at 45° and compared with a BS 1006: Section A02 grey scale for assessing change in colour, the contrast produced by weathering shall not exceed GS3.

6.4 Hydrostatic pressure testing

All tests shall be performed by the method described in BS 4728 except that test pieces shall have a minimum unrestrained length between the end closures as defined in 14.2 of Part 1 and 24.2 of Part 2 of this specification.

The end closures should be of the 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 purposes of this specification devices such as blanked-off fusion welded flanges are considered acceptable.

6.4.1 Long term hydrostatic strength at 20°C

The individual requirements for Parts 1 and 2 are given in 14.2 and 24.2 respectively.

6.4.2 Short term pressure requirement at 20°C

Samples of pipe shall be capable of withstanding an internal pressure equivalent to a circumferential stress of 12.0 MPa for one hour at $20 \pm 1^\circ\text{C}$. This may be demonstrated by extrapolating the regression line produced for 14.2 and/or 24.2 back to one hour and recording the stress indicated.

NOTE A stress of 12.0 MPa represents an approximate pressure of 24.0 bar for SDR 11 pipe and 14.5 bar for SDR 17.6 pipe.

6.4.3 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. [The depth of the notches shall be such that, when pressurised as required below, a minimum stress across the ligament of 4.6 MPa results.]

NOTE to (a) If calculations result in a notch depth equivalent to more than 20% of the wall thickness then the cut depth need not exceed 20%.

(b) Butt fusion welded with a radial offset (in one axis) of at least 10% of the wall thickness.

(c) Butt fusion welded and fusion welded to saddles and also to sockets (if appropriate to size) using the manufacturer's recommended technique.

(d) Test pieces of pipe weathered for one year as

indicated in 6.3.1 and, after weathering, welded as required in (c).

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

The test pieces shall be subjected to an internal pressure of 8.0 bar for SDR 11, or 5.0 bar for SDR 17.6, at $80 \pm 1^\circ\text{C}$ until failure.

The time to failure of assemblies type (a), (b) and (c) shall be not less than 1,000 hours.

The time to failure of assemblies type (d) shall be not less than 500 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.

6.5 Tensile strength and elongation

When tested in accordance with Appendix C the tensile yield stress and elongation at break of each test piece shall be not less than 15.0 MPa and 500% respectively.

6.6 Tensile weld test

When tested in accordance with Appendix G the failure mode shall be as shown in Figure 11(a) of Appendix G. "Flat" fracture in a brittle manner as shown in Figure 11(d) or mixed modes, as in Figures 11(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 for examination.

7. CONTROL OF TEST CONDITIONS

7.1 Test conditions

Unless otherwise specified, the test measurements shall be conducted at a standard laboratory temperature of $23 \pm 2^\circ\text{C}$.

7.2 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 $23 \pm 2^\circ\text{C}$ 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.

8. MARKING

8.1 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:

- (1) the manufacturer's identification;
- (2) the letters "PE" followed by polymer type identification (X or A);
- (3) the number of this specification, i.e. No. 4-32-03, (only to be applied to complying pipe by manufacturers covered by a third party certification scheme acceptable to WRc);
- (4) (a) for Part 1; the nominal size and pressure rating in bar shown in Table 3;
(b) for Part 2; the nominal size and SDR shown in Table 4;
- (5) identification of the shift, production line and date of manufacture. Coding of this information is permitted providing that the meaning of the code is available to purchasers or their representatives on request. This information need only be marked on one side;
- (6) the word WATER shall be repeated at regular intervals three times within any metre length.

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

SDR 11 Dark blue
SDR 17.6 Red.

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

8.4 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 and including 12.7mm or 0.3mm on pipes of wall thickness greater than 12.7mm shall be deemed to comply with this clause without jeopardising the wall thickness requirements of 4.1. Depths greater than this may be used subject to compliance with the basic test requirements of 6.4.3.

9. PROTECTION OF PIPES

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

9.2 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.

10. 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 1006 Methods of test for colour fastness of textiles and leather.
- 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 550A Methods of exposure to natural weathering.
Method 620A Determination of density of solid plastics excluding cellular plastics (immersion method).
Method 620D Determination of density of solid plastics excluding cellular plastics (density gradient column method).
Method 930A Preparation of test specimens by machining.
Method 1101A Measurements of dimensions of pipes.
Method 1106A Assessment of pigment dispersion in polyolefin pipes and fittings microtome method.
- BS 3412 Polyethylene materials for moulding and extrusion.
- BS 4728 Determination of the resistance to constant internal pressure of thermoplastics pipe.
- BS 4901 Specification for plastics colours for building purposes.
- BS 5214 Testing machines for rubbers and plastics.
Part 1 Constant rate of traverse machines.
- BS 5556 Specification for general requirements for dimensions and pressure ratings of pipe of thermoplastics materials (metric series).
- BS 5750 Quality systems.
Part 2 Specification for manufacture and installation.
- BS 6572 Specification for blue polyethylene pipes up to nominal size 63 for below ground use for potable water.

CP 312 Plastics pipework (thermoplastics materials).

Part 2 Unplasticised PVC pipework for conveyance of fluids under pressure.

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

“Guidelines for drinking water quality”, Volume 1 “Recommendations”, World Health Organisation (WHO), Geneva 1984. Available from HMSO.

EC Directive of 15 July 1980 relating to the quality of water for human consumption (Official Journal of the European Communities L229 pp11-29)(Also contained in Department of Environment Circular 20/82 “EC Directive relative to quality of water for human consumption). Available from HMSO.

WAA Sewers and Water Mains Committee Information and Guidance Note No. 4-32-02: Specification for polyethylene pressure pipe for cold potable water (underground use).

WAA Sewers and Water Mains Committee Information and Guidance Note No. 4-32-04: Specification for polyethylene fusion joints and fittings for use with cold potable water pressure pipes.

WAA Sewers and Water Mains Committee Information and Guidance Note No. 4-32-05: Specification for polyethylene (PE) pipes for sewer linings (non-pressure applications).

UK Water Fittings Byelaws Scheme Information and Guidance Note No. 5-01-02: Requirements for the testing of non-metallic materials for use in contact with potable water.

