

Information and Guidance Note

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DUCTILE IRON PIPES AND FITTINGS

FOREWORD

The objective of this note is to provide general information and guidance on ductile iron pipes and fittings for pressure applications in the UK Water Industry. It has been prepared by the Ductile Iron Liaison Group of the Sewers and Water Mains Committee, with membership drawn from both the Water Industry and relevant UK manufacturers.

At present, the governing specification for ductile iron pipes and fittings in the UK Water Industry is British Standard BS 4772: 1988. This specification was first issued in 1971, and was subsequently revised in 1980. The present note is intended to supplement and explain the information contained in the latest revision, BS 4772: 1988. In particular, it highlights the new developments in this revision, the most significant of which are:-

- the admission of validated, non-destructive test (NDT) inspection procedures, which can be used to verify the key mechanical properties (strength and ductility) of every pipe through production;
- the introduction of Portland pulverised-fuel ash cement (PFAC) for mortar linings, and the inclusion of minimum bore clearance criteria for small diameter, cement mortar lined pipe;
- the introduction of sprayed zinc metal coatings as standard for all pipes up to and including 800mm nominal size (DN 800);
- the inclusion of a new range of "unified design" fittings, as an alternative to the designs offered in previous versions of the standard, and which are retained in the present revision; and
- the allowance of the supply of fittings to designs which differ from those detailed in the standard (i.e. Group II fittings) (see Clause 9).

These and other developments are discussed in more detail in the following guidance note.

At publication, BS 4772: 1988 represented arguably the most technically advanced, and certainly the most comprehensive, specification for ductile iron pipes and fittings available nationally and internationally.

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1. HISTORICAL DEVELOPMENT

Until the early 1920's, iron pipes were normally manufactured by casting grey iron into vertical sand moulds (pit casting). These pipes were invariably eccentric (i.e. non-uniform wall thickness) due to difficulties in pipe mould core location, and exhibited relatively low strengths and poor ductilities, the latter being due to the flake graphite form and the high phosphorus content of cast iron produced by foundries of that period. The microstructure of



vertically cast grey iron pipe is illustrated in Figure 1(a). The casting of grey iron pipes in horizontal, water-cooled, spinning metal moulds began commercially in the United Kingdom during 1922. This high production rate technique eliminated certain sand casting defects (e.g. blowholes) and in particular resulted in uniform pipe wall thicknesses. Furthermore, the refinement of pipe wall microstructure achieved by the centrifugal casting and subsequent heat treatment process (which was necessary to break down the chilled microstructure of metal spun cast iron) resulted in somewhat higher tensile strengths and ductilities than those obtained by pit casting: the microstructure of spun grey iron pipe is shown in Figure 1(b). The combination of enhanced tensile properties and uniform pipe wall thickness obtained by centrifugal casting thus allowed the manufacture of thinner, and hence lighter, pipes than had previously been possible with the pit casting technique.

Spun ductile iron pipe was first manufactured in the United Kingdom on a commercial scale in 1961. Ductile iron is produced by treating a low phosphorus, low sulphur, grey iron melt with magnesium immediately prior to casting. This treatment causes the carbon present in the melt to precipitate predominantly in the form of graphite nodules on solidification, rather than as flake graphite (as is normally the case for grey cast irons). In order to improve the as-cast microstructure developed as a result of centrifugal casting into water-cooled moulds, ductile iron pipes are subsequently heat treated. The finished pipe wall microstructure consists of a uniform distribution of spheroidal graphite particles in a substantially ferritic matrix, Figure 1(c). This confers a combination of tensile strength and ductility on the material which is markedly superior to that which can be achieved in grey iron pipes.

The greater strength of ductile iron permits the manufacture of pipes and fittings with thinner walls than those of similar diameter grey iron castings. Thus, spun ductile iron pipes are typically 30% lighter than equivalent spun grey iron pipes. Where pipeline failure due to external stresses is anticipated, the superior mechanical properties of ductile iron pipes and fittings render them considerably more resistant to fracture under beam loading conditions than equivalent grey iron castings. Ductile iron castings are also resistant to the deep fissure corrosion which can occur on metal spun grey iron pipes under certain combinations of stress and soil environment (as distinct from simple corrosion, such as thinning, pitting, etc.) Ductile iron pipes and fittings (in common with their grey cast iron counterparts) are, however, susceptible to corrosion attack (i.e. thinning and/or pitting) by some conveyed waters (notably soft waters) and some soils (usually of low resistivity)⁽¹⁾ unless adequately protected (see clause 7).

2. APPLICATIONS

Ductile iron pipes and fittings to BS 4772: 1988 are used in the construction of pipelines for the conveyance, above and below ground, of potable water,

sewage and raw water, and are suitable for both pressure and non-pressure applications. Further, detailed guidance on the use of ductile iron pipes is given in the WAA/WRC Pipe Materials Selection Manual⁽²⁾.

Spun ductile iron pipes are currently available in a range of nominal sizes from DN 80 to DN 1600, with either spigot and socket ends or flanged ends (see clause 8 for details of types of joint available). Flexibly jointed ductile iron pipe is available in standard lengths of 5.5m up to and including DN 800; pipe in the size range DN 900 to DN 1600 is supplied in 8m lengths. Flanged pipe is available in lengths of up to 5m in sizes up to DN 800, and in lengths up to 6m in size range DN 900 to DN 1600, as standard.

The maximum hydraulic working pressure ratings, exclusive of surge, of the most commonly used Class K9 ductile iron spigot and socket pipe (see clause 4 for details of class designation), and of the other pipes and fittings detailed in BS 4772, have been revised in the 1988 version of the standard. These are shown in Table 1.

Some manufacturers' large diameter tees (DN 900 and above with large branches) are Group II fittings as defined in BS 4772: 1988, and have pressure ratings less than those given in Table 1 (consult manufacturers for details).

Generally, the maximum working pressure of a ductile iron pipeline system is governed by the rating of any branched fittings present, or the ratings of flanges, if used. Flanges with a nominal pressure rating of 16 bar (PN 16) are normally supplied, although flanges with higher pressure ratings (PN 25 up to DN 1600 and PN 40 up to DN 600) are available (note that PN 10 is a non-preferred pressure rating).

The surge pressure ratings of ductile iron pipes and fittings with spigot and socket joints are 5 bar greater than the corresponding maximum hydraulic pressure ratings for sustained operation. Where PN 16 ductile iron flanges are incorporated into the pipeline, the maximum surge pressure rating is 25 bar (see BS 8010: Part 2: Section 2.1:1987 for further details).

3. REQUIRED PROPERTIES

Adequate structural strength to withstand internal water pressure (including surges) and external loadings, with or without additional bedding support; adequate resistance to internal and external corrosion; smooth internal surface to minimise hydraulic resistance, ease of jointing.

4. BRITISH STANDARD SPECIFICATION

The British Standard specifying the requirements for ductile iron pipes and fittings is BS 4772: 1988. This revised standard supersedes the previous British Standard on ductile iron pipes and fittings, BS 4772: 1980, which has now been withdrawn.

