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SPECIFICATION FOR POLYETHYLENE (PE) PIPES FOR SEWER LININGS (NON-PRESSURE APPLICATIONS)

FOREWORD

This specification is one of a number of specifications which have been prepared by WRc in consultation with the Water Industry and the British Plastics Federation in order to assist engineers responsible for renovation of sewers. It covers polyethylene pipes suitable for Type II lining designs as defined in the Sewerage Rehabilitation Manual (published by WRc) and in which simplified design charts are shown. It is intended that the pipes should be joined by butt fusion welding, inserted into sewers and the remaining annulus subsequently grouted using cementitious grout.

Pipes are designated by their nominal sizes.

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. Different materials found 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 fusion jointing dissimilar materials.

It has been assumed in the drafting of this specification that the execution of its provisions is entrusted to appropriately qualified and experienced people, for whose guidance it has been prepared.

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

This specification does not purport to include all the necessary provisions of a contract. Users of this specification are responsible for its correct application.

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.

Attention is drawn to the policy of the Water Industry to purchase products produced to an acceptable Quality Assurance and Third Party Certification Scheme.

Throughout this specification SI units are used. Thus stress and modulus values are quoted in MPa (megapascals)*.

* 1MPa = 1MN/m^2 = 1N/mm^2

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APPENDICES

1. SCOPE

This specification defines the requirements for materials, dimensions, jointing, testing, marking and workmanship of black polyethylene (PE) pipes intended for the renovation of gravity sewers by sliplining where the lining is designed to act as a flexible pipeline i.e. one in which the passive reaction of side support is required to assist resistance to deformation by vertical forces (Type II design).

The pipes are specified in nominal sizes 90 to 1200. Wall thicknesses for pipes of Standard Dimension Ratio (SDR) 11. 17.6 and 26 are specified.

This specification is not intended to cover polyethylene pipes or linings for use in pressure or pumping mains.

2. DEFINITIONS

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

Ovality
The difference between the measured maximum outside diameter and the measured minimum outside diameter in the same cross section of lining.

Out-of-squareness
The maximum distance between two planes square to the axis, at the end of a pipe, passing through the extremities of the cut walls.

Type II design (Sewerage Rehabilitation Manual)
This procedure is applicable to the design of pipe linings forming no reliable bond to the grout or old sewer. The design assumption is that the lining eventually bears the full load from the ground and traffic. The lining system is designed to act as a flexible pipe with the old sewer, annulus grout and soil providing the necessary support to maintain stability.

3. MATERIALS

3.1 Base polymer

The base polymer shall be polyethylene with a derived density greater than 930kg/m^3 when determined in accordance with the method required by BS 3412. This includes co-polymers of ethylene and higher olefins in which the higher olefin constituent does not exceed 10% by mass.

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3.2 Compound composition

The base polymer shall be blended with additives (antioxidants, carbon black, UV stabilisers, etc.) that are necessary for the manufacture, storage and use of PE pipes for sewer linings to this specification.

The base polymer and the compound made therefrom shall conform to clauses 4.5.9 and 10 of BS 3412: 1976 in respect of density, melt flow rate, impurities, carbon black characterisation and dispersion.

The compound shall be Class W as defined in BS 3412 and conform to all relevant clauses of that standard.

3.3 Antioxidants

Only antioxidants as listed in Table 2 of BS 3412: 1976 shall be used.

3.4 Rework material

Clean black rework material meeting this specification may be incorporated provided that it is reground under the manufacturer's supervision.

3.5 Thermal stability

The material in pipe form shall have a thermal stability (and individual oxidation induction times) of at least 15 minutes when tested in accordance with Appendix A.

3.6 Carbon black dispersion

The carbon black dispersion of material in pipe form when tested by the method described in BS 2782: Method 823B shall be equivalent to photo-micrographs 1 to 5 of Figure 1 of that standard and the uniformity of appearance in respect of smears and streaks shall be equal to or better than photo-micrograph A of that standard.

4. APPEARANCE AND SURFACE CONDITION

The internal and external surfaces of the pipe shall be smooth and free from defects which might impair its properties.

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 Table 1.

The cross-section of the pipe shall be essentially circular i.e. there shall be no obvious flat regions on the bore irrespective of the wall thickness tolerances being complied with.

The diameter of the pipe at the ends may be less than that required above but shall not be less than 98% of the diameter measured at least one pipe diameter away from the ends.

5.2 Ovality

The ovality of pipes up to and including nominal size 250 shall not exceed 0.02 x nominal size (mm). The ovality of pipes greater than nominal size 250 shall not exceed 0.035 x nominal size (mm).

Table 1 - Polyethylene pipe dimensions (non-pressure applications)
See page 18

5.3 Out-of-squareness

The ends of the pipes shall be cut, cleanly and squarely, to within the tolerances given in Table 2.

Table 2 - Out-of-squareness tolerances for ends

Nominal size	Maximum out-of-squareness (mm)
90 - 110	2
125 - 160	3
180 - 225	4
250 - 315	5
355 - 500	7
560 - 800	10
900 - 1200	12

5.4 Length

5.4.1 Preferred lengths of pipes shall be 6 and 12m.

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

6. JOINTING

Pipes shall be capable of jointing by fusion welding techniques. The pipe manufacturer shall, upon request, provide the purchaser with written welding instructions appropriate to the sizes of pipe (see Appendix B).

