WHITE, R.T., and DULIGAL, E.A. Performance of buried 3CR12 pipes in various environments. *INFACON 6. Proceedings of the 1st International Chromium Steel and Alloys Congress, Cape Town.* Volume 2. Johannesburg, SAIMM, 1992. pp. 179–184.

Performance of Buried 3CR12 Pipes in Various Soil Environments

R.T. WHITE* and E.A. DULIGAL†
**Middelburg Steel & Alloys, Sandton, South Africa*
†Duligal & Associates, Clubview, South Africa

In 1988 a five-year sub-soil exposure programme was commissioned by MS&A on the suitability of 3CR12 for buried pipelines. The pipelines were to be used for the carriage of potable water, the objectives of the study being merely to determine the exterior corrosion resistance of 3CR12 in various soil backfills.

This paper reports on the results of two inspections, one in the PWV area and one in the Durban area. Many municipalities are facing costly replacements of cast-iron and wrought carbon-steel pipes owing to exterior corrosion. It can be shown that bare 3CR12 can be used in buried applications provided that a number of simple rules are adhered to. These include the provision of a relatively inert (biologically) free-draining backfill and proper pickling and passivation of fabricated areas.

The use of exterior linings is briefly reported, and a cost appraisal of the various options for buried pipelines is presented. The cost-effective nature of using a corrosion-resistant material can clearly be justified when an installation is used until eventual destruction. This is more often than not the case with buried pipelines, where recovery and excavation tend to occur only when leaks are noticed.

Introduction

Corrosion failures of underground water pipes is becoming a major problem in South African cities. Many failures in buried pipes are attributed to external attack, the corrosivity of the soil systems being held responsible for the attack[1]. Some municipalities have made extensive use of asbestos-cement pipes, but this material is subject to mechanical damage as a result of ground movement.

The use of 3CR12 as a replacement for coated mild-steel and cast-iron piping was considered as early as 1985. However, a lack of data on the performance of 3CR12 in buried service precluded advice on the use of the material. With this in mind, a comprehensive test programme was started using 3CR12 pipe sections inserted into existing buried water-supply installations. In addition, insulated coupon racks containing 304, 316, 317L, and 3CR12 were buried in close proximity to the pipes.

Methodology

After consultations with a number of municipalities, several test sites were chosen that were considered to represent a cross-section of likely buried conditions encountered in South Africa. These test sites are shown in Table I.

The pipes were, in general, spirally welded 3CR12 that had been fully pickled and passivated by the supplier. A small number of pipes were coated in order to assess the viability and costs associated with coating. The quality assurance for the coating systems is covered elsewhere[2]. The pipes were laid in trenches according to whatever procedure each municipality uses. In brief, no special precautions were taken. Samples of the various backfill soils were taken for analysis, and the condition of the burial site was noted at the time of burial (Table II).

Results

Pipe Inspections

To date, inspections have been carried out in Johannesburg, Roodepoort, Pretoria, and Durban. The Caledon site will be inspected when arrangements can be made. Pipe inspections comprised excavation of the pipe and visual external inspection. Table III summarizes the results.

Where the pipes had been laid in dry or well-drained conditions, no corrosion was noted. This accounted for eight of the eleven sites inspected. The excellent condition of the 3CR12 pipe at Westlake Road in Roodepoort is shown in Figure 1. Three of the buried pipes showed surface staining. These were at Attie and Ninth Streets in Pretoria and at City Deep in Johannesburg. At the time of burial at City Deep, the trench was recorded as being wet. The conditions at Attie and Ninth Streets at the time of pipe burial are unknown. However, the black turf soil of Ninth Street was considered to be corrosive by Pretoria City Engineers. In all the cases of surface staining, the stain was caused either by the precipitation of calcium salts as at Ninth Street, or simply by adhering deposits from the soil such as iron silicates. Although no soil potential or resistivity measurements were taken, it can be assumed that the pipe would provide a common earth ground path. Thus, variations in soil potential could result in the deposition of salts from the soil onto the