The scope of BS 4772: 1988 covers cast iron pipes and fittings in which the graphite present is substantially in spheroidal form, and includes specifications for both spun cast and gravity cast products. The

Table 1 – Maximum hydraulic working pressures, exclusive of surge, for ductile iron pipes, fittings and flanged joints

Nominal size DN	Maximum hydraulic working pressures					
	Centrifugally cast pipes class K9, fittings class K12 (including flanged pipes with integrally cast flanges) (bar)	Fittings (i.e. tees) class K14 and thicker (bar)	Flanged joints			
			(bar)	(bar)	(bar)	(bar)
80	60	60	10	16	25	40
100	60	60	10	16	25	40
150	60	60	10	16	25	40
200	60	50	10	16	25	40
250	53	40	10	16	25	40
300	47	40	10	16	25	40
350	43	25	10	16	25	40
400	40	25	10	16	25	40
450	38	25	10	16	25	40
500	36	25	10	16	25	40
600	33	25	10	16	25	40
700	31	25	10	16	25	40
800	29	25	10	16	25	40
900	28	25	10	16	25	40
1000	27	25	10	16	25	40
1100	26	25	10	16	25	40
1200	25	25	10	16	25	40
1400	25	25	10	16	25	40
1600	25	25	10	16	25	40

NOTE: Additional information on hydraulic working pressure ratings is given in the notes to Table 2 of BS 4772: 1988.

standard provides for ductile iron pipes with spigot and socket ends (for flexible coupling), ductile iron pipes with flanged ends (either cast-on, screwed-on or welded-on) and ductile iron pipeline fittings, plus cement mortar lining of ductile iron pipes and fittings and the external zinc coating of centrifugally cast spigot and socket pipes (uti DN 800).

The specification (or class designation) system used in BS 4772: 1988 for ductile iron pipes and fittings follows that previously established in ISO 2531. In this system, the class designation for each pipe and fitting consists of the prefix letter "K" and a whole number. This integer is the coefficient which is inserted into a formula specified in BS 4772: 1988 for the determination of the standard pipe (or fitting) wall thickness. For a given nominal pipe (or fitting) diameter, the standard wall thickness increases as the integer specified in the class designation increases. This is illustrated by the examples given in Table 2. BS 4772: 1988 provides details relating to the dimensions and properties of Class K9 ductile iron pipes with spigot and socket ends, Class K9 ductile iron pipes with either welded-on or screwed-on flanges, and Class K12 ductile iron pipes with either cast-on or screwed-on flanges. The standard also covers Class K12 non-branched fittings and Class K14 and thicker branched fittings.

Table 2 – Relationship between class designation number and standard wall thickness for ductile iron pipes – examples

Nominal size (DN)	Nominal wall thickness*	
	Class K9 (mm)	Class K12 (mm)
100	6.1	7.2
300	7.2	9.6
600	9.9	13.2
1200	15.3	20.4

* N.B. Tolerances on standard wall thicknesses are given in Table 10 of BS 4772: 1988.

Although three designations of ductile iron pipes and fittings are specifically referred to in BS 4772: 1988 (i.e. K9, K12 and K14), the standard allows the use of classes other than those detailed, provided that such pipes and fittings are of a wall thickness appropriate to the class designation, are marked accordingly, and meet all the other requirements in the specification. It should be noted that increases or

decreases in the wall thickness of centrifugally cast ductile iron pipe may only be obtained by variation of the internal diameter of the pipe.

5. BRITISH STANDARD TESTS

The principal tests carried out on ductile iron pipes and fittings in accordance with BS 4772: 1988, together with their respective frequencies, are as follows:

5.1 Routine quality control checks

- Dimensional checks – external diameter and uniformity of wall thickness. In practice, these are checked on every pipe. The external diameter tolerance specifications given in Table 9 of BS 4772: 1988 apply to the full length of the barrel section for pipes up to and including DN 300. For pipes DN 350 and greater, these tolerances apply to the full length of the barrel section only in those cases where the pipes are intended for cutting in the field. Such pipes are supplied by special agreement between the purchaser and manufacturer and are marked as being suitable for cutting in the field. However, pipe manufacturers state that the large majority of spun ductile iron pipes DN 350 and greater, if cut in the field, would exhibit outside diameters at the cut end which fall within the limits given in Table 60 of BS 4772: 1988.
- Check for straightness – on every pipe.
- Weight check – normally only for each pipe DN 150 and greater.
- Hydrostatic pressure test – on every pipe and fitting. Every pipe must be capable of withstanding the specified works hydrostatic test pressure for a duration of 15 seconds without evidence of leakage, sweating or other failure. It should be noted that the hydrostatic pressure test applied to fittings and gravity-cast pipe is a check for leak-tightness only.
- Tensile property determinations – ultimate tensile strength and percentage elongation. The tensile properties shall comply with the requirements specified in the standard; see Table 3.

In the past, these mechanical properties were conventionally monitored during normal production by destructively testing tensile test bars taken from representative pipes and fittings on a batch sampling basis (one test bar per batch). In recent years, UK manufacturers have made significant progress in the development of non-destructive testing (NDT) inspection techniques, which can be used to assess the mechanical properties of ductile iron pipe indirectly. These techniques essentially determine the microstructural condition of the pipe after casting and heat treatment; this, in turn, is related to the mechanical properties of the iron.

Table 3 – Tensile property requirements for ductile iron pipes and fittings

Nominal size (DN)	Type of casting	Minimum tensile strength§	Minimum elongation (%)
80 to 1000	Centrifugally cast pipes	420	10*
Over 1000	Centrifugally cast pipes	420	7
All sizes	Pipes not centrifugally cast, and fittings	420	5

* 7% for pipes thicker than K12.
 § All DI pipes and fittings to BS 4772: 1988 have a minimum 0.2% proof strength of 300MPa.
 N.B. 1MPa = 1N/mm² = 0.06475tsi.

These developments have been acknowledged in the revised BS 4772: 1988, which now permits the use of either:

- conventional batch sampling and the destructive testing of tensile test bars at the frequency indicated in Table 4;

Table 4 – Batching of bar test pieces: conventional tensile testing

Type of product	Nominal size (DN)	Batch size (max)
Centrifugally cast pipe	80 to 300	100 pipes
	350 to 800	40 pipes
	900 to 1600	10 pipes
Gravity cast pipe and fittings	all sizes	4 tonnes

or

- verification of mechanical properties by means of validated NDT inspection techniques on a 100% sampling basis, together with complementary tensile testing at a reduced sampling frequency (see Table 5).

The key microstructural features which govern the strength and ductility of ductile iron pipe are:

- graphite nodularity, which should be maximised through correct inoculation and nodularisation procedures during casting; and
- the hard and brittle matrix micro-constituents, pearlite and cementite, which must be controlled to acceptably low volume fractions by heat treatment.

**Table 5 – Batching of bar test pieces:
complementary tensile testing in conjunction
with 100% NDT inspection**

Type of product	Nominal size (DN)	Batch size (max)
Centrifugally cast pipe	80 to 300	1200 pipes
	350 to 800	480 pipes
	900 to 1600	120 pipes
Gravity cast pipe and fittings	all sizes	48 tonnes

The two NDT techniques which have been developed by UK pipe manufacturers for this microstructural assessment are:

- (a) ultrasonic inspection: this determines the degree of nodularity of the iron; and
- (b) eddy current inspection: this indicates the volume fraction of pearlite present in the matrix microstructure.

These systems are now in full operation in routine production in the UK, and are used to monitor the metal quality of centrifugally cast pipe.

Since neither ultrasonic nor eddy current inspection is able to identify the presence of the brittle phase cementite in the matrix microstructure, the standard requires that such inspection should be supplemented by other testing which is capable of doing so (e.g. microstructural examination, ring crush testing, etc.) at a frequency not less than that shown in Table 4.