7. PERFORMANCE REQUIREMENTS

The pipes shall meet the minimum requirements given in Table 3 when tested as prescribed in 8.2.

Table 3 - Lining performance requirements

Property	Minimum mean requirement
Short term flexural creep modulus (24 hour) E_s	350 MPa
Long term flexural creep modulus (50 year) E_L	130 MPa

The manufacturer shall supply to the purchaser, upon request, the modulus values measured on his material.

NOTE The simplified design tables and graphs shown for PE in the Sewerage Rehabilitation Manual use values for 24 hour and 50 year creep moduli of 350 MPa (N/mm^2) and 130 MPa (N/m^2) respectively.

8. TYPE TESTS

8.1 General

The requirements given in 8.2 to 8.8 shall be met before compliance to this specification can be claimed and whenever a change in process technique or introduction of a new or modified compound has occurred. The Quality Assurance Schedule of the quality system (see 9.1) may also require type tests to be repeated at specified intervals.

Unless otherwise specified, the test samples shall be taken from a production run from which the product has complied with all other requirements of this specification.

Details and results for type tests relevant to each material composition and manufacturing process shall be made available to the purchaser or his representative on request.

Specimens shall be conditioned prior to test by being kept at 23 ± 2°C in air or water for not less than 12 hours for linings of wall thickness up to and including 12.7mm or not less than 24 hours for linings of wall thickness over 12.7mm.

8.2 Creep modulus

The calculated 24 hour and 50 year creep moduli shall be not less than the values given in Table 3 when tested according to either Appendix C or Appendix D.

NOTE Complying certificated results from the pipe manufacturer's polymer supplier will be acceptable.

8.3 Short term ring creep test

If the pipe manufacturer has not performed the full creep tests required by 8.2, then he shall perform corroborative tests of at least 500 hours duration on a sample representative of each range manufactured (see Table 4) by the method described in Appendix C.

The data shall be plotted and shall fall on or above the full regression line.

Table 4 - Size ranges for tests

Range number	Nominal sizes
1	90 – 180
2	200 – 315
3	355 – 500
4	560 – 1200

8.4 Density

The density of samples taken from inner surface, mid-wall and outer surface regions of the test pieces used in 8.2 and 8.3 shall be determined in accordance with either Appendix E or BS 2782: Method 620A and recorded for comparitive purposes.

8.5 Tensile strength and elongation at break

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

Alternative test methods for determining yield stress and elongation at break may be used by agreement with BSI CAS/WRc and provided that equivalence to specified methods can be demonstrated.

8.6 Tensile weld test

When tested in accordance with Appendix G the failure mode shall be by ductile tearing. No "flat"

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fracture in a brittle-like manner shall be evident. At least two welds shall be made from at least one pipe size representative of each range given in Table 4.

8.7 Stress crack resistance

8.7.1 **Requirements for ranges 1 and 2 of table 4.** Tests shall be performed on at least two pipe samples from at least one pipe representative of each range manufactured in accordance with BS 4728 except that the free length of sample between end caps shall not be less than 400mm and shall be at least three times the outside diameter. The type of end caps shown in Figure 1 of BS 4728: 1971 or equivalent types, e.g. welded PE end caps or flanges with blanking plates, shall be used.

The pipe samples shall withstand a pressure equivalent to a circumferential stress of 4.6MPa for at least 170 hours at 80 $\pm$ 1^{o}C.

8.7.2 **Requirements for ranges 3 and 4 of table 4.** When tested in accordance with Appendix H test pieces shall be taken to failure (or may be removed at 500 hours, if sooner). They shall not fail within 36 hours. No additional test is required if the sample survives 100 hours but if failure occurs between 36 and 100 hours the test shall be repeated on pipes from a production run other than that from which the initial test pieces were taken.

A sample from at least one pipe size representative of both ranges 3 and 4 (Table 4) shall be tested.

NOTE If the crack initiates within 5 hours or propagates in an unstable manner the pipe will not be suitable.

8.8 Heat reversion

After the test samples have attained a temperature of 110^{o}C for 15 minutes, when tested by the method described in BS 2782: Method 1102B. The value of T (referred to in that method) shall not be greater than 3%.

9. QUALITY CONTROL TESTS

9.1 General

The test requirements given in 9.2 to 9.4 are necessary in order to demonstrate a continuing satisfactory level of product quality in day to day production. The manufacturer shall establish a BSI approved quality system to meet the requirements of BS 5750: Part 2.

The manufacturer shall not knowingly supply any defective unit in any batch.

9.2 Dimensions

The outside diameter, wall thickness, ovality and out-of-squareness of each pipe sample shall be measured and shall meet the requirements of clause 5.

Outside diameter shall be measured according to BS 2782: Method 1101A, at a point at least one diameter away from the pipe end and at the pipe end.

Wall thickness at any point around the circumference shall be measured according to BS 2782: Method 1101A or alternative methods of equivalent accuracy.

9.3 Thermal stability

The oxidation induction time shall be determined as prescribed in 3.5.

9.4 Elongation at break

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

NOTE See also 8.5.