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

SPECIFICATION – PART 1

11. SCOPE

This part of this specification details the requirements in addition to those of Part 0 for blue pigmented polyethylene (PE) pipe in sizes 90 to 315 inclusive and in two series of wall thicknesses

for the conveyance of cold potable water. The maximum working pressures of the pipes are 10 bar and 6 bar for SDRs 11 and 17.6 respectively.

12. DIMENSIONS

Pipes shall meet the requirements of clause 4 in Part 0 of this specification, and shall also conform to the outside diameter and wall thickness values given in Table 3.

13. QUALITY CONTROL TESTS

13.1 General

The pipes shall meet all the requirements of clause 5 of Part 0 of this specification.

14. TYPE TEST REQUIREMENTS

14.1 General

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

14.2 Long term hydrostatic strength at 20°C

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

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

Where rework material conforming to clause 3.5 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 6.4 with test pieces having a minimum unrestrained length between end closures of 400mm or at least three times the outside diameter whichever is greater. The results shall be analysed separately for each size according to Appendix H and the extrapolated failure time at a stress of 8.3 MPa shall be greater than 50 years.

Table 3 – Dimensions for sizes 90 – 315

Nominal Size	Mean outside diameter (mm)		Wall thickness (mm)			
	Minimum	Maximum	10 bar (SDR 11)		6 bar (SDR 17.6)	
			Minimum	Maximum	Minimum	Maximum
90	90.0	90.6	8.2	9.2	–	–
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 $1.1e + 0.2\text{mm}$ (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.

The 97.5% lower confidence limit of the failure time of a stress of 8.0 MPa 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 mode without visible yield deformation, (Figure 1(b)), in less than 10,000 hours shall constitute a failure to meet the requirements of this specification.

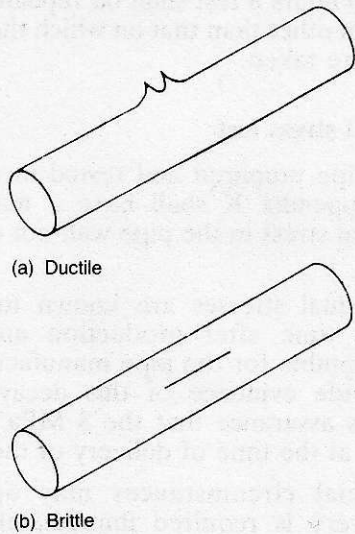


Figure 1 Types of failure

SPECIFICATION – PART 2

21. SCOPE

This part of this specification details the requirements in addition to those of Part 0 for blue pigmented polyethylene (PE) pipe in sizes 355 to 1000 inclusive and two series of wall thickness, namely SDRs 11 and 17.6, 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 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. 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 4 in Part 0 of this specification, and shall also conform to the outside diameter and wall thickness values given in Table 4.

23. QUALITY CONTROL TESTS

23.1 General

The pipes shall meet all the requirements of clause 5 of Part 0 of this specification.

23.2 Density profile

To monitor consistency of extrusion the variation in density across the pipe wall shall be determined in accordance with Appendix I or, using a similar method of sample preparation, in accordance with BS 2782: Method 620A.

There shall be no major changes in the density range and shape of the profile across the pipe wall at any stage of the pipe production and when

Table 4 – Dimensions for sizes 355 – 1000

Nominal Size	Mean outside diameter (mm)		Wall thickness (mm)			
	Minimum	Maximum	SDR 11 (10 bar)		SDR 17.6 (6 bar)	
			Minimum	Maximum	Minimum	Maximum
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 $1.1e + 0.2\text{mm}$ (rounded to the nearest 0.1mm) where “e” is the minimum wall thickness in mm.

compared with the quality control data examined during initial approval.

NOTE Whilst it has not yet been possible to place specific limits on allowable variations, this test will alert manufacturers and assessors to changes in the product and provide a data base for correlation with developing procedures.

24. TYPE TEST REQUIREMENTS

24.1 General

The pipes shall meet all the requirements of clause 6 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 6.4; 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 to 8.3 MPa at the 50 y intercept and determine the stresses relevant to 2,500 hours, 5,000 hours, 7,500 hours and 10,000 hours.
- (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 hours and 5,000 hours; 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 WRc and the certification body.

(c) Two samples shall be tested at each of the stresses relevant to 7,500 hours and 10,000 hours; these failure times shall 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 WRc and the certification body. Minimum regression data from ranges 3 or 4 may be used.

24.2.4 Manufacturers not having full regression data on pipe within range 2 of Table 2, must comply with the requirements given in clause 14.2 of this specification except that test pieces from ranges 3 or 4 shall be used 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 within 36 hours. Any sign of unstable crack propagation in the failed test piece (e.g. glass-like) is unacceptable.

No additional test is required if the sample survives 500 hours but if failure occurs between 36 hours and 500 hours a test shall be repeated on a production run other than that on which the initial test pieces were taken.

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 3.0 MPa.

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 MPa will be met at the time of delivery of the pipe.

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

APPENDIX A – HYDRAULIC 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 past the 50 year line assuming that the failure mode does not change from ductile to slit type and a log-log relationship continues to exist over the whole period. An illustration of this is shown in Figure 2. The 80°C pressure tests give a high degree of confidence that the failure mode of samples on the mean line would not change before 50 years.

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

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

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 8.3 MPa. The design stress is determined by the application of a safety factor to this stress, i.e.

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

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

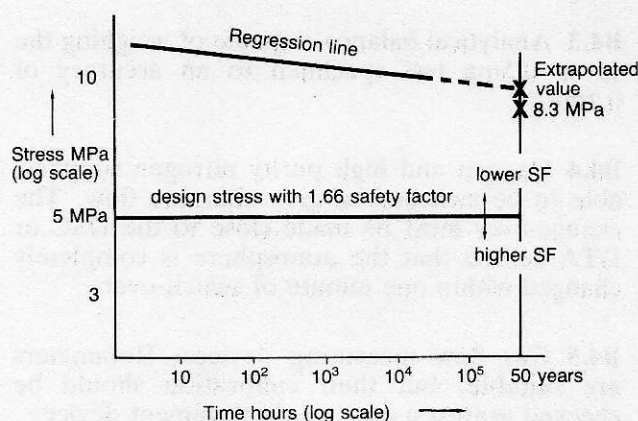


Figure 2 Typical regression line

A.2 FAST FRACTURE

It is theoretically possible for rapid long line fracture of butt welded PE pipes to occur in extremely adverse conditions and it has been produced in air filled pipes under pressure. This is currently a topic of ongoing research. 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) 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.