Despite this limitation of the currently available methods, it is quite clear that the recent adoption of these NDT techniques by the UK manufacturers for routine inspection of centrifugally cast pipe represents a major step forward in ensuring, and demonstrating, that the requisite mechanical properties are consistently achieved in production.

5.2 Type test requirements

- Flange-to-pipe attachment – the revised standard BS 4772: 1988 has introduced quantitative performance requirements for evaluating the designs of welded and screwed pipe-to-flange attachments. The test essentially involves subjecting an assembled flange joint to a combination of internal pressure (equal to twice the nominal pressure rating of the flange) and an externally applied bending moment (equal to four times that due to the weight of the pipes and the water contained therein when the joint is positioned at the mid-point of a simply supported span of 8m for sizes up to DN 250, and 12m for sizes DN 300 and above). The joint must show no evidence of leakage or mechanical failure (other than some local permanent distortion in the area of the attachment) under this combined loading condition.

5.3 Metal quality checks (including non-standard methods)

- Hardness tests – BS 4772: 1988 requires that the quality of ductile iron castings shall be such that they can be cut, drilled, tapped and machined. If the purchaser considers that the castings do not comply with this requirement, BS 4772: 1988 recommends that the Brinell hardness of the castings concerned should be determined. The Brinell test should be carried out in accordance with BS 240, except that the period of load application should be 15 ± 1 seconds. Those centrifugally cast ductile iron pipes found to have Brinell hardnesses in excess of 230 HB, and other ductile iron castings with Brinell hardnesses greater than 250 HB, would be deemed not to comply with the requirements of the British Standard.
- Ring crush tests – although the tensile property and hardness determinations described above provide the purchaser with the means of establishing the quality of ductile iron castings after delivery, they require the use of specialised test equipment which may not be readily available to all Water Utilities.

A simple ring crush test has therefore been proposed for use within the Water Industry on those occasions when doubt arises regarding pipe metal quality, and a decision must be reached quickly on whether to continue with pipeline installation. This test is based on measurement of the extent to which a ring section from an undamaged length of the pipe concerned can be crushed diametrically before fracture occurs. Such a test may be readily undertaken by Water Utilities, since it requires only the use of an uncalibrated press.

The proposed acceptance values of minimum diametrical deflection before fracture in the ring crush test are presented in Table 6. In the event that a pipe ring sample fails to meet the appropriate requirement in the ring crush test, it is imperative that the remainder of the pipe from which the ring sample was taken should be retained for the determination of the standard tensile properties of the pipe metal. In such cases, samples of undamaged metal from the pipe concerned should, as a matter of course, be submitted to the manufacturer for investigation and comment: note in particular that the pipe socket should be retained for inspection by the manufacturer (for identification purposes). If an independent evaluation of pipe metal tensile properties is also desired under such circumstances, WRc Swindon should be contacted for advice.

It must be emphasised that the standard tensile properties of the material (determined in accordance with the requirements of BS 4772: 1988 – see Table 3

above) will remain the final arbiters in all instances in which the quality of pipe metal is in dispute.

Table 6 – Ductile iron pipe ring crush test: proposed acceptance values of minimum diametrical deflection (squeeze) before fracture

Nominal size (DN)	Wall thickness (mm)	Minimum squeeze before fracture (mm)
100	>6.0	15
	≤6.0	20
150	>6.6	25
	≤6.6	45
200		60
250		80
300		100
350		120
400		140
450		160

Pipe ring sample to be cut perpendicular to the pipe axis: sides to be approximately parallel. A saw or disc cut finish is acceptable. Remove any cement mortar lining before testing.

Ring width 50 ±5mm; crushing rate 300mm/minute maximum.

Platen size to be not less than the flattened dimensions of the ring.

MANUFACTURING IMPERFECTIONS AND CASTING QUALITY

6.1 Types of imperfections and defects

Certain specific types of imperfections and defects can arise in centrifugally cast ductile iron pipes as a result of irregularities during manufacture. The principal types of manufacturing imperfections and defects observed in spun pipes are as follows:

(a) Imperfections

- Pits and pinholes (sometimes referred to as blow holes or honeycombing) – are shallow cavities on the external surface of the pipe.

Pinholes are roughly circular cavities with diameters of the order of 1mm. Larger, more elongated surface cavities are referred to as pits.

- Laces – are thin ribbons of metal laid down as part of a spiral on the external surface of the pipe and may extend around more than half of the pipe circumference. The metal ribbon may be more or less separated from the surrounding pipe metal.

- Laps – are formed on the pipe surface as a result of incomplete fusion between successive layers of metal laid down during the casting process. Laps are usually shallow and can be associated with slight surface depressions which are readily visible on uncoated pipes.

(b) Defects

- Draws (or hot tears) – are oxidised cracks in the spun pipe wall. These may be produced during contraction of the pipe in the mould, or if excessive force is inadvertently applied to extract a pipe from the mould while it is still hot and in a low-strength condition.
- Cracks – can be produced as a result of impact damage to the pipe when it is in its low toughness condition after casting but prior to heat treatment.

6.2 Acceptance of casting imperfections

It is recognised that certain types of casting imperfections which can be encountered in spun ductile iron pipes (e.g. pinholes, laces and laps) are acceptable provided that they are of reasonably small size and are limited in number. Furthermore, for pits and pinholes, it has been established by both accelerated corrosion tests in the laboratory and burial trials that the incidence and rate of corrosion at such imperfections are no greater than elsewhere on the pipe surface.

On the basis of these observations and practical experience, the maximum permissible depths of surface imperfections on ductile iron pipes and fittings have for the first time been quantified in BS 4772: 1988. These limits are shown in Table 7.

Table 7 – Maximum depths of surface imperfections

Class K9 centrifugally cast pipes (DN)	Wall thickness (e) of other classes of pipe and fittings (mm)	Maximum depth of surface imperfections (mm)
80 to 200	$6 \leq e \leq 6.5$	1.75
250 to 600	$6.5 < e \leq 10.0$	2.0
700 to 900	$10.0 < e \leq 13.0$	3.0
1000 to 1200	$13.0 < e \leq 15.5$	4.0
1400	$15.5 < e \leq 17.5$	4.5
1600	$e > 17.5$	5.0

NOTE: The standard permits the maximum depth of surface imperfection to be greater where the actual wall thickness exceeds the nominal value specified in the standard, by an amount equal to that difference.

Practical difficulties however precluded the quantification of the maximum permissible number, density and surface area of such imperfections in the revised standard. These details (as well as the depth limits shown above in Table 7) were previously the subject of a specific agreement between the former National Water Council Standing Technical Committee on Sewers and Water Mains (superseded by the WAA and subsequently WSA/FWR Sewers and Water Mains Committee) and the manufacturers. In this agreement, the permissible number, density and surface area of imperfections were indicated by means of reference pictorial standards. Until such time as it becomes possible to quantify these particular details in a format suitable for incorporation in a British Standard, the former agreement will remain in force. As previously, these supplementary requirements to BS 4772: 1988 will continue to be subject to BSI quality assurance supervision, which will be carried out in conjunction with the existing BS 4772 Kitemark surveillance scheme for spun ductile iron pipe.

BS 4772: 1988 permits the rectification of minor imperfections on ductile iron pipes and fittings by simple dressing.