10. WORKMANSHIP, INSPECTION AND CERTIFICATION

10.1 Workmanship

All raw materials shall be tested to ensure consistency and compliance with this specification.

The manufacturer shall adequately supervise all stages of production and keep records of the raw material batches used and products made each work shift or day.

Manufacture shall be under environmental conditions compatible with producing satisfactory linings and raw materials shall be stored and used in compliance with the recommendations of their manufacturers.

The manufacturer shall provide the purchaser with written recommendations for the transport, handling and storage of all lining units.

10.2 Inspection

In addition to the manufacturer's own inspection and supervision, the purchaser or his appointed inspecting authority shall have access at all reasonable times to those parts of the manufacturer's works engaged on production and testing of linings for the purchaser and all relevant test records.

10.3 Certification

The manufacturer shall, on request, furnish the purchaser or purchaser's representative, with copies of a signed certificate for each size and SDR value of pipe stating that the manufacture and testing of lining units supplied, comply with the requirements of this specification. If required by the purchaser, the quality control test results or a suitable summary shall be provided with the certificate.

NOTE The requirements of 10.1 to 10.3 do not compromise those of BS 5750: Part 2. Additional inspection and certification should not be necessary for a Registered Firm manufacturing within its scope of registration.

11. MARKING

All linings shall be permanently marked along two strips at intervals not exceeding one metre, along opposite sides of the pipe. No method of marking shall prejudice the performance of the lining in service. At least one of the markings shall be in the following colours: SDR 11 - blue, SDR 17.6 - red, SDR 26 - yellow. The markings shall give the following information:

(a) The manufacturer's name, initials or identification mark.

(b) The number 4-32-05. The marking of the number 4-32-05 on products produced to this specification may only be applied by manufacturers covered by a third party certification scheme acceptable to WRc.

(c) The nominal size and SDR value.

(d) Identification of the shift, production line and date of manufacture. Coding of this information is permitted provided that the meaning of the code is available on request.

(e) The words "PE SEWER LINING".

The marking shall remain legible under normal handling, storage and installation procedures.

NOTE If the pipe is already marked 4-32-03 (having been manufactured by a Registered Firm and complying with that specification), and is eligible for marking 4-32-05 under the provisions of this specification, then the words "PE SEWER LINING", the SDR value and the number 4-32-05 may be applied by other suitable means, e.g. adhesive tape.

12. PROTECTION OF PIPES

12.1 Storage

Whilst under the manufacturer's control the pipes shall be stacked/stored in such a way as to minimise dimension changes, external scratches, etc.

12.2 Covering of ends

Unless agreed otherwise with the purchaser the ends of pipes shall be covered or plugged.

13. REFERENCES

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

Sewerage Rehabilitation Manual published by WRc.

BS 2872 Methods of testing plastics.

Part 0 Introduction.

Methods 320A to 320F Tensile strength, elongation and elastic modulus.

Method 335A Determination of flexural properties of rigid plastic.

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 720A Determination of melt flow rate of thermoplastics.

Methods 823A and 823B. Methods for assessment of carbon black dispersion in polyethylene using a microscope.

Method 930A Preparation of test speciments by machining.

Method 1101A Measurement of dimensions of pipes.

BS 3412 Polyethylene materials for moulding

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and extrusion.

BS 4618 Recommendations for the presentation of plastics design data subsection 1.1.2: 1976 Creep in flexure at low strains.

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

BS 5750 Quality Systems.

Part 2: Specification for manufacture and installation.

WAA SWMC Information and Guidance Note No. 4-32-03: Specification for polyethylene pressure pipe for cold potable water (for nominal sizes greater than 63).

APPENDIX A - DETERMINATION OF THE OXIDATIVE THERMAL STABILITY OF POLYETHYLENE PIPE MATERIAL USING DIFFERENTIAL THERMAL ANALYSIS: ISOTHERMAL METHOD

A. 1 INTRODUCTION

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

A.2 SCOPE

The method provides a means of measuring the oxidative thermal stability of polyethylene pipe and fittings materials 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 antioxidant 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.

A.3 PRINCIPLE

In principle the test measures the time during which the antioxidant present in the sample inhibits oxidation whilst the specimen is held isothermally at 200°C under a flow of oxygen.

The process 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.

A.4 APPARATUS

The following apparatus is required:

A.4.1 Differential scanning calorimeter (DSC) or differential thermal analyser (DTA) capable of:

(a) recording the difference in temperature of 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 min^{-1}.

(d) programming the specimen temperature over the range 150 to 250°C at a rate of 1°C min^{-1} or less,

(e) continuously recording the specimen temperature with a resolution of 0.1°C. If this is not available then A4.2 applies.

A4.2 Temperature measuring apparatus, capable of continuously monitoring the specimen temperature with a resolution of 0.1°C.

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

A4.3 Analytical balance, capable of weighing the 15 ± 0.5mg test specimen to an accuracy of 0.1mg.

A4.4 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 1 minute of switch over.

A4.5 Gas flow measuring devices. Rotameters are suitable, but their calibration should be checked against a positive displacement device.

A4.6 High purity metal standards:
Indium.
Tin.