Work is continuing to provide more definitive guidance relating to the conditions under which fast fracture may potentially occur. Meanwhile, as interim guidance, a derating table of maximum advisable operating pressures for sizes 315 – 500 is given in Table 5. When considering sizes 500 –

Table 5 – Maximum advisable operating and test pressures for butt-fusion welded pipes containing 10% free air

Nominal size	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 No safety factors have been applied.

1000 it is advisable to consult the Materials and Structural Performance Group at WRc.

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

A.3 DYNAMIC PRESSURE RESISTANCE

Research into possible fatigue effects of dynamic pressures is being undertaken by WRc and manufacturers in the smaller sizes in order to produce valid guidance in due course. Meanwhile, 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 flow charts, 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.

A.5.1 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).

A.5.2 Information to be provided by the manufacturer

- (a) Confirmation that the pipe to be supplied is capable of a maximum continuous working stress of 5.0 MPa at 20 ± 3°C.
- (b) Safety factor expected for 5.0 MPa operation based on the appropriate regression data. (If the safety factor is based on a stress greater than 8.3 MPa this should be made clear and the full data supplied.)
- (c) Predicted lifetime for the pipe when subjected to constant wall stresses of 5.0 MPa and 6.3 MPa.
- (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:

- recording the difference in temperature or energy flow between sample and reference compartments against time.
- maintaining the test temperature within $\pm 0.25^\circ\text{C}$ for the duration of the test.
- exposing the sample to a flow of oxygen equal to 50 mL min^{-1} .
- programming the specimen temperature over the range 150 to 250°C at a rate of 1°C min^{-1} or less.
- 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 $1\mu\text{V}$ 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 $15 \pm 0.5\text{mg}$ test specimen to an accuracy of 0.1mg .

B4.4 Oxygen and high purity nitrogen supplies, able to be switched to give alternate 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 switch-over.

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:

- 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.

- Using a scalpel, cut discs from the core samples of an approximate thickness to give specimen weights of $15 \pm 0.5\text{mg}$. Select the two inner and one outer surface as the minimum sample points which are to be tested individually.
- 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:

- Prepare a melt flow rate extrudate in accordance with BS 2782: Method 720A.
- 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 $15 \pm 0.5\text{mg}$.

B.6 PROCEDURE

B6.1 Temperature calibration

Establish an oxygen flow of 50mL min^{-1} 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 min^{-1} 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 $\pm 0.1^\circ\text{C}$. 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 $156.6 \pm 0.5^\circ\text{C}$ and $231.9 \pm 0.5^\circ\text{C}$ 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 min^{-1} through the DSC or DTA cell. Check that when a switch-over to oxygen is made the gas flow will continue at that rate and then revert to a nitrogen flow of 50mL min^{-1} .

Introduce a $15 \pm 0.5\text{mg}$ 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 $200 \pm 0.1^\circ\text{C}$ raising the temperature at a rate of $20^\circ\text{C min}^{-1}$, and allow the temperature to stabilise. Make any minor corrections to the heater voltage to bring the specimen temperature to $200 \pm 0.1^\circ\text{C}$. 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

- Full identification of the product from which samples were taken.
- Sample weights.
- Individual oxidation induction times.
- Position of sample in pipe wall.
- Test temperature.
- The date of the test.

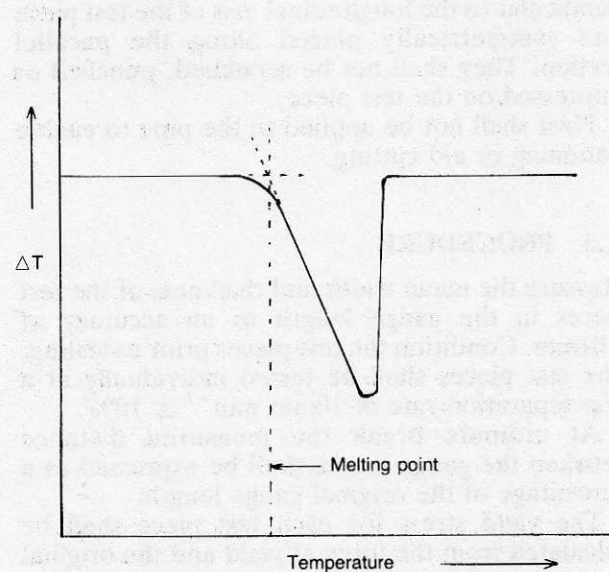


Figure 3 Metal melting point

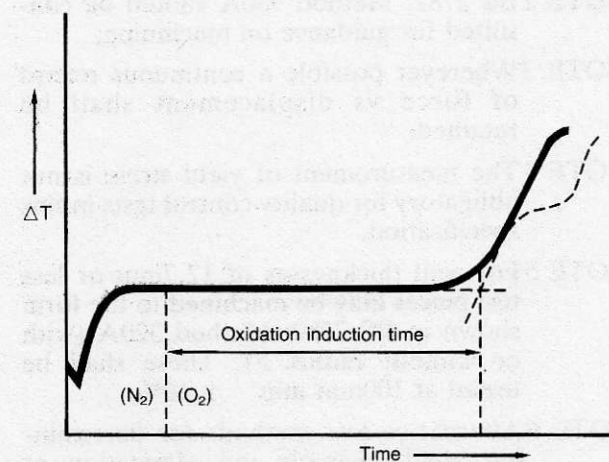


Figure 4 Example of thermogram

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 thicknesses 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 pieces 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 $10\text{mm min}^{-1} \pm 10\%$.

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 vs displacement shall be retained.