6.3 Rectification of defects

Defects such as cracks and tears are specifically excluded from repair by BS 4772: 1988.

The revised BS 4772: 1988 now permits the use of welding procedures, agreed between the purchaser and manufacturer, for the rectification, in the factory, of certain defects (other than cracks or tears) in ductile iron pipes and fittings which would otherwise be the cause for pipe rejection. This technique is based on experience gained on the performance of ductile iron pipes with welded-on flanges. Tests on welds carried out in accordance with the currently proposed procedure on ductile iron pipe materials have demonstrated that the strength of the weld meets the requirements of BS 4772: 1988 for the parent metal, and that the weld exhibits satisfactory corrosion resistance under accelerated corrosion test conditions.

The present agreement permits the weld rectification of defects in accordance with the proposed procedure on pipes DN 600 and larger.

7. CORROSION PREVENTION

7.1 Internal

The bore surface of ductile iron pipe can be corroded by certain raw and potable waters. This may result in the internal tuberculation of the pipe, with a consequent loss of hydraulic capacity and dirty water problems. In order to minimise bore surface corrosion, it is essential that all ductile iron pipes and fittings should be internally protected with a suitable lining. In this respect, it is important to consider the effects of any future changes in the water conveyed by the system when specifying the internal protection to be applied to new ductile iron water mains pipe (particularly where a change from a non-

aggressive supply to a more corrosive water is likely). For potable water applications, the lining material should have approval from the Department of the Environment Committee on Chemicals and Materials of Construction for use in Public Water Supply and Swimming Pools (DoE-CCM).

- (a) Bituminous coatings – these were developed for the internal protection of iron pipes to replace the original coal tar coatings which are now unacceptable for applications involving contact with potable water. Two types of bitumen coating are permitted by BS 4772: 1988, i.e. a cold-applied grade complying with the requirements of BS 3416: 1988 and a hot-applied grade complying with the requirements of BS 4147 for Type I material. One of the new features in BS 4772: 1988 is that the standard now specifies the thickness requirements for bitumen coatings; the mean thickness must not be less than 70 μ m, and the minimum thickness measured at any point must not be less than 50 μ m. However, bituminous coatings of these thicknesses do not provide a complete barrier layer, owing to the large number of through-thickness defects (holidays) which are inevitable with such thin coatings.
- (b) Cement mortar linings – afford a better degree of protection against the internal corrosion of ductile iron pipelines than is achieved with conventional bituminous coatings. The cement mortar lining provides an alkaline environment adjacent to the pipe bore surface which effectively inhibits corrosion attack, thereby preventing internal tuberculation and hence minimising any losses in hydraulic capacity. An advantage of this lining is that it is self-healing: small cracks and defects in the cement mortar lining may become bridged by the precipitation of calcium salts (autogenous healing). Cement mortar lined iron pipes have now been in service for periods of up to 50 years in the UK, with no significant evidence of lining deterioration leading to attack on the iron pipe substrate.

The range of cements which may be used for lining ductile iron pipes and fittings has been extended in the revised standard BS 4772: 1988 to include Portland pulverised-fuel ash cement in accordance with BS 6588 (with a minimum PFA content of 25%). The other cements which may be used for this purpose remain as previously, i.e. ordinary Portland Cement in accordance with BS 12, or Portland blast furnace cement to BS 146: Part 2, or a sulphate-resisting Portland cement complying with BS 4027.

Both sulphate-resisting cement to BS 4027 and Portland pulverised-fuel ash cement to BS

6588 are generally considered suitable for the majority of pipeline installations which require the cement mortar lining to be sulphate-resisting. Guidance should be sought where an installation requires a lining with a higher level of sulphate resistance than that provided by BS 4027 or BS 6588 cements. One source of information on the sulphate resistance of cements is Building Research Establishment Digest 250⁽³⁾. For applications involving the conveyance of sewage, the type of cement used for lining should be selected on the basis of the quality of sewage to be conveyed, and may require acid resistance, sulphate resistance and/or other properties.

The revised standard requires that the cement mortar mix used for lining pipes and fittings should consist of at least one part of cement to 2.5 parts sand (by mass). The cement mortar mix may be applied to the internal surface of the pipe either centrifugally or through a centrifugal applicator head, the latter being standard practice in UK manufacturing plants; fittings should be internally lined with cement mortar by any method which produces a lining comparable to that obtained on pipes.

The cement mortar lining thickness requirements in BS 4772: 1988 are shown in Table 8.

Table 8 – Cement mortar lining thicknesses, maximum crack widths and radial displacements for ductile iron pipes and fittings

Nominal size (DN)	Thickness (mm)			Maximum crack width and maximum radial displacement (mm)
	Nominal	Minimum arithmetical mean value	Individual minimum	
80	5	3.5	2.5	0.8
100 – 600	5	4.5	3.5	1.2
700 – 1200	6	5.5	4.5	1.5
1400 – 2000	9	8.0	7.0	2.0

The thickness of the cement mortar lining is measured at each end of the pipe in at least one section perpendicular to the pipe axis. At each section, which for pipes DN 200 and greater shall be at least 200mm from the pipe end, measurements of thickness are taken in four places spaced at 90° intervals. The arithmetical mean value and the individual minimum values of the four measurements in each section shall not be less than those specified in Table 8 above.

The revised standard also now specifies the minimum clear bores of cement mortar lined pipe, for sizes up to and including DN 200; these are shown in Table 9.

In cases of dispute, the bore clearance would be checked using a 10mm thick flat disc gauge of the appropriate diameter given in Table 9.

An attempt has been made in BS 4772: 1988 to quantify the limits of ridging, corrugations and other surface defects which are acceptable in cement mortar linings. The basic principle adopted is that such features should not reduce the lining thickness

Table 9 – Minimum bore clearance of cement mortar lined pipe

Nominal size (DN)	Minimum bore of cement mortar lined pipe (mm)
80	65.5
100	87.0
150	138.5
200	188.5

to values less than the appropriate individual minimum thickness noted above in Table 8. Where linings on large diameter (i.e. \geq DN 900) pipe are smoothed by trowel, the revised standard now requires that the peak-to-trough height of any ridges so formed should be less than $(0.008P + 0.3)$ mm, where P is the pitch (spacing) between consecutive peaks (in mm). This criterion has been adopted with the aim of ensuring that the Hazen-Williams hydraulic roughness coefficient (C-value) of such lined pipe does not fall below 143.

The revised standard permits the presence of shrinkage cracks in dry finished linings, provided they do not affect the stability of the lining, and

provided that their widths and any radial displacements at such cracks do not exceed the limits given in Table 8 above. In this respect, experience has shown that cracks in linings due to pipe expansion or mortar shrinkage tend to close on continuous exposure to water, and substantially heal by an autogenous process. In a similar fashion, areas of disbonded linings tend to swell and retighten on continuous exposure to water. Apart from this, the lining surface should be substantially free from laitance, but fine crazing and hair-line cracks associated with cement-rich surfaces are permitted.