TABLE I
DETAILS OF TEST SITE LOCATIONS

Test site	Pipe information	Use
Durban		
Pinkney Reservoir	4 m longitudinal welded 300NB; 4,5 mm t*; ends coated	Potable water
Nerissa Road	6 m spirally welded 100NB; 3 mm t*; ends coated	Potable water
Anstey's Beach	6 m spirally welded 100NB; 3 mm t*; ends coated	Potable water
Harrison Drive	4 m spirally welded 100NB; 3 mm t*; ends coated	Potable water
Nugget Road	4 m spirally welded 100NB; 3 mm t*; ends coated	Potable water
Roodepoort		
Westlake Road	6 m spirally welded 300NB; 4,5 mm t* – bare – coated with epoxy powder – coated with solvent-free epoxy – medium-duty tape wrap – heavy-duty tape wrap	Potable water
Johannesburg		
Pretorius Street	6 m spirally welded 300NB; 3,5 mm t*; flanged and ends coated	Potable water
City Deep	6 m spirally welded 250NB; 3,5 mm t*; flanged and ends coated	Potable water
Pretoria		
Attie Street, Booysens	6 m spirally welded 100NB; 3 mm t*; flanged	Potable water
Ninth Street, Gezina West	2 of 6 m spirally welded 100NB; 3 mm t*; flanged	Potable water
Buitekant Street	6 m spirally welded 500NB; class 12; ends coated	Recycled sewage water
Caledon		
Ruensveld Rural Water Supply Scheme	5 m spirally welded 80NB; 3 mm t*; flanged and ends coated	Potable water

* t = wall thickness

TABLE II
BURIAL DETAILS

Test site	Soil type/backfill	Chemical analysis*	Backfill depth, m	Comments
Durban				
Pinkney Reservoir	Loam/sandstone, some red clay	pH 6,1; Cl^- 142; SO_4 189; sol. salts 670	2	Buried in dry conditions in well-drained soil
Nerissa Road	Red bluff sand	pH 7; Cl^- 14; SO_4 24; sol. salts 1630	1,2	Buried in dry conditions in well-drained soil
Anstey's Beach	Beach sand	pH 7,1; Cl^- 21; SO_4 35; sol. salts 1660	1,2	Buried in dry conditions in well-drained soil
Harrison Drive	Berea sand/some silt with Umgeni River sand as backfill	Berea sand pH 7,1; Cl^- 57; SO_4 86; sol. salts 2440 Backfill pH 7,5; Cl^- 14; SO_4 32; sol. salts 2490	1	Buried in dry conditions, virgin soil, well-compacted and damp
Nugget Road	Yellow shale, rather clayey mixed with sand	pH 6,9; Cl^- 14; SO_4 34; sol. salts 1130	1	Buried in dry conditions, returned soil very clayey
Roodepoort				
Westlake Road, Roodepoort	Red sandy silt over clay substrate	pH 10; Cl^- 20; SO_4 40; sol. salts 275	1	Buried in dry conditions, but problems arose with insulation from CP system
Johannesburg				
Pretorius Street, Oaklands	Red sandy soil	Analysis not taken	1	Buried in dry conditions in well-drained soil
City Deep	Mine-dump sand	N/A	2	Buried in dry conditions but trench wet
Pretoria				
Attie Street, Booysens	Sandy/stoney soil	N/A	1	Burial conditions not known
Ninth Street, Gezina West	Black turf mixed with sand	pH 6,7; Cl^- 45; SO_4 40; sol. salts > 200	1	Soil conditions considered to be corrosive
Buitekant Street	Mixed black soil/yellow clay/shale/ash. Backfill: power-station ash	Soil pH 6,4; Cl^- 45; SO_4 n.d.; S^2 65; sol. salts > 200 Backfill: pH 8,3; Cl^- 20; SO_4 80; S^2 10; sol. salts > 500	1 1	Trench dug in clay but, at time of installation, backfill given as ash, sand, and clay
Caledon				
Ruensveld Rural Water Supply Scheme	Clay/shale	pH 6,5; Cl^- 30; SO_4 40; conductance 240 S/cm	1	Dept of Water Affairs describes area as Bokkeveld Shale with salty vleis