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

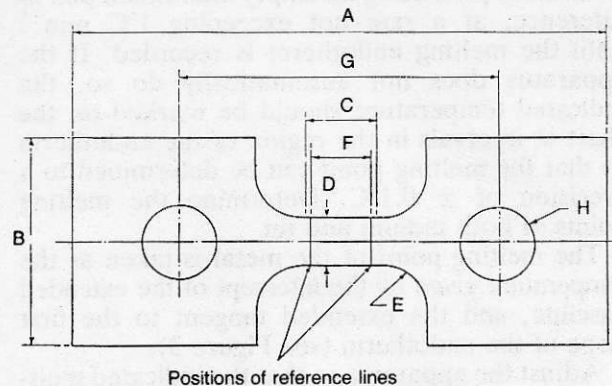
NOTE 5 For wall thicknesses of 12.7mm or less test pieces may be machined to the form shown in BS 2782: Method 320A (with or without radius F). These shall be tested at $100\text{mm min}^{-1} \pm 10\%$.

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:

- The full identification of the pipe from which samples were taken.
- Type of test specimen.
- Rate of grip separation.
- Test temperature.
- Individual results of elongation at break and/or tensile yield stress.
- Make and model of test instrument used.
- 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 to 35
(All dimensions in mm)	

Figure 5 Tensile test piece

APPENDIX D – METHOD OF PREPARATION OF NOTCHED TEST PIECES FOR 80°C HYDROSTATIC TESTS

D.1 APPARATUS

The notching equipment shall comprise a rigid bed and arbor such that a sharp 60° , 76.2mm diameter x 12.5mm wide double equal angle milling cutter rotating at $700 \pm 100\text{rpm}$ can be traversed along a pipe mounted on the bed at a rate of $150 \pm 25\text{mm min}^{-1}$ at a controlled depth in the pipe wall (see Figure 6). The cutter shall not have been used on any other material and shall be replaced or resharpened before 500m of notching has been performed. The rotation of the cutter shall be such that it cuts from the surface of the pipe downwards to the apex of the notch.

D.2 PROCEDURE

Each pipe shall be rigidly clamped to the bed of the milling machine and four longitudinal external

notches shall be cut in turn equi-spaced around the circumference.

Each cut shall be made in one continuous pass. One notch shall be on the section of minimum wall thickness.

For a test pressure of 8.0 bar (SDR 11) or 5.0 bar (SDR 17.6), to give a stress of 4.6 MPa across the ligament the target cut depth shall be calculated from formula 3 (for SDR 11 pipes) or formula 4 (for SDR 17.6 pipes).

$$a = 1.19t - 0.095D \quad (3)$$

$$a = 1.115t - 0.057D \quad (4)$$

where

a is the notch depth (mm)

t is the measured wall thickness in line with the notch (mm)

D is the measured outside diameter in the region of the notches (mm).

The notches shall be 125mm long and centrally positioned within the length of the test piece.

Any operation involving the use of heat (e.g. welding of flanges) shall not affect the properties of the notched samples.

The rotation and feed rates shall be recorded.

A test cut shall be made when a cutter is new and the cross-section examined to enable future monitoring of wear. The test piece or photographic evidence shall be retained.

NOTE Starting the cut on PE can be difficult. To enable the initial touch to be seen, a black marker can be used or sound detection via stethoscope or similar device.

D.3 MEASUREMENT OF NOTCH DEPTH

Before testing, the notch depth shall be measured (to 0.1mm) and recorded together with the pipe wall thickness at either end of the sample in line with the notch. The actual cut depth shall be $a(-0.01t)$.

NOTE The notch depth measurement can be accomplished using a stylus tipped dial test indicator supported on the pipe by two rollers in a frame. The indicator shall be zeroed adjacent to the notch and the measurement then taken.

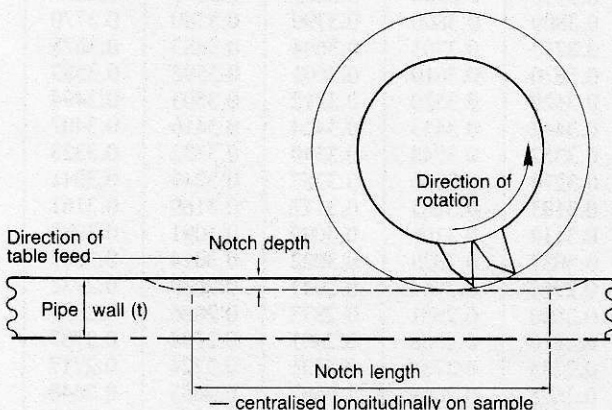


Figure 6 Details of notching method

APPENDIX E – METHOD FOR THE DETERMINATION OF CRITICAL STRAIN ENERGY RELEASE RATE G_c

E.1 APPARATUS

E.1.1 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.

E.1.2 Means of producing notches of variable depth across the test specimen. The resulting notch profile shall be $45 \pm 15^\circ$ included angle and have a notch root radius of $10\mu\text{m}$ or less.

E.1.3 Measuring apparatus for the determination of depth, thickness and crack depth to an accuracy of 0.01mm.

E.2 PROCEDURE

E.2.1 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 7 and 8) 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 give an adequate finish.

A band saw should not be used unless followed by finishing. 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 ϕ of approximately 0.12 to 0.6 is covered in approximately equal steps (see Figure 8 and Table 7).

Condition the specimens at $23 \pm 2^\circ\text{C}$ 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.

E.2.2 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:

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

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 9). 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 accurate value of Charpy calibration factor ϕ .

Calculate the value of the product $BD\phi$ (m^2) for each test piece and plot a graph of impact energy W (Joules) against $BD\phi$. 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 G_c (kJ/m^2) from the slope $W/BD\phi$ of this line.

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	0.4445	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	0.3485	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

Table 7 – Charpy calibration factor (ϕ) for $S/D = 5.833$ (continued)

a/D	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
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	0.1266	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	-	-	-	-	-	-	-	-	-

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 G_c (kJ/m^2).
- (d) Impact energy of tup used (J).
- (e) Velocity of test (m/s).
- (f) Strain rate of test (s^{-1}).
- (g) Date of test.