A.5 PREPARATION OF TEST SPECIMENS

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

A5.1 Test specimens from pipe or fittings:

(a) A through wall core is taken from the top segment of the pipe as extruded by using a core drill of suitable size, ensuring that the sample is not overheated during this operation.

NOTE The core may be cleaned and lightly scraped to remove any contamination etc.

(b) Using a scalpel, cut discs from the core sample of a thickness to give a specimen weight of 15 ± 0.5mg. Select the inner surface, outer surface and mid-wall 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.

A5.2 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.

A.6 PROCEDURE

A6.1 **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 seated 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 ±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 1).

Adjust the apparatus so that the indicated melting points of indium and tin lie within 156.6 ± 0.5°C and 231.9 ± 0.5°C respectively.

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

A6.2 **Time calibration**
Check that the pen moves along the abscissa at the selected rate using a stopwatch.

A 6.3 **Oxidation induction time measurement**
Establish a nitrogen flow of 50mL min^{-1} 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 min^{-1}.

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 200 ± 0.1°C raising the temperature at a rate of 20°C min^{-1} 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 1 minute of atmosphere changeover. Continue to run the thermogram until the oxidation exotherm has occurred, and has reached its maximum.

A.7 INTERPRETATION OF RESULTS

The oxidation induction time of the 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 2).

The thermal stability of each sample shall be the arithmetic mean of at least three oxidative induction time measurements, made at 200°C, two from the inner surface and one from the outer surface.

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A.8 TEST REPORT

The report shall include the following information:

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

(b) Sample weights.

(c) Individual oxidation induction times.

(d) Position of sample in pipe wall.

(e) Thermal stability, i.e. arithmetic mean of at least three oxidation induction time measurements.

(f) Test temperature.

(g) The date of the test.

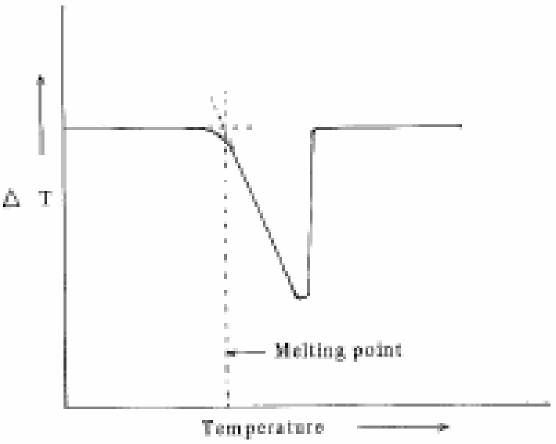

Figure 1 – Metal melting point

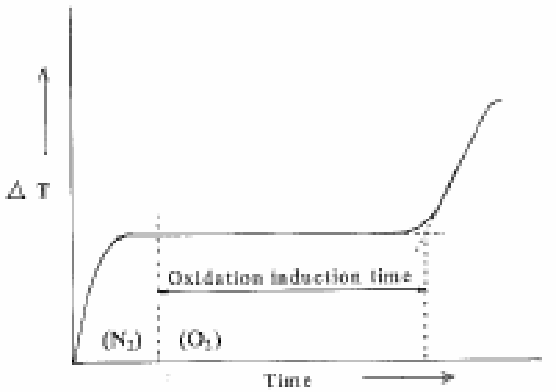

Figure 2 – Example of thermogram

APPENDIX B - 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:

(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 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.

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

(g) The finished bead size limits.

(h) Any debeading limitation.

APPENDIX C - METHOD FOR THE DETERMINATION OF CREEP MODULUS USING PIPE RINGS IN TENSION

C.1 APPARATUS

(a) Rigid support base.

(b) Accurate means of measuring deflection e.g. dial gauges or linear displacement transducers.

(c) A means of applying a constant tensile force to a ring specimen via application of a force to the inside surface e.g. height hanger and lead shot (see Figure 3).

C.2 TEST PIECE

Rings of pipe at least 50mm wide (at least two for type tests) shall be cut from production pipe representative of each range in Table 4 (if manufactured). The surfaces shall be machined as square and parallel as is practicable.

The rings shall be conditioned for at least 24 hours at 23 $\pm$ 2^{o}C prior to commencing the test.

C.3 PROCEDURE

(a) Measure the thickness, width and inside diameter of the ring at least eight points around the circumference and determine the average thickness, width and mid-wall diameter.

(b) Calculate the appropriate mass M to be applied from:

$$M = \frac{1.047\ S\ b\ t^2}{D}\ \text{kg} \qquad (1)$$

Where S is the required stress = 3 MPa
b is the average width (mm)
t is the average thickness (mm)
D is the average mid-wall diameter (mm).

(c) Mount the ring on to the apparatus.

(d) Set or zero the deflection measuring device.

(e) The mass M shall be applied smoothly and timing shall commence.

(f) If continuous monitoring of deflection δ is not employed a series of readings shall be taken between approximately 1 minute and at least 10,000 hours. There shall be at least 18 data points between 10 hours and 10,000 hours for each test piece. The following nominal times are recommended: 1,2,3,4, 12, 18, 24, 36, 48 minutes: 1,2,4,6,8, 10,20,40,80. 100, 200, 400, 600, 1.000, 2,000, 4,000, 8,000, 10,000+ hours.