Unsealed cement mortar linings can give rise to problems of lime leaching and consequent high pH levels in supply when conveying soft (i.e. low alkalinity) water, particularly where residence times are lengthy, e.g. in dead end sections of small diameter mains. Research into the performance of in situ relined pipes has indicated that such problems may become appreciable where conveyed water alkalinities are below 35mg/l. Whilst there is some evi-

dence that pH increases in conveyed waters caused by contact with factory-lined pipe may be marginally smaller than those recorded for in situ applied linings, for a given water quality, the magnitude of this effect has not been fully quantified and is currently under investigation. What is clear is that factory-lined pipe can still give rise to this problem. Pending the results of current research, it would be prudent to consider the above guideline value where cement mortar lined ductile iron pipes are likely to be used for conveying low alkalinity (soft) waters. Elevated pH levels in supply associated with lime leaching from unsealed cement mortar linings are transient, but can last for many months (in some cases, years) after commissioning, dependent on conveyed water alkalinity. The risk of very high pH levels in supply can be reduced substantially, certainly in the short term, by the application of a coating (typically bituminous paint) to the bore of lined pipe. There is, however, some historical evidence that the adhesion of conventional thin bituminous seal coats to spun (centrifuged) cement mortar linings can deteriorate with time, leading to localised flaking and exposure of the lining, although the levels of lime leaching associated with this are likely to be small. Research is currently in progress to assess the durability and performance of current bituminous seal coats on centrifugally applied cement mortar linings.

7.2 External

External corrosion of buried iron mains occurs by an aqueous electrochemical mechanism. In terms of corrosivity, the precise environmental conditions experienced by a buried main can range from atmospheric to fully immersed, depending on the degree of soil compaction and its moisture content. In general, wet clay is more corrosive than a well-drained sandy soil. Furthermore, the heterogeneous nature of soils can give rise to different areas of the pipe surface being exposed to different soil environments. This can result in the generation of microscopic and/or macroscopic differential concentration cells along the pipe, which can exacerbate localised corrosive attack (pitting).

This is thought to be a particular problem where clay is used for backfilling the pipe trench. Large clay clods can take up to 15 years to fully reconsolidate after pipe laying. During this period, differential aeration cells may be generated along the pipe surface between areas in contact with the clay and areas where no contact occurs due to soil bridging: this can produce intense pitting of the pipe in those areas in contact with the clay. Rapid corrosion of iron pipes also occurs in made-up soils containing ashes, clinker, domestic refuse, industrial waste and chemical effluents. Microbiological attack of buried iron mains can take place under anaerobic conditions, e.g. in permanently waterlogged soils, due to the action of sulphate-reducing bacteria. The problem of external corrosion attack on unprotected ductile iron pipe has been reviewed comprehensively by WRC⁽¹⁾.

Soil resistivity is generally acknowledged to be the most convenient and reliable single indicator of the corrosivity of soils towards buried iron mains.

Experience in the UK has shown that, in general, soils exhibiting resistivities less than 40ohm.m (4000ohm.cm) are potentially corrosive towards mains having only the standard, works-applied coating.

Of the other parameters which have been used to supplement the assessment of corrosivity based on soil resistivity measurements, moisture content appears to be the most useful. Since soil resistivity and moisture content are inevitably interrelated, it is clear that the resistivity (and hence corrosivity) of a soil may exhibit seasonal variations due to changes in water table level, etc. Thus, soil resistivity determinations carried out on a single occasion may not necessarily identify all of the potentially corrosive areas along the line of a main.

It must also be recognised that these measures alone will not necessarily identify the presence of other potentially corrosive pipe backfill materials, such as made-up ground, soils containing coal measure products, ash or clinker, waste materials or otherwise contaminated soil. The presence of such materials may only be identified from soil maps, historic records of site usage, local knowledge, existing site investigations reports and/or trial hole sampling and analysis.

It is clearly advisable that all ductile iron pipes and fittings should be adequately protected against external corrosion. When specifying the external protection system for a buried iron main, consideration should be given to the effects of any foreseeable changes in the soil environment which may arise in the future, e.g. due to changes in the soil drainage, effects of highway construction, etc.

(a) Zinc coatings

The revised standard BS 4772: 1988 now requires that all new ductile iron pipes in the size range DN 80 to DN 800 must be supplied with a coating of sprayed zinc metal (130g/m² mean) sealed with a layer of a conventional bituminous paint on all external surfaces, as illustrated schematically in Figure 2. The specification for the zinc metal coating system has been developed from (but is more demanding than) the corresponding International Standard, ISO 8179.

Whilst sprayed zinc metal coatings are not currently available as standard on larger diameter (i.e. \geq DN 900) ductile iron pipes manufactured in the UK, due to plant limitations, zinc-rich paint can be provided at the purchaser's request. This should be specified in accordance with the requirements of ISO 8179.

It has been clearly demonstrated^(4,5,6) that the metallic zinc coating system can protect areas of coating damage by itself corroding sacrificially, provided that the damaged areas are not too large. However, the sacrificial

protection to damaged areas may be regarded as of limited duration, particularly in aggressive soil environments and where coating damage is extensive. Furthermore, current evidence⁽⁴⁾ indicates that the zinc-rich paint is not as effective as metallic zinc with respect to the sacrificial protection of coating damage sites. Consequently, it is recommended that all new ductile iron mains should be protected by PE sleeving prior to burial⁽⁷⁾, in order to ensure that durable protection is afforded.

(b) Bituminous coatings

This is the standard form of external protection applied to all ductile iron pipes and fittings. BS 4772: 1988 identifies two grades for this purpose: a cold-applied grade conforming with the specification given in BS 3416: 1988, and a hot-applied grade complying with the requirements in BS 4147 for Type I material. As noted above, BS 4772: 1988 now specifies the minimum thickness requirements for such bituminous coatings; these are a mean value of 70 μ m, and a minimum of 50 μ m.

However, bituminous coatings of these thicknesses do not provide a complete barrier layer, owing to the large numbers of through-thickness defects (holidays) which are inevitable with such thin coatings. Whilst such bitumen coatings are primarily intended to prevent atmospheric corrosion of iron pipes and fittings in the stockyard, they can provide a limited degree of protection against corrosion in certain less aggressive soils, e.g. well drained sandy soils. In corrosive soils, additional external protection is essential to ensure satisfactory service lives.

(c) Polyethylene (PE) sleeving

Correctly applied, loose PE sleeving is a simple and inexpensive technique which can significantly reduce the risk of external corrosion failure on buried ductile iron mains in most naturally occurring soils in the UK. Although not intended to be an air-and water-tight enclosure, the PE sleeving should prevent contact between the pipe and surrounding backfill. The mechanism of corrosion protection afforded by PE sleeving has been discussed in a WRc Report⁽⁷⁾ which includes a summary of field experience with PE sleeved iron pipes. The performance of correctly applied loose PE sleeving has more recently been demonstrated in a series of pipe exhumations in the USA⁽⁸⁾. There it was found that sleeved pipes laid in a range of corrosive soils for up to 28 years had suffered negligible levels of external corrosion attack.

PE sleeving film for on-site application should conform with the requirements in BS 6076. Blue coloured PE sleeving should be used for wrapping potable water mains: black PE sleeving should be used for all other appli-

cations. The nominal PE sleeving thickness currently recommended for all pipe diameters is 225 \pm 25 μ m.

Operational guidelines for the site application of loose PE sleeving are given in IGN No. 4-50-01; an illustrated booklet on the site sleeving procedure is also available for pipe laying crews⁽⁹⁾. Although research suggests that small tears, rips and punctures could be tolerated in the sleeving provided that no contact occurs between the soil and the pipe surface, it is recommended that **all** sleeving damage should be repaired before pipe laying, e.g. with plastic tape for smaller defects, or with an additional layer of film taped over larger areas of damage. It is further recommended that adjoining sections on the pipeline should not be electrically bonded, as this may stimulate galvanic corrosion at any areas of bare metal, e.g. ground spigot surfaces. Care should be taken with backfilling PE sleeved pipe to prevent damage to the film. The backfill should be free of cinders, refuse, large rocks and sharp stones, and any other materials which could damage the PE sleeve.