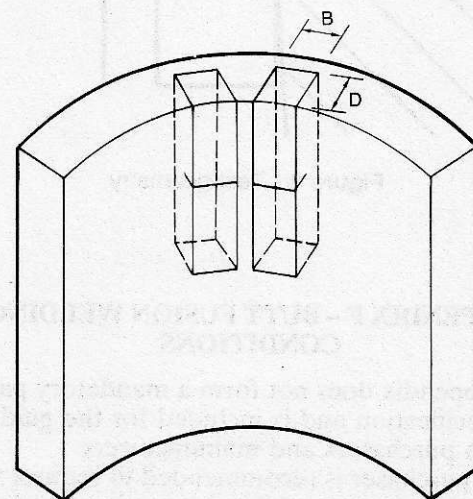
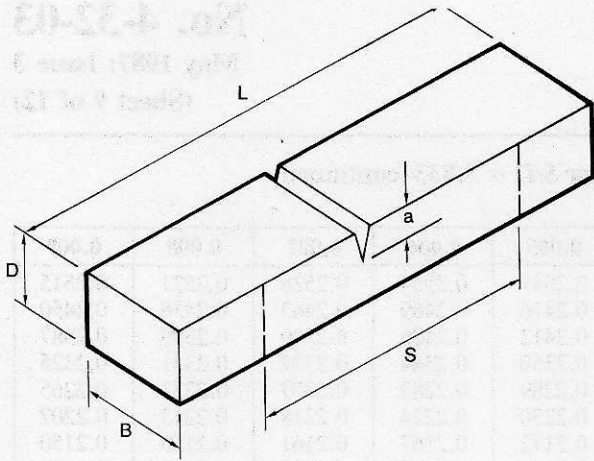


Figure 7

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 8 Charpy impact test piece

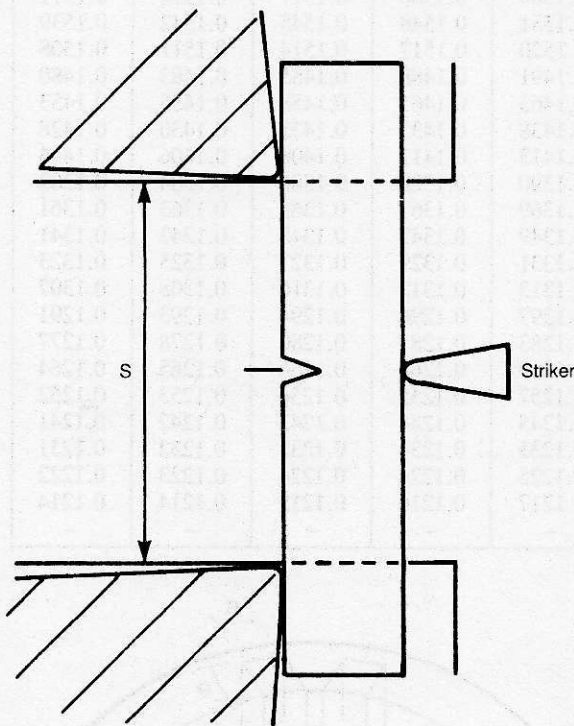


Figure 9 Test geometry

APPENDIX F – BUTT FUSION WELDING CONDITIONS

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

The purchaser is recommended to request from the manufacturer, welding instructions, including details of the following, as a function of the temperature where appropriate:

- Heater plate temperature and acceptable limits.
- Pressure cycle for initial beading and/or bead size.
- The soak time and pressure at soak.
- Maximum heater plate removal/pipe contact time.
- The welding pressure and limits (appropriate to particular welding machines). Where machine gauge pressures for a particular welding machine are not available from the pipe manufacturer then the force per unit area of pipe wall necessary for the appropriate operation should be provided.
- The weld cooling time and pressure conditions during cooling.
- The finished bead size limits.
- Any debearing limitation.

APPENDIX G – METHOD OF ASSESSING INITIAL BUTT WELDING CAPABILITY

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 normal technique. The distribution and number of samples shall be as in clause C.2. Prepare test pieces of the form shown in Figure 10. 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.

NOTE 1 A "spade" type wood drill has 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 $5\text{mm min}^{-1} \pm 10\%$. Allow the tests to continue until the test piece breaks and observe the failure modes e.g. ductile tearing, flat brittle failure.

Figure 11 shows examples of the tensile failure modes of welds.

NOTE Where a load/deflection trace is available it would be expected to appear as in Figure 12 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.

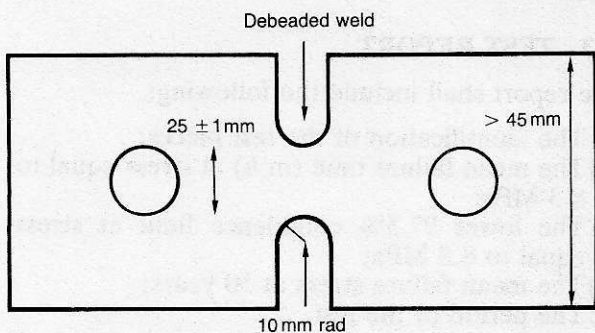
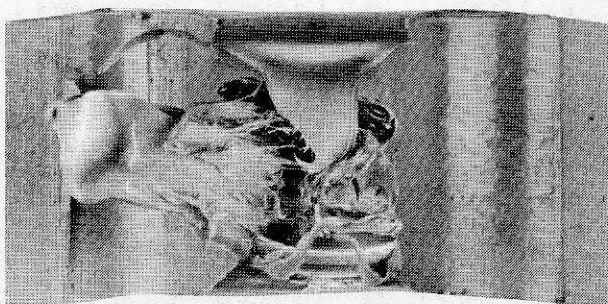
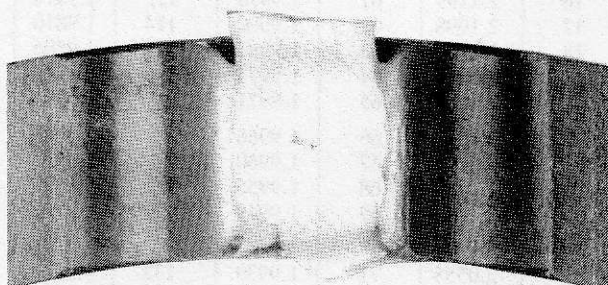