(g) Calculate the flexural creep modulus for each value of $\delta_{(t)}$ the time t from:

$$E_{(t)} = \frac{1.79\ M\ D^3}{8\delta_{(t)}\ b\ t^3}\ \text{MPa} \qquad (2)$$

(h) Plot $\log_{10} E_{(t)}$ against $\log_{10}$ time. If the readings do not approximate to a smooth line for any reason the test shall be abandoned, the occurrence recorded and the test repeated.

(i) The graph produced for each test specimen may appear to be a straight line which goes through a transition to another slope. This being so, observe where the change in slope occurs. After the transition regress the measured values of $\log_{10}$ modulus on $\log_{10}$ time by the method of least squares and determine the value of flexural creep modulus E_L at 50 years.

From the graph determine the value of creep modulus E_s at 24 hours.

NOTE TO C The edge effect due to relief of residual stress may affect initial deflection and render the test inaccurate particularly in small diameters of minimum width. It is recommended that 'nominal size 180 should be the lowest size tested. For pipes of large wall thickness it is permissible to file the edges slightly to present a flat bore to the loading bar.

C.4 REPORT

For each test piece the test report shall include:

(a) Complete description and identification of the samples.

(b) Dimensions of the specimens.

(c) Details of specimen preparation and test conditions.

(d) Graph of $\log_{10}$ creep modulus against $\log_{10}$ time.

(e) Mass applied to the specimen.

(f) The calculated value of creep modulus E_s at 24 hours.

(g) The calculated value of creep modulus E_L at 50 years.

(h) The period of the test.

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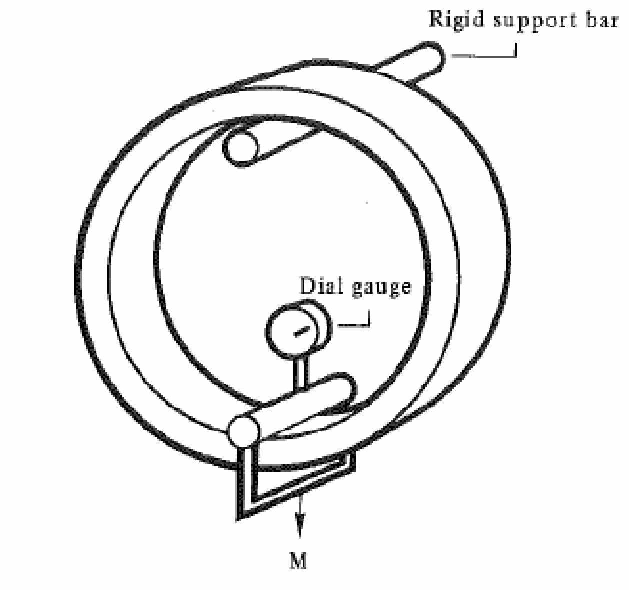

Figure 3 - Schematic diagram of ring creep test

APPENDIX D - METHOD FOR THE DETERMINATION OF FLEXURAL (BENDING) CREEP MODULUS IN THREE POINT BEND

D.1 SCOPE

Method of test to determine 50 year flexural creep modulus of sewer lining material subjected to a constant flexural stress under aqueous conditions.

The method is based on BS 4618: Subsection 1.1.2: 1976.

D.2 APPARATUS

The apparatus is shown schematically in Figure 4. It shall consist of the following equipment such that the specimen is maintained at 23 ± 2°C.

D2.1 A pair of supports that:

(a) are parallel.

(b) can be adjusted to give a variable span.

(c) do not deflect under experimental forces.

(d) do not impose significant longitudinal restraint on the specimen.

(e) provide line contacts with the specimen without significant indentation.

(f) preferably have a radius of less than 1.0% of the span length L.

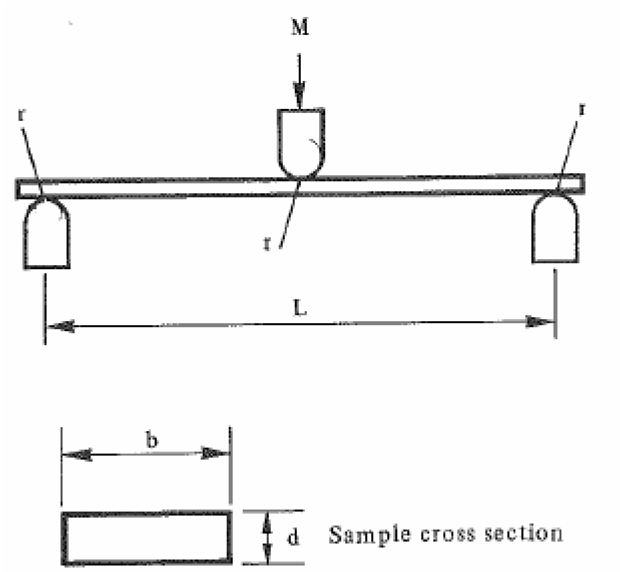

Figure 4 - Schematic layout for three point flexural creep tests

D2.2 A means of applying to the specimen a force that:

(a) is constant,

(b) is applied by a mass through a central loading member which shall preferably have a radius r of less than 1.0% of the span length L.