TABLE III
SUMMARY OF INSPECTIONS

Test site	Material	Results
Durban		
Pinkney Reservoir	3CR12	Pipe in good condition. Some surface lamination noted (suspected skin lamination)
Nerissa Road	3CR12	Excellent condition
Anstey's Beach	3CR12	Localized pitting/etching, one area to perforation
Harrison Drive	3CR12	Localized pitting/etching. Crevice attack through coating at coupling
Nugget Road	3CR12	Excellent condition
Roodepoort		
Westlake Road	3CR12 pipe	Excellent condition
	Epoxy powder	No defects
	Solvent-free epoxy	Delamination, poor adhesion, some corrosion
	Medium-duty tape wrap	Some mechanical damage to tape, but no other defects
	Heavy-duty tape wrap	As for medium-duty
Johannesburg		
Pretorius Street	3CR12	Excellent condition
City Deep	3CR12	Slight staining, but no measurable corrosion
Pretoria		
Attie Street	3CR12	Staining by soil only
Ninth Street	3CR12	Tenacious calcareous deposit, but no corrosion
Buitekant Street	3CR12	Random pitting on top surface. Etched appearance. No defects at painted ends. New backfill applied

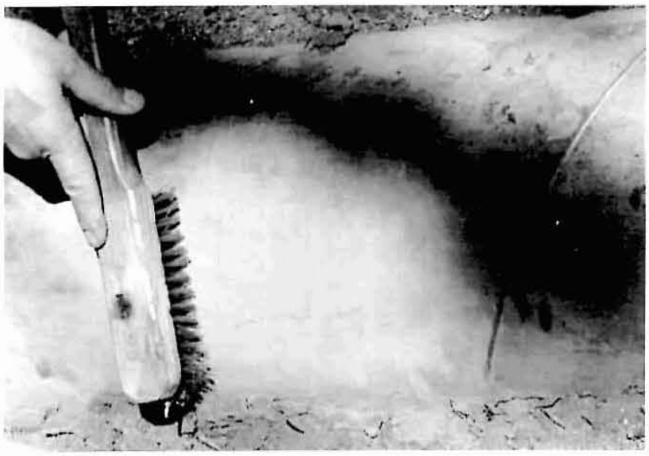

FIGURE 1. Bare 3CR12, Westlake Road, Roodepoort

pipe. It is unlikely that calcareous deposits would cause accelerated corrosion of 3CR12.

Where the 3CR12 pipes showed attack, only two forms of corrosion could be identified. The first is crevice attack, noted at three sites: Anstey's Beach, Harrison Drive, and Buitekant Street. Similarly, at these sites surface etching with deep, pitted areas was noted. The soil conditions at Anstey's Beach and Harrison Drive were originally given as sandy but, on closer inspection it was clear that major clay fractions existed. Thus, anaerobic conditions could be encountered. At Buitekant Street, the power-station ash backfill was shown to be high in sulphide residue. All soils can be considered to be organically active since they provide a home for a host of organisms, and the above three sites can be considered to contain sulphate-reducing bacteria (SRB). Micro-biologically induced corrosion (MIC) as a result of SRB is a well-documented phenomenon. The presence of SRB is inferred from the soil analysis at Buitekant Street (Table II). Unfortunately, at Anstey's Beach and Harrison Drive, the presence of SRB was more difficult to prove.

A laboratory examination of the pits from the pipe removed from Anstey's Beach showed the growth of the pits to follow the rolling direction and to be fibrous in nature. At the coated ends of the pipe where attack had occurred, the coating flaked off to reveal a black corrosion product. Figure 2 shows typical energy-dispersive spectra taken from the inside of the pits. A characteristic feature of these spectra is the presence of large amounts of sulphur and the total absence of chlorides. The presence of a black corrosion product together with large amounts of sulphur inside the pits is indicative of MIC. It would certainly appear as if both the apparent crevice attack under the coated ends of these pipes and the etched pitting on the bare surface is the result of MIC. The pitting attack on the Anstey's Beach pipe is shown in Figure 3. The directionality of the attack is clearly evident.

Coupon-test Results

The inspection comments on the coupons are shown in Table IV. It can clearly be seen that the austenitic stainless steels 304L, 316L, and 317L all performed satisfactorily. This has been borne out by other studies[3]. However, although beyond the scope of this work, local experience has shown that 316 stainless-steel pipes can suffer MIC under certain conditions such as sewage-saturated soils, clayey soils, or generally aggressive anaerobic conditions.

The coupon-test results for 3CR12 could be misleading if used to predict the performance of a 3CR12 pipe. At a number of sites (Nugget Road, Pretorius Street, and Ninth Street), the 3CR12 coupons showed that localized attack was likely despite 6 m lengths of pipe being free of corrosion. Conversely, attack at the sheared-edge area of pipes at Anstey's Beach and Buitekant Street was slight, despite severe pitting attack on the pipes.