(d) Site-applied PE sleeving – problems

The effectiveness of PE sleeving as a long-term corrosion protection system can however be compromised by certain errors which must be guarded against during site application and installation, i.e.

- entrapment of soil between the sleeving and pipe surface;
- accidental sleeving damage;
- poor application of the sleeving such that large gaps remain between the sleeving and pipe surface, and/or poor sealing of the sleeving such that groundwater is able to flow through the annulus between the sleeving and pipe surface. (In this respect it should be noted that corrosion attack under PE sleeving can only be sustained if a supply of fresh corrodent (e.g. oxygenated or acidic groundwater) to the pipe surface is maintained.)

The small number of external corrosion failures which have been reported on PE sleeved, **bitumen** coated ductile iron mains in the UK have generally been attributed to at least one of the above factors⁽¹⁰⁾. The combination of zinc coating and PE sleeving will improve this situation, and in particular will reduce the risk of problems associated with soil entrapment and sleeving damage.

Both the zinc coating and PE sleeving systems, either separately or in combination, can, however, fail if the pipe surface becomes exposed to flowing (ground)water, since this provides an effectively unlimited supply of fresh corrodent to sustain the corrosion reaction. This highlights the importance of correct

sleeving application and installation, and the need to avoid damage to the sleeving at all stages.

It follows that the standard protection system of zinc coating plus PE sleeving may not be sufficiently robust to provide adequate corrosion protection in:

- soils containing relatively large (e.g. >30mm size) hard and sharp edged objects, e.g. clay soils containing large flints, some shaley soils, etc. which may damage the sleeving (unless the pipe is to be bedded and surrounded in suitable selected/imported backfill);
- contaminated soils⁽¹¹⁾ where for example ash, clinker, domestic and/or industrial refuse may be present, (again, unless the pipe is to be bedded and surrounded in suitable selected/imported backfill); and
- where there is a risk of stray (interference) currents from adjacent impressed current cathodic protection systems, DC railway operations, etc. The potential risk of corrosion arising from such causes needs to be assessed through liaison with operators of impressed current CP/DC traction systems in the vicinity of the proposed pipeline. Guidance on interaction testing for impressed current CP systems is given in BS CP 1021. In cases of doubt, expert guidance should be sought.

Furthermore, where the quality of site-applied sleeving cannot be assured or may be uncertain (e.g. due to limitations of available supervision), the combined system may also be at risk in:

- highly acidic ($\text{pH} \leq 5$) soils and alkaline ($\text{pH} \geq 9$) soils;
 - soils where the water table level is either intermittently or continuously above the pipe invert (e.g. peat marsh, salt marsh, waterlogged heavy clays and alluvial soils), particularly if the groundwater conductivity is greater than about $10^4 \mu\text{S}/\text{cm}$ (i.e. resistivity $< 100 \text{ohm.cm}$) and/or its chloride content is greater than about 300ppm; and
 - situations where the pipe trench may act as a drain for groundwater.
- (e) Factory-applied PE sleeving

A recent development in the UK has been the introduction of factory-applied PE sleeving. Factory application of PE sleeving ensures that the sleeving material is wrapped tightly and uniformly over the pipe barrel. In addition, the problem of soil entrapment associated with the site-application of sleeving is virtually eliminated. Factory application of PE sleeving

should improve the reliability of the combined zinc coating/PE sleeving protection system, provided that steps are taken to minimise the risk and extent of sleeving damage during transportation, handling and laying, and provided that all damage incurred is properly repaired prior to pipe burial. The importance of correct on-site joint protection should not however be overlooked. Guidance on these aspects is given in IGN No. 4-50-02. A specification for factory-applied PE sleeving is under development.

Both site-sleeved and factory-sleeved pipe may however fail in any of the soil environments mentioned above where there is also a high risk of sleeving damage due to interference after installation. In any of the risk situations described above, consideration should be given to the specification (albeit at extra cost) of more sophisticated external corrosion protection measures.

Polyethylene sleeving (either site-applied or factory-applied) is NOT recommended for use in conjunction with cathodic protection systems for buried iron pipelines.

7.3 Special corrosion protection systems

In applications where bitumen or cement mortar linings would be unsuitable for the internal protection of ductile iron pipelines, polymeric materials (such as epoxy resins) may offer a suitable alternative. Such alternatives may be used within the scope of section 3 of BS 4772: 1988, subject to agreement between the purchaser and manufacturer.

Other more sophisticated external corrosion protection measures may be necessary in certain soils (see above). A range of alternatives is offered by the manufacturers for such applications, including reinforced bitumen sheathing, high performance polymeric coatings (e.g. fusion-bonded thermosetting resins (epoxy, polyurethane; typically 400 – 1000 μm thick) or sintered thermoplastic coatings (e.g. polyethylene; typically 1 – 3mm thick)), and tape wrappings. There will be occasions when it will be necessary to use these in conjunction with a correctly designed, installed and maintained cathodic protection system. The purchaser is then left with a choice which balances the cost of coating with that of cathodic protection and the prevailing conditions. Clearly, high level coating and pipelaying specifications and practices giving holiday (defect) -free coatings would certainly result in lower protective current demands (impressed current systems) or longer anode lives (sacrificial anode systems), and would influence subsequent maintenance costs. Whilst the cathodic protection of ductile iron pipelines is technically feasible, conventional CP systems may be impracticable for certain applications, e.g. for small diameter distribution mains laid

in congested urban areas. The long-term effectiveness of some of the joint overbonding systems which are available for providing electrical continuity on ductile iron mains with rubber gasketed joints can depend critically on the skill of the installer and the level of site supervision, which should also be taken into consideration at the design stage. Lastly, but by no means least, the adoption of CP as a corrosion protection measure necessarily involves a long-term commitment to the provision of adequate resources for monitoring and maintaining the performance of the system, and therefore may be either financially or operationally unattractive.

8. JOINTS

Two basic types of joints are available for ductile iron pipes and fittings, i.e.:

- (a) Spigot and socket type joints with flexible elastomeric sealing rings. Push-fit joints are commonly used for buried ductile iron pipelines due to their ease of assembly and reliability. Spigot and socket joints with flexible rings can accommodate small angular deflections in the pipeline, and also some longitudinal movement. Ductile iron pipes and fittings are also available with bolted gland joints, which offer similar joint flexibilities. Buried pipelines with such joints will therefore tolerate limited ground movements. However, unrestrained bends and tees require anchorage to resist the longitudinal forces experienced by pipelines under pressure.

Mechanically-anchored spigot and socket joints are also available. The excellent combination of strength and ductility of ductile iron pipes and fittings has permitted the development of flexible sealing rings with moulded-in toothed metal inserts which can be used to convert a standard spigot and socket joint into a self-anchoring joint (these are currently available for pipes up to and including DN 400). Anchored push-in joints of the tie-bar type are available in the full size range DN 80 to DN 1600. The end-load resistance of anchored flexible joint types is not however covered by BS 4772: 1988.