(c) is midway between the supports (within a tolerance of ± 1% of the span).

(d) is uniform along a continuous line perpendicularly across the width of the specimen.

D2.3 A means of measuring the deflection of the specimen that:

(a) is as close as practicable to the line of application of the force.

(b) itself applies only an insignificant force to the specimen.

(c) is accurate to within ± 0.3%.

D.3 TEST PIECES

D3.1 **Preparation**
At least three test pieces shall be machined, representative of each range manufactured, to produce rectangular cross sections (without rounded corners) and the following dimensional requirements:

(a) Span length (L) of 10d or greater.

(b) Total length of not greater than 12L.

(c) Width b greater than d but less than 3d.

(d) Width and thickness (d) constant to within a tolerance of ± 1%.

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

D3.2 **Conditioning**
The specimens shall be stored in air or water at the test temperature for at least 24 hours prior to testing.

D.4 PROCEDURE

(a) Prepare each test piece.

(b) Mark on the test piece with a felt tipped marker, the approximate positions where each end support will bear, then mark ten intermediate positions on the test piece so that the span length is divided into eleven equal sections.

(c) Determine the width and thickness at each of the ten lines to within an accuracy of - 0.2% and calculate the arithmetic mean of the width and thickness measurements.

(d) Condition each test piece.

(e) Set the span length L to approximately the required value.

(f) Measure the span length L mm (0.5%)

(g) Calculate the mass M. to be applied to the test pieces to give the required flexural stress from:

$$M = \frac{bd^2S}{14.71L} \text{ kg} \qquad (3)$$

Where
b is the average width of the test piece (between the supports) (mm)
d is the average thickness of the test piece between the supports (mm)
S is the required flexural stress = 3 MPa.
L is the distance between the supports or span length (mm).

The applied mass shall be accurate to within ± 0.1% of the calculated mass.

(h) Place the test piece in the apparatus with its longitudinal axis at right angles to the supports.

(i) Set and zero the deflection measuring device.

(j) Immediately after carrying out step (i), smoothly apply the mass M and commence timing the test.

(k) If continuous monitoring of deflection (δ) is not employed a series of readings shall be taken between approximately 1 minute and at least 10.000 hours. There shall be at least 18 data points between 10 hours and 10,000 hours for each test piece. The following nominal times are recommended: 1,2,3,4, 12, 18, 24, 36, 48 minutes. 1,2,4, 6, 8, 10, 20, 40, 80, 100, 200, 400, 600, 1,000, 2,000, 4,000, 8,000, 10,000+ hours.

(l) Calculate the flexural creep modulus for each value of $\delta_{(t)}$ at time t from

$$E_t = \frac{2.45 M L^3}{b d^3 <>_{(t)}} \text{ MPa} \qquad (4)$$

(m) Plot $\log_{10} E_{(t)}$ against $\log_{10}$ time. If for any reason the readings do not approximate to a smooth trace the test shall be abandoned, the occurrence recorded and the test repeated.

(n) The graph produced for each test specimen may appear to be a line which goes through a transition to an approximately straight line of greater slope. This being so, observe the position of the transition. After the transition regress the calculated values of $\log_{10}$ creep modulus on $\log_{10}$ time using the method of least squares and determine the extrapolated 50 year value of creep modulus E_L.

From the graphs determine the value of creep modulus E_s at 24 hours.

(o) If the graph does not approximate to a straight line and continues to curve downwards, the procedure in (n) is invalid.

D.5 REPORT

For each specimen the test report shall include:

(a) Complete description and identification of the lining.

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(b) Dimensions of the specimen.

(c) Method of specimen preparation.

(d) Graph of $\log_{10}$ flexural creep modulus versus $\log_{10}$ time.

(e) Mass applied to the specimen.

(f) The calculated value of flexural creep modulus E_s at 24 hours.

(g) The calculated value of flexural creep modulus E_t at 50 years.

(h) The period of the test.

(i) Any other relevant information.

APPENDIX E - METHOD FOR THE DETERMINATION OF DENSITY BY THE DENSITY GRADIENT METHOD

E.1 APPARATUS

A graduated density gradient column containing a sufficient number of calibrated floats to cover the density range of the product. (Refer to BS 2782: Method 62OD for preparation of density gradient columns and floats).

E.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 pipe. The test specimens shall be prepared from this sample by cutting sections from the inner and outer pipe walls and a mid-wall position. 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.

E.3 PROCEDURE

After the density column has been stabilised at 23 $\pm$ 0.5°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.

E.4 REPORT

The report shall include the following:

(a) Full identification of the sample;

(b) The measured density;

(c) The date of the test.

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

F.1 APPARATUS

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

F.2 TEST PIECES

Longitudinal samples shall be taken for the full wall thickness of positions equally spaced around the circumference of the pipe. The minimum number required for each range of Table 4 is 4 for range 1, 6 for range 2, 8 for range 3, and 10 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 3. Alternatively, for wall thicknesses of 12.7mm or below, test pieces of the form shown in BS 2782: Method 320A (with or without radius F) may be prepared by machining or punching.

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 for any purpose.

F.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 10mm/min ± 10% or 100mm/minute ± 10%, for the test pieces described in F.2. respectively.