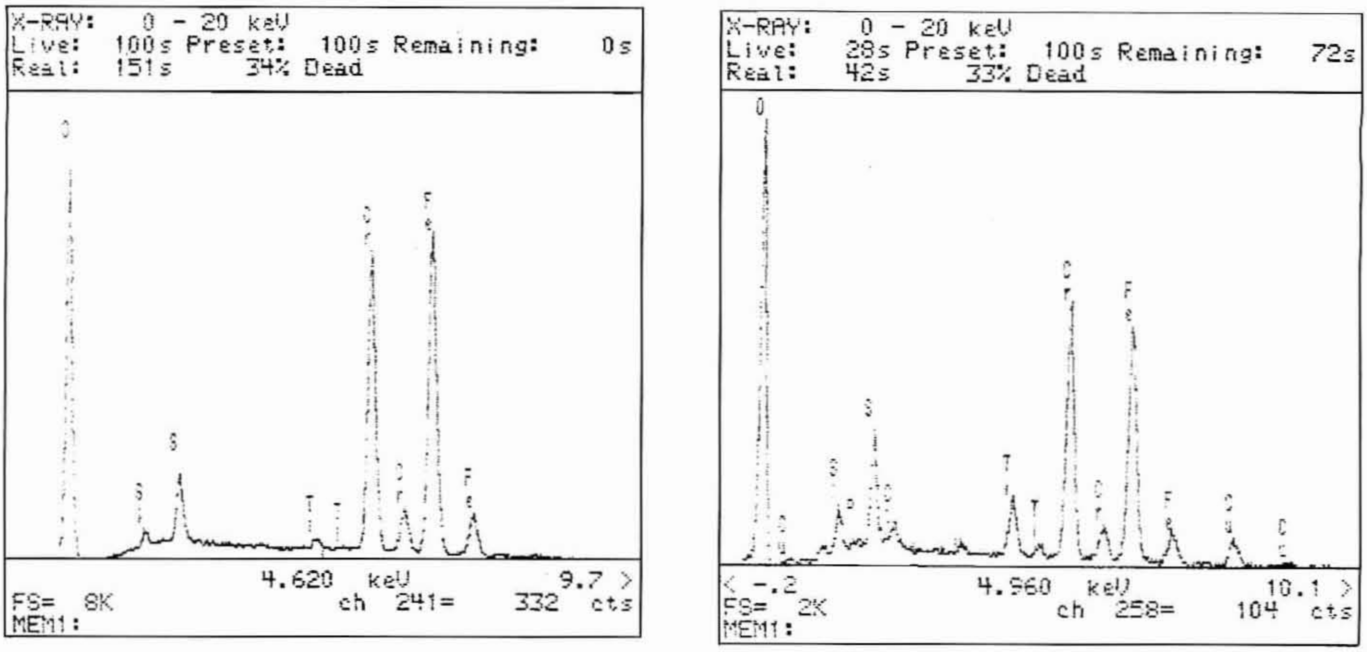

FIGURE 2. Energy-dispersive spectra of the corrosion product at the base of two pits. The high sulphur level should be noted

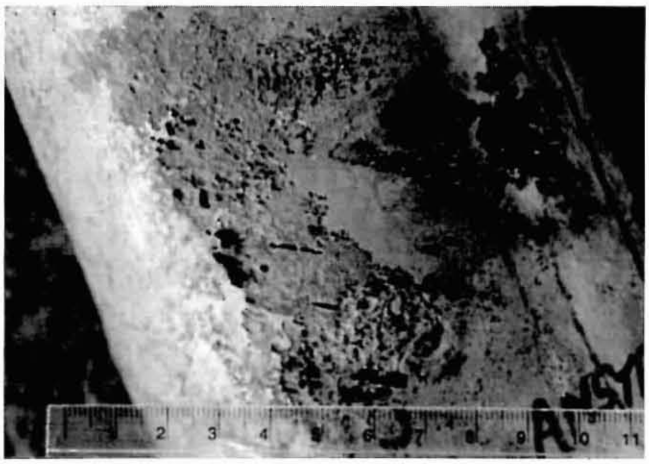
FIGURE 3. Area of corrosion on pipe, showing the parallel direction of the pitted areas

Coating-test Results

Coatings were tried at one site only. In general, provided that adhesion parameters are met, the corrosion resistance of a coating depends upon its chemical resistance. The coating of epoxy powder performed excellently, but the solvent-free epoxy coating delaminated from the substrate and provided a crevice environment where some attack of the 3CR12 occurred. Both tape-wrap systems were in good condition.