- (b) Flanged joints sealed with a flexible elastomeric gasket. These are mainly recommended for "above ground" applications and for the installation of valves, etc. in spigot and socket jointed pipelines.

BS 4772: 1988 recommends the use of bolts to BS 4190 grade 4.6 (minimum) and washers to BS 4190. Consideration may need to be given to the protection of these bolts against corrosion, or the use of alternative bolt materials e.g. stainless steel.

Elastomeric gaskets for both spigot and socket (flexible) joints and flanged (rigid) joints should meet the requirements of BS 2494: 1986 and, for water mains applications, must be suitable for use in contact with potable water.

Gaskets for flanged joints should conform with the dimensional requirements of BS 4865 Part 1. Reference should also be made to IGN No. 4-40-01 which discusses the selection, properties, storage and installation requirements for elastomeric seals and sealing rings.

9. FITTINGS

BS 4772: 1988 now defines fittings in two groups, i.e.:

- Group I fittings, which are those detailed in the tables of the standard; and
- Group II fittings, which are those manufactured in compliance with the requirements of the standard for mechanical properties, tolerances on dimensions and mass, coatings and linings, manufacturers' certificates and marking, but which differ from those detailed in the tables of the standard in respect of the type of fitting, e.g. angle branches and crosses, thickness class, hydraulic working pressure rating, laying lengths or combinations of nominal sizes.

A wide range of Group I and Group II socketted and flanged ductile iron fittings is available.

One long-term future development reflected in the revised standard is the introduction of a comprehensive range of socketted and flanged "Unified Design" fittings, in parallel with the existing fittings of conventional design specified in previous editions of BS 4772. The "Unified Design" approach has been introduced to enable manufacturers to achieve greater efficiency and economy in production by basing standard fittings designs on a minimum number of component parts of foundry tackle. The introduction of such Unified Design fittings will, of necessity, be phased in over a number of years.

Ductile iron pipes and fittings are manufactured in metric dimensions in accordance with the specifications in BS 4772: 1988. Various adapters are available for joining metric size ductile iron pipe to existing imperial size pipe, i.e.:

- (i) Double spigot change piece;
- (ii) Spigot and socket change piece plus metric collar;
- (iii) Double socket change collar. The use of a double socket collar is only recommended where the differential force produced by internal pressure is insufficient to produce movement of the collar.

10. CONNECTIONS

Normal tapping methods and machines are suitable for making service connections on to ductile iron mains, provided that certain precautions are observed, i.e.:

- (a) For service connections sealed directly into the wall of a ductile iron main, the diameter of the service connection hole should not exceed one-sixth of the nominal main diameter. Where an external seal is to be used, the diameter of the service connection hole should not exceed a quarter of the nominal main diameter. Where the diameter of the connection exceeds a quarter of the nominal main diameter, a drilled and tapped collar of suitable design should be used.
- (b) The drill should be sharp and accurately shaped. Hardened drill bits should be used when drilling into cement mortar lined ductile iron mains.
- (c) The drill should be fed gradually without overtightening the drill feed screw.
- (d) When drilling cement mortar lined pipes, the rate of feed should be reduced and the drill speed increased immediately the drill penetrates into the lining. Lubrication of the drill with water is also recommended while drilling through the cement mortar lining.
- (e) The service connection should not be overtightened if it is threaded directly into the iron mains pipe.

When making service connections to a PE sleeved ductile iron main, it is essential to repair any damage to the film caused by the tapping machine and to protect all exposed metal surfaces at the connection by the application of waterproof wrapping tape. For underpressure tapping of PE sleeved ductile iron mains, sufficient area of the sleeving film must be cut away so that the tapping machine can be located directly onto the pipe surface, in order to effect a satisfactory pressure-tight seal. Further guidance on these aspects is given in IGN Nos. 4-50-01 and 4-50-02.

Service connections to iron mains are conventionally made using copper alloy (e.g. gunmetal) ferrules. In addition, some use continues to be made of copper tube for new service connections in certain areas, although MDPE pipe now generally predominates for this application, principally due to its lower cost.

The direct attachment of a copper service connection (i.e. copper alloy ferrule with or without a copper service pipe) to an iron main introduces the risk of stimulating galvanic corrosion attack on the iron pipe by the electrochemically more noble copper service. This risk will be less where MDPE is used for the communication pipe since, in this case, the galvanic couple is limited to the small area of copper alloy ferrule attached to a relatively large area of iron pipe.

In order to minimise the risk of galvanic corrosion action on the external surface of the iron pipe, it is essential to protect all the exposed surfaces of the ferrule, after installation, using a suitable waterproof wrapping tape in accordance with the guidance in IGN Nos. 4-50-01 and 4-50-02, as appropriate. Alternatively, the ferrule may be electrically isolated

from the main using a suitable insulating piece. For similar reasons, where copper tube is to be used for making service connections to uninsulated copper alloy ferrules on iron mains, plastic coated tube should be specified, or alternatively bare copper tube should be protected by wrapping with a suitable waterproof tape. After installation, it is equally important to protect any remaining areas of exposed metal on the service line (e.g. areas of coating cutback at the ends of coated copper tube), again using a suitable waterproof wrapping tape (see IGN Nos. 4-50-01 and 4-50-02).

Whilst there is also a potential risk of galvanic corrosion attack on the internal surface of an iron main where copper service lines are used, there have been no incidents of internal attack leading to failure on iron mains in the UK which have been attributed to this cause. Furthermore, the risk of this occurring is considered to be negligible where MDPE is used for the communication pipe, owing to the relatively small ratio of ferrule to pipe bore surface area.

11. HANDLING AND LAYING

The excellent strength and ductility of ductile iron pipes and fittings render them considerably less liable to damage and fracture during transportation, handling and laying than grey iron castings. Ductile iron pipes and fittings must nevertheless be handled and laid with care in order to minimise damage to the internal and external corrosion protection systems, and also to prevent damage to the joint faces. The backfill used for buried mains should not contain large stones, sharp rocks or other materials which could damage the external coating of the pipe, and should be compacted according to the recommended procedure.

Guidance on general pipelaying practice is given in the British Standard Code of Practice BS 8010 Pipelines, Part 1: Pipelines on land: general; specific recommendations on laying ductile iron pipelines are given in BS 8010, Part 2, Section 2.1: 1987.

12. RECOMMENDATIONS

It is recommended that water undertakings specifying ductile iron pipes and fittings should, as far as possible, require them to comply with the requirements of the latest version of BS 4772 or equivalent standards.

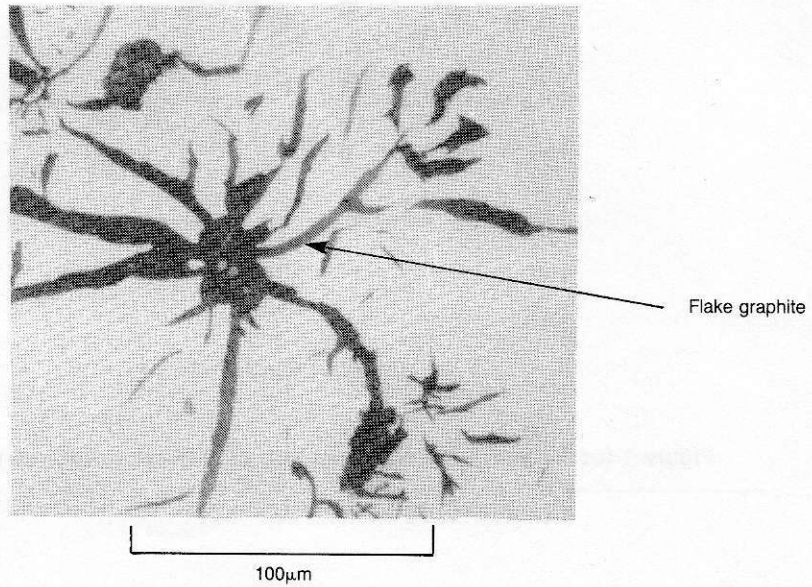
It is further recommended that:

- (a) Ductile iron pipes and fittings for water mains applications should be purchased with a cement mortar lining.