NOTE Whenever possible a continuous record of force vs displacement should be retained.

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

NOTE 2 The standard of sample production is very important.

NOTE 3 The measurement of yield stress is not obligatory for quality control tests in this specification.

F.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.

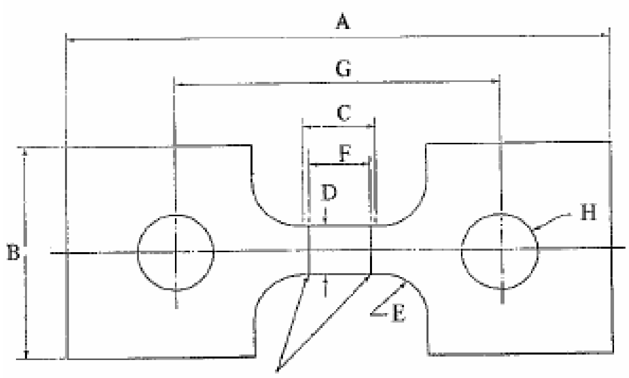
(c) Rate of grip separation.

(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.



Positions of reference lines

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 G - METHOD OF ASSESSING SHORT TERM WELDING CAPABILITY

G.1 APPARATUS

Tensile testing machine (see clause B.1).

G.2 TEST PIECES

Cut longitudinal rectangular samples from the full wall thickness of pipes welded. The distribution and number of samples shall be as in clause B.2. Prepare test pieces of the form shown in Figure 6. 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 specimen shall be smooth.

*A "spade" type wood drill has been found to give satisfactory results.

G.3 METHOD

Condition the specimens and test them in tension at a grip separation rate of 5mm/min ± 10%. Allow the

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tests to continue until failure and observe the failure modes e.g. ductile tearing, flat brittle 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.

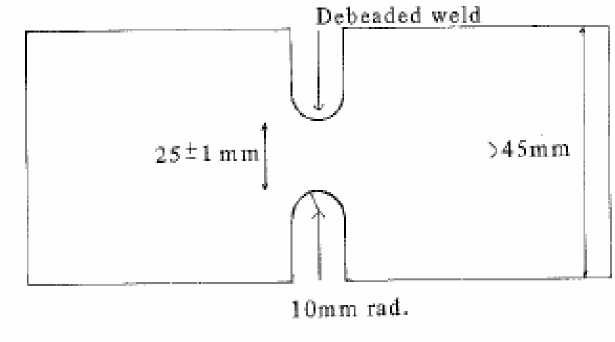

Figure 6 – Tensile specimen geometry for welds

APPENDIX H - METHOD FOR THE DETERMINATION OF SLOW CRACK GROWTH RESISTANCE

H.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 specimen and an adjustable counter-balance.

(c) Rigid curved supports extending the full length of the specimen (see Figure 7) are recommended to ensure that a controlled bending moment is applied to the notched section.

H.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 (Dm = 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 8).

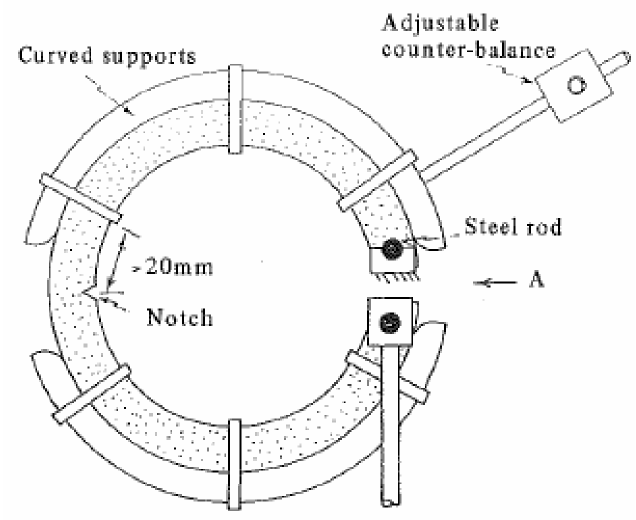

Figure 7 – Test piece assembly

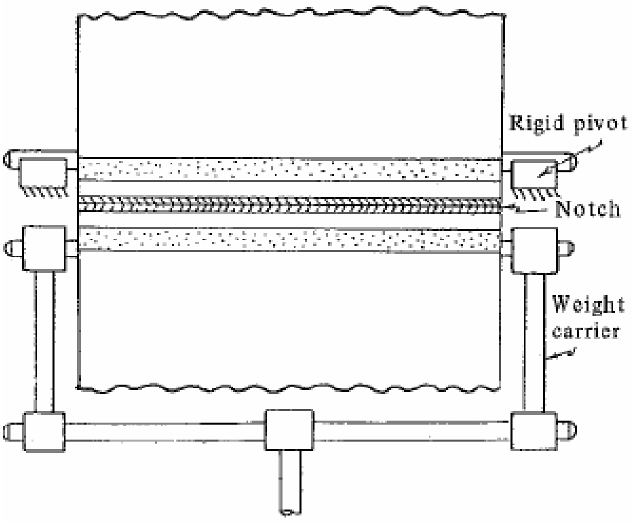

Figure 8 – Side view from A (diagrammatic)

NOTE The supports are unlikely to be necessary for SDR 11. pipe.