Discussion

General

The corrosion attack on 3CR12 as noted in these studies deserves highlighting. In many instances, the coupons showed edge attack. In fact, pipes at six of the sites showed attack at the sheared edge. It may be considered that the duplex structure of 3CR12 results in a banded structure in the final rolled product. Many instances have been reported of incorrect guillotining, where shear break has occurred. This phenomenon and the way to avoid it is well illustrated in the 3CR12 fabrication guide[4]. During the shearing process, a portion of the material is actually cut, followed by a breaking of the remaining cut face. This can cause microscopic opening of the broken area of the face, which, should corrosive attack be likely, will provide sites for pitting attack. This attack is clearly shown in Figure 4. It can be argued that this makes 3CR12 coupons more prone to attack than fabricated products where the edges are not exposed. It is contended that this is really the case only in MIC, where attack can be seen to follow the rolling direction as noted.

However, some further work will be needed to confirm these observations. It will be necessary to retrieve a pipe suffering from proposed MIC and return it to the laboratory within 24 to 48 hours so that the presence of SRB in the pits can be identified. In addition, redox measurements will be taken at sites suffering and not suffering from proposed MIC to see if the 200mV criterion is met[3]. In conclusion, it can be assumed that, as the pitting attack on the pipes and coupons follows the rolling direction, the banded nature of 3CR12 causes MIC to follow the line of least resistance, i.e. to be intergranular in nature. This is shown in Figure 5.

Some concern is expressed when coupon extrapolations are used in predictions of the life of a buried pipe. In general, predictions based on 3CR12 coupons tend to over-estimate the performance of 3CR12, discounting the sheared-edge attack outlined above. This could be due to the size of a pipe when compared with the small area of a coupon available for attack. Local microscopic variations in conditions along the length of a pipe that could contain aggressive situations could be missed in a coupon survey.

Performance Criteria

In an assessment of the performance of materials that rely upon the presence of a passive film in order to preserve their corrosion resistance, it is not relevant to note general material wastage with time. Local attack may affect only a small proportion of the product but nevertheless render its

TABLE IV
COUPON CORROSION

Test site	Material	Coupon results	Pipe
Durban			
Pinkney Reservoir	304L, 316L, 3CR12	All coupons OK	Some areas of delamination noted in 3CR12. No corrosion attack
Nerissa Road	Coupons	Lost	Good condition
Anstey's Beach	304L, 317L, 316L, 3CR12	All coupons OK, except 3CR12. Pitted at sheared edge	3CR12 pipe pitted and failed
Harrison Drive	304L, 317L, 316L, 3CR12	Slight discoloration of 3CR12. Some edge attack. Other coupons OK	Crevice attack at end. Some pitting
Nugget Road	304L, 316L, 3CR12	304L and 316L untouched. 3CR12 had two pits on one surface. Attack at sheared edge	3CR12 pipe in good condition
Roodepoort			
Westlake Road	304L, 316L, 317L, 3CR12	All coupons OK	Bare pipe in good condition
Johannesburg			
Pretorius Street	304L, 316L, 317L, 3CR12	Some crevice attack on 3CR12	Pipe in good condition
City Deep	Coupons	Lost	Pipe in good condition
Pretoria			
Attie Street	Coupons	Lost	Pipe in good condition
Ninth Street	304L, 316L, 317L, 3CR12	Severe attack on sheared edge of 3CR12, and crevice attack of 3CR12, and crevice attack at point of holder	No corrosion, but severe salt deposition
Buitekant Street	304L, 316L, 317L 3CR12	Slight attack starting at edge of 3CR12. All coupons showed iron staining	Pitting attack on crown of pipe