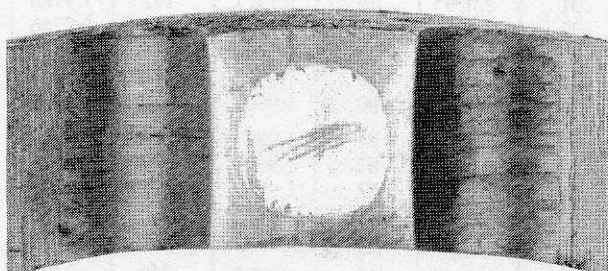
Figure 10 Tensile specimen geometry for welds



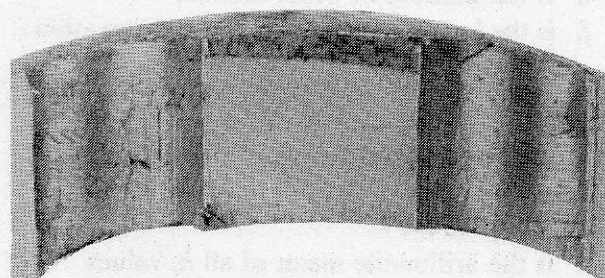
(a) Ductile



(b) Mixed



(c) Mixed



(d) Brittle

Figure 11 Examples of tensile failure modes

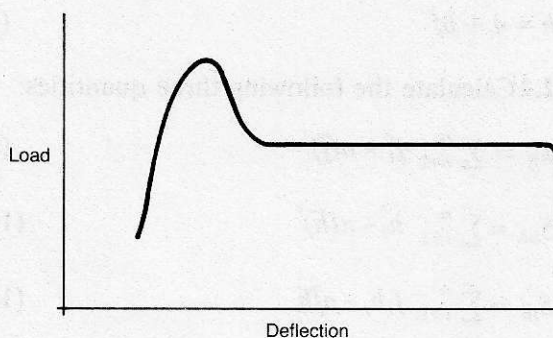


Figure 12

Example of load/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 h if they increase the value of the extrapolated time (see H.2.4 and H.2.5).

Table 8 – Failure point distribution

Failure time range (h)	Minimum data point distribution	Recommended* data point distribution
> 10 but < 50	2	≥ 4
≥ 50 but < 2500	3	≥ 5
≥ 2500 but < 6500	3	≥ 4
≥ 6500 but < 10000	2	≥ 4
≥ 10000	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.

H.2 CALCULATION OF LINEAR REGRESSION WITH ONE INDEPENDENT VARIABLE

H.2.1 The following symbols are used:

- n is the number of observations;
- f_i is the log of stress (in MPa) of observation i ; $i = 1, \dots, n$;
- h_i is the log of time (in h) of observation i ; $i = 1, \dots, n$;
- f is the arithmetic mean of all f_i values

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

h is the arithmetic mean of all h_i values

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

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

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

H.2.2 Calculate the following three quantities:

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

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

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

H.2.3 Calculate b and a from the following equations:

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

$$a = h - bf \quad (13)$$

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

H.2.4 Calculate the mean failure time (in h) at a stress of 8.3 MPa from equation (8).

H.2.5 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:

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

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

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

where:

t_{ν} is Student's t for $\nu = n - 2$ degrees of

freedom, as given in Table 9 which gives the upper 2½% 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).

H.2.6 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 h) at stress equal to 8.3 MPa;
- (c) The lower 97.5% confidence limit at stress equal to 8.0 MPa;
- (d) The mean failure stress at 50 years;
- (e) The period of the test.

Table 9 – Percentage points of Student's "t" distribution (upper 2½% points)

ν	t_{ν}	ν	t_{ν}	ν	t_{ν}
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

I.1 APPARATUS

A graduated density gradient column containing a sufficient number of calibrated floats covering the density range of the product. (Refer to BS 2782: Method 620D for preparation of density gradient columns and floats).

I.2 TEST SPECIMENS

A sample of material containing the whole thickness of the pipe wall and approximately 10mm square in cross-section shall be taken from the top segment of the pipe as extruded. The test specimens shall be prepared from this sample by cutting sections from the inner and outer pipe walls and at intervals through the pipe wall thickness. The two sections from the pipe surfaces shall be less than 0.3mm in thickness and those within the pipe wall no thicker than 1mm. The specimens shall then be individually shaped such that their original position within the pipe can be identified. (If necessary the specimens may be tested in two batches to aid identification).

I.3 PROCEDURE

After the density column has been stabilised at $23 \pm 0.5^\circ\text{C}$ for at least 6 hours, a graph shall be prepared from the calibrated floats relating specific gravity to position within the column.

Each specimen in turn shall be pre-wetted and then placed with tweezers into the density column, care being taken to ensure that no air bubbles are attached to the surface of the specimens. After a period of one hour the position of each specimen within the column is noted and its density determined from the calibration graph.

The density profile shall be presented graphically in the form of specific gravity vs position in the pipe wall. The position of each specimen shall be taken to be that of its mid-point.

I.4 REPORT

The report shall include the following:

- Full identification of the pipe from which the sample was taken;
- Position of sample in pipe wall;
- The density profile graph;
- The date of the test.

APPENDIX J – METHOD FOR THE DETERMINATION OF SLOW CRACK GROWTH RESISTANCE

J.1 APPARATUS

- A tool capable of cutting a notch of less than 90° included angle of uniform depth with a notch tip radius not exceeding $10\mu\text{m}$.

- Equipment capable of applying a calculated load accurate to within 50g to the test piece and an adjustable counter-balance.
- Rigid curved supports extending the full length of the test piece (see Figure 13) are recommended for SDR 17.6 pipe to ensure that a controlled bending moment is applied to the notched section.

J.2 TEST SPECIMEN

The test specimen shall be a section of pipe of length $95 \pm 5\text{mm}$ 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 ($D_m = \frac{1}{2} [OD + ID]$) 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 14).