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 7).

H3 PROCEDURE

H3.1 Weigh the lower curved support and clamps if used and the weight carried.

H3.2 Condition the test specimen.

H3.3 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.

H3.4 Carefully add the test mass calculated by the method given in clause H.4. The loading time shall be less than one minute. The ambient temperature shall be maintained at 23 $\pm$ 2^{o}C throughout the test.

H3.5 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 H.4).
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.

H.4 CALCULATION OF THE TEST WEIGHT

Read off from Figure 9 the value of stress intensity factor Kc corresponding to the measured wall thickness. A value of K_{IC} = 1.5MNm$^{3/2}$ has been used to construct this graph which compensated for plasticity effects in test specimens of different dimensions.

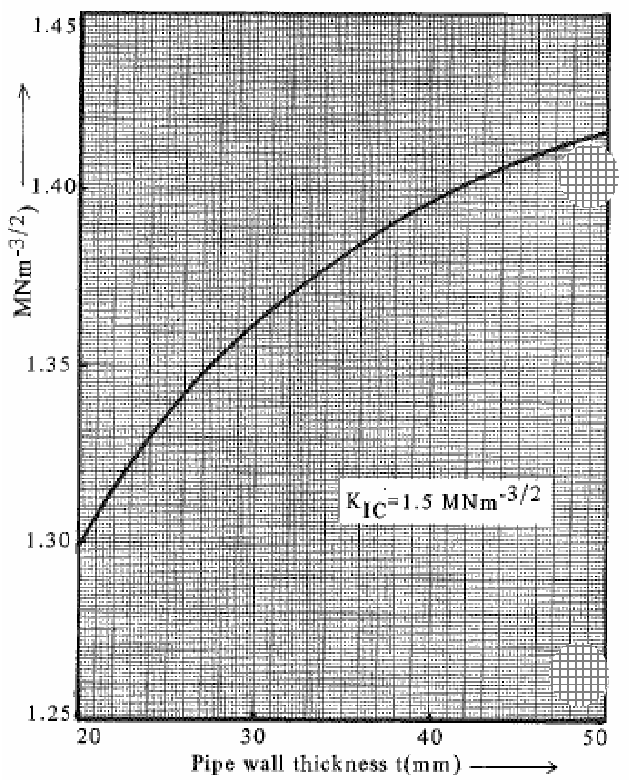

Figure 9 – Calibration curve for split ring specimen

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

$$M = \frac{Kc\, l\, t^{3/2}}{181.6} \quad \text{Nm} \qquad (5)$$

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:

$$W = \frac{101.9M}{D_m} \quad \text{kg} \qquad (6)$$

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

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notch and the vertical plane through which the load acts should replace the dimension D_m in equation 6.

H.5 REPORT

The report shall include the following information:

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

(b) Test temperature.

(c) The mass applied.

(d) The time to failure.

(e) The date of the test.

Table 1 - Polyethylene pipe dimensions (non-pressure applications)

Nominal size	Mean outside diameter (mm)		Wall thickness (mm)					
			SDR 26		SDR 17.6		SDR 11	
	Minimum	Maximum	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
90	90.0	90.6	-	-	-	-	8.2	9.2
110*	110.0	110.6	-	-	6.3	7.1	10.0	11.2
125	125.0	125.6	-	-	7.1	8.0	11.4	12.7
140*	140.0	140.8	-	-	8.0	9.0	12.7	14.2
160*	160.0	161.0	6.2	7.0	9.1	10.2	14.6	16.3
180	180.0	181.2	6.9	7.8	10.2	11.4	16.4	18.3
200*	200.0	201.2	7.7	8.7	11.4	12.7	18.2	20.2
225	225.0	226.4	8.6	9.7	12.8	14.3	20.5	22.8
250	250.0	251.5	9.6	10.8	14.2	15.8	22.7	25.2
280	280.0	281.6	10.7	12.0	15.9	17.7	25.4	28.1
315	315.0	316.8	12.1	13.5	17.9	19.8	28.6	31.7
355	355.0	357.1	13.6	15.2	20.1	22.3	32.3	35.7
400	400.0	402.3	15.3	17.0	22.7	25.1	36.4	40.2
450	450.0	452.6	17.2	19.1	25.6	28.4	41.0	45.3
500	500.0	502.9	19.1	21.2	28.3	31.3	45.5	50.3
560	560.0	563.2	21.4	23.7	31.7	35.1	50.8	56.1
630	630.0	633.7	24.1	26.7	35.7	39.5	57.2	63.1
710	710.0	714.1	27.2	30.1	40.2	44.4	-	-
800	800.0	804.6	30.6	33.9	45.3	50.0	-	-
900	900.0	905.0	34.4	38.0	50.9	56.2	-	-
1000	1000.0	1005.0	38.2	42.2	56.6	62.5	-	-
1200	1200.0	1205.0	45.9	50.7	-	-	-	-

NOTES 1. The maximum wall thickness is equal to 1.1e + 0.2mm (to the nearest 0.1mm) where e is the minimum wall thickness in mm.
2. Not all sizes may be available in a manufacturer's range, in particular, those asterisked.