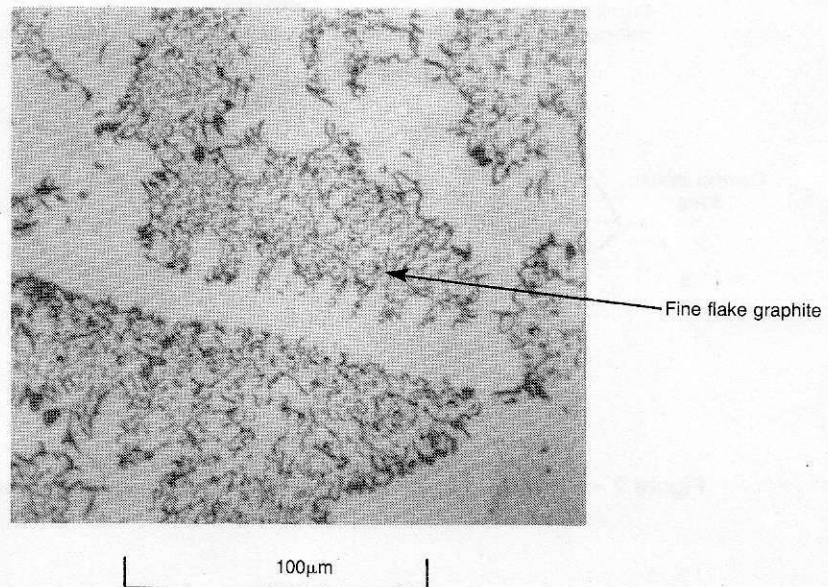
- (b) All ductile iron pipes and fittings should be protected with PE sleeving as a minimum, prior to burial according to the recommended procedure.

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- BS 2494: 1986 Materials for elastomeric joint rings for pipework and pipelines.
- BS 3416: 1988 Bitumen-based coatings for cold application suitable for use in contact with potable water.
- BS 4027: 1980 Sulphate-resisting Portland cement.
- BS 4147: 1980 Hot applied bitumen-based coating for ferrous products. Metric units.
- BS 4190 ISO metric black hexagon bolts, screws and nuts.
- BS 4772: 1988 Ductile iron pipes and fittings.
- BS 4865: 1989 Dimensions of gaskets for flanges to BS 4504
Part 1: Specification for non-metallic flat gaskets (including gaskets for flanges to BS 4772).
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- BS 6588: 1985 Portland pulverised-fuel ash cement.
- BS 8010 Code of practice for pipelines
Part 1: 1988 Pipelines on land: general
Part 2: 1987 Section 2.1 Ductile iron
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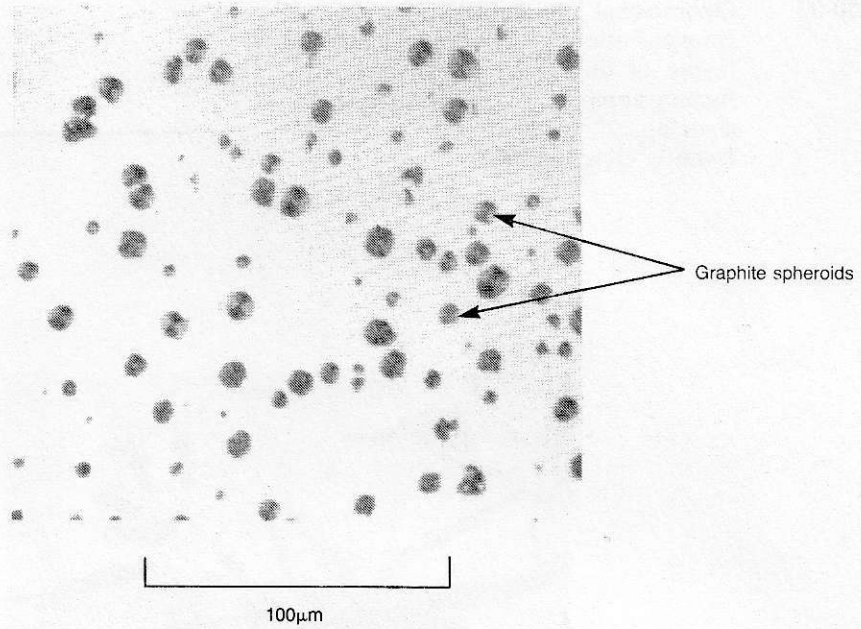


(a) Vertically cast grey iron



Metal spun grey iron

Figure 1 – Typical cast iron pipe microstructures (as polished)



(c) Spun ductile iron

Figure 1 (continued) – Typical cast iron pipe microstructures (as polished)

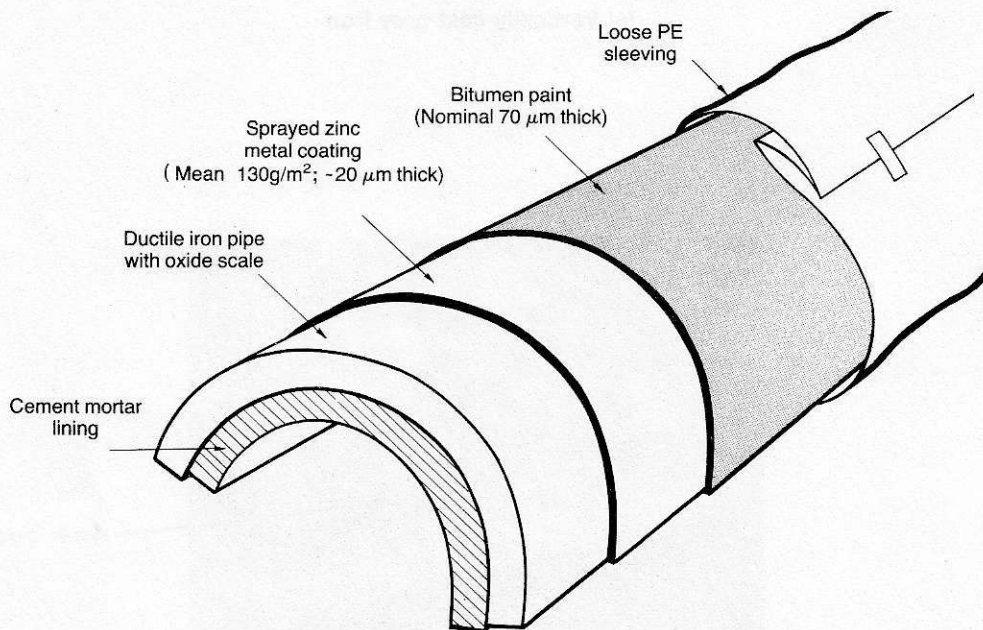


Figure 2 – Ductile iron pipe: corrosion protection systems (not to scale)