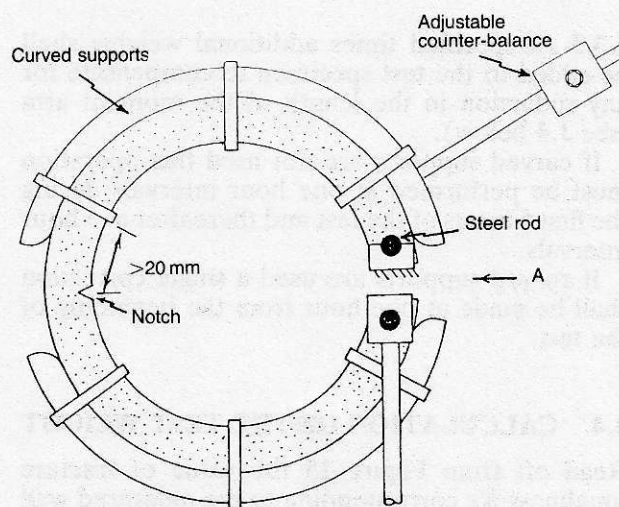


Figure 13 Test piece assembly

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 13).

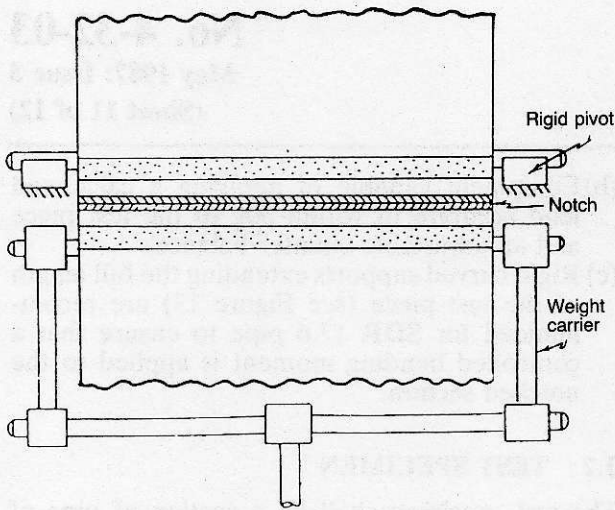


Figure 14 Side view from A (diagrammatic)

J.3 PROCEDURE

J.3.1 Weigh the lower curved 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 $23 \pm 1^\circ\text{C}$ throughout the test.

J.3.5 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 15 the value of fracture toughness Kc corresponding to the measured wall thickness. A value of $K_{IC} = 1.5\text{MN m}^{-3/2}$ has been used to construct this graph which compensated for plasticity effects in test specimens of different dimensions.

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

$$M = \frac{Kc l t^{3/2}}{181.6} \text{ Nm} \quad (16)$$

where

l is the length of the pipe ring (mm)

and

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:

$$W = \frac{101.9M}{D_m} \text{ kg} \quad (17)$$

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 load acts should replace the dimension D_m in equation 17.

J.5 REPORT

The report shall include the following information:

- The full identification of the pipe from which the test piece was prepared.
- Test temperature.
- The mass applied.
- The time to failure.
- The date of the test.

APPENDIX K – METHOD FOR THE DETERMINATION OF RESIDUAL STRESS

K.1 TEST SPECIMEN

A complete section of pipe at least one pipe diameter in length.

K.2 PROCEDURE

Measure the mean internal diameter (D_1 mm) of the pipe and the mean wall thickness (t mm).

By sawing longitudinally, remove a section of pipe covering an arc of approximately 30° .

After 1 hour measure the internal diameter (D_2 mm) of the pipe.

NOTE If the ring closes completely within the one hour period, then a further segment shall be removed – of size appropriate to allow the true change in diameter to be measured.

K.3 CALCULATION

Assuming a linear stress distribution across the pipe wall the residual stress (O_R) may be determined from thin curved beam theory as:

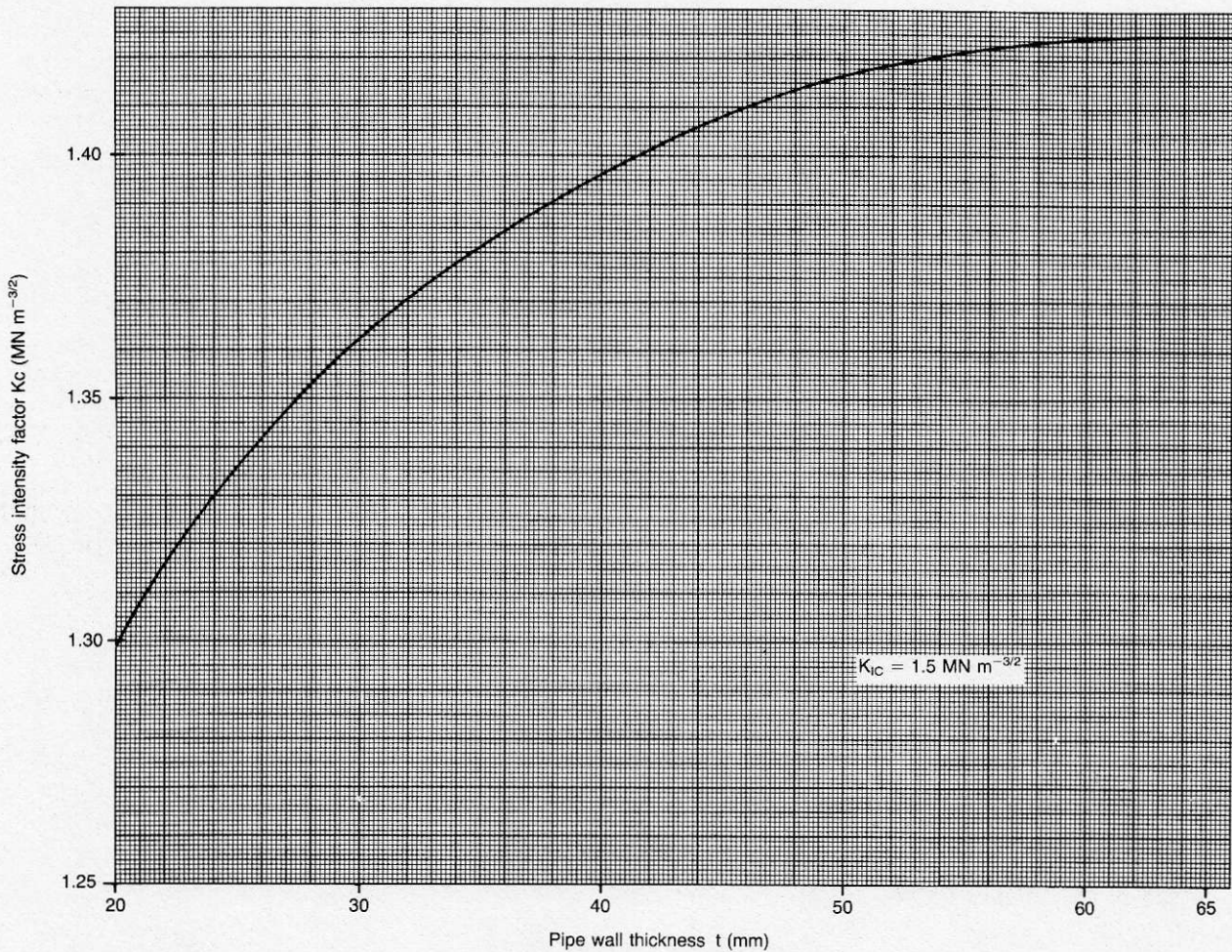


Figure 15 Calibration curve for split ring test piece

$$O_R = \frac{2Et(D_1 - D_2)}{(D_2 + t)(D_1 + D_2 + 2t)} \quad (18)$$

The modulus of the material (E MPa) should be taken as the one hour value from a constant stress creep curve on the pipe material. The preferred methods are given in Appendix C or Appendix D of IGN No. 4-32-05: Issue 1. The value used shall be given together with the source data.

K.4 REPORT

The report shall include the following information:

- (a) The full identification of the pipe from which the test piece was taken.
- (b) Test temperature.
- (c) Value of residual stress calculation.
- (d) The date of the test.

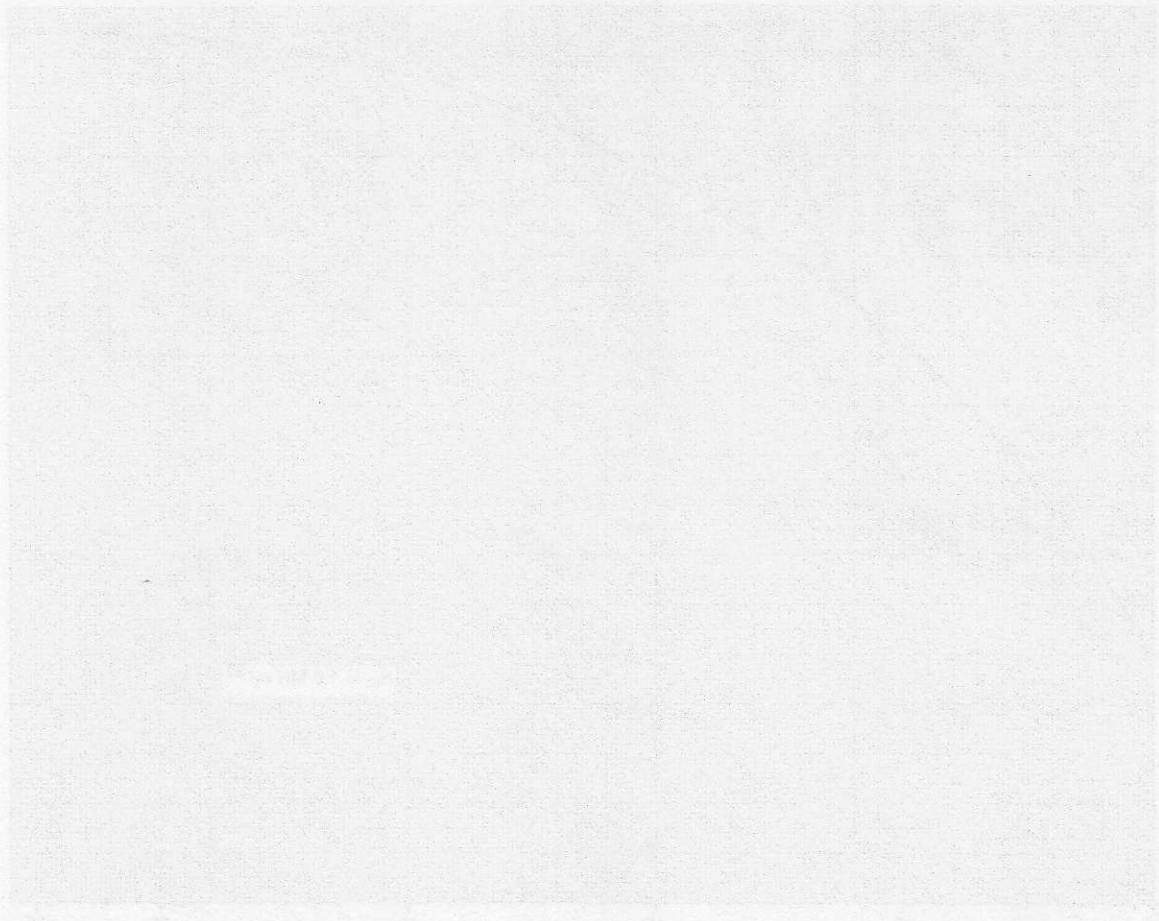


Figure 12 - Calibration curve for slip ring test bench

3.2. REPORT

- The report shall include the following information:
- (a) The full identification of the test item which the test piece was taken;
 - (b) Test conditions;
 - (c) Value of residual stress calculation;
 - (d) The date of the test.

$$D_s = \frac{2B(D_0 - D_1)}{D_0 + D_1 + D_2 + D_3} \quad (10)$$

The modulus of the material (E MPa) should be taken as the same value from a constant stress-strain curve on the test material. The predicted modulus is given in Appendix C, as per Table C.1 (see 4.1.1 of Issue 1). The value used shall be given together with the source data.