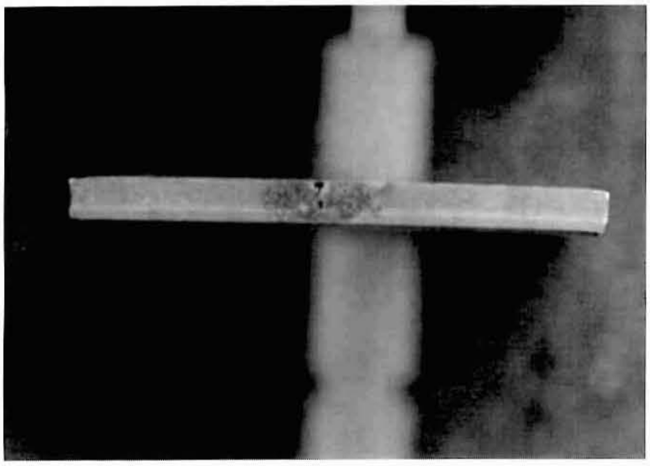

FIGURE 4. Corrosion on the sheared edge of a 3CR12 coupon from Anstey's Beach

continued service impossible. This may certainly be considered to be the case with 3CR12 buried pipelines. Thus, any exposure site that has resulted in localized attack must be viewed with suspicion. As described above, only in three cases can the performance of 3CR12 be viewed as poor. In these cases, the soil contained clay or, in the case of Buitekant Street, unsuitable backfill. It can clearly be argued that 3CR12 is acceptable as a piping material provided that proper backfilling conditions are met. While

FIGURE 5. Cross-section of a pit, showing the intergranular nature of the attack

many municipalities argue that they do backfill correctly, many do not have a standard written procedure. It is recommended that a standard such as SABS 1200 Class B[5] should be used. This specifies that a well-drained backfill be used, and lays down the pipe-laying details such as the bottom of the pipe should be above the base of the trench.

To obtain a lifetime of 20 to 25 years, which is a minimum in these applications, a first cost comparison needs to be made. Table V shows the relative costs of piping materials as supplied by various municipalities. While an initial comparison does not favour 3CR12, a number of points must be raised. Firstly, it was assumed that the cathodic-protection

TABLE V
INITIAL COST COMPARISONS (MILD STEEL = 100)

Material	Initial cost	Coating costs	Burial costs	Cathodic protection	Total cost
Mild steel	100	0	150	50	300
Mild steel, epoxy	100	110	150	50	410
Mild steel, tape	100	80	150	50	380
3CR12	300	0	150	N/A	450
3CR12 epoxy	300	110	150	N/A	560
Mild steel, tape	300	80	150	N/A	540

system is properly maintained throughout the life of the system. This is not always the case. Secondly, once a coated mild-steel line has to be replaced, the costs involved far exceed the initial costs of even a coated 3CR12 system. Finally, despite the 3-times initial cost of 3CR12 over carbon steel, only twice the life is needed to justify the usage of 3CR12 on a first-cost basis. In brief, although coated 3CR12 may not be justified in many instances, bare 3CR12 can offer a cost-effective solution in areas where mild steel may not have the required corrosion resistance.

Conclusions and Recommendations

This study has shown that MIC attack is the dominant cause of failure of buried 3CR12 pipes. In general, 3CR12 performs well where

(1) correct fabrication procedures have been followed
(2) the buried area is free-draining, eliminating the presence of stagnant water
(3) anaerobic conditions do not prevail for any significant length of time
(4) bacterial activity is minimized.

Burial conditions should therefore comply with SABS 1200.

In addition, 3CR12 coupons should not be used in tests on site-buried pipes. Pipe spools provide a better indicator of material performance. Finally, bare 3CR12 can provide a cost-effective alternative to mild steel (coated or uncoated), provided that the life expectancy is approximately double that of bare mild steel.

Acknowledgment

This paper is published by permission of MS&A Stainless (Pty) Ltd. The co-operation of the various municipalities involved in the survey is appreciated.

References

1. Jakobs, J.A., and Hewes, F.W. (1987). Underground corrosion of water pipes in Calgary, Canada. *Materials Performance,* May, pp. 42–49.
2. Duligal, E.A., White, R.T., and Ambrose, B.A. (1990). Investigation into the use of 3CR12 as a material for underground pipelines. 5th International Conference of the South African Corrosion Institute, Johannesburg.
3. Japanese Stainless Steel Association and Nickel Development Institute. (1988). A report on the performance of stainless steel pipe for water supply in underground soil environments.
4. MS&A Stainless (Pty) Ltd. (1990). *3CR12 fabrication guide.*
5. South African Bureau of Standards. (1983). *SABS 1200: Standardized specification for civil engineering construction,* LB: Bedding (pipes), p. 9.