

SP2 Report

On

**Survey and Review of Current Rehabilitation and Coating Technologies for
Many Entry Sewer Pipes and Manholes with Protective Coatings**

Part 2: COATING PERFORMANCE

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SUMMARY OF FINDINGS AND RECOMMENDATIONS

This review provides an overview of the performance of protective coating in sewer, specifically for application in large man entry pipes and manholes. This review followed the survey process used for decision tools used by the industry in the use of protective coatings.

State of Coating Systems

Two types of coating systems are used in protecting sewer pipes and related infrastructures against microbiologically induced corrosion; polymer and cement based coatings. Part of this coating system is the surface repair material and primers, which may be used by the asset owners if deemed required.

Among the polymer based coating the use of epoxy and epoxy based mortars has dominated the market. There appears to be three principal suppliers used by the water utilities surveyed today, Sika, Parchem and Hychem, but more recently Fernco has also began to enter the Australian market. Although polyurethane and polyurea have been used extensively in the UK and US, particularly in protecting water mains, there is little application of these coatings in Australia with the exception of utilities in Queensland where this is used extensively in rehabilitation of manholes. Previous trials have shown that polyurethane had difficulty in adhering to the moist concrete substrates, and since most rehabilitation works occur in live sewer environments, its use is limited. It appears there have been no other trials in the use of polyurea, although Sydney Water (SW) sees this as an emerging coating.

There are two types of cement based lining are currently used by the industry, calcium aluminate cement (CAC) and calcareous aggregate cement. Two types of CAC are currently supplied by Kerneos for sewer rehabilitation, Sewpercoat (40% Al_2O_3) and Sewperspray (16% Al_2O_3). The number of CAC supplier has increased to three in 2011. Previously the market was monopolised by Kerneos (previously known as Lafarge). Today two additional suppliers have entered the market BASF and Parchem, both supplying the equivalent of Sewpercoat.

Epoxy based coatings are currently applied only for the protection of sewer pipes and related infra-structure. Whereas cement based lining may be applied for both protection and to provide structural integrity to the corroding pipe. Calcareous aggregate cement is manufactured by incorporating limestone into OPC or high early cement and maybe supplied by Humes Cement.

Two types of surface repair material are currently used in the restoration of corroded pipes after cleaning, gunite and shotcrete, which are fast curing portland cements. These materials are essentially similar. Shotcrete is the trade name from BASF and is widely used because it was the first product of its kind. Gunite is a more generic

name. These are used in restoration because they are cheap and could be quickly and easily applied.

Primers are used concurrently with some coating applications, but its use is not consistent with all application. It appears the primers used are prescribed by the manufacturer and cross-using coating and primers from different manufacturers is currently not practiced. Although epoxy is known to be self priming, primers is usually required or recommended if significant amount of moisture is present on the concrete substrate. Most technical data sheets refer to the requirement of 'dry' conditions on the concrete prior to epoxy application. A more quantitative measure of the moisture content do not appear in all TDS, but some refer to the requirement of less than 5%.

Performance of Coatings

Epoxy

The performance of *epoxy coatings* is highly variable in the field and is characterised by various features including:

- Long-term resistance to biogenic acid attack

Lowering of the surface pH of the coatings with time indicates epoxy is not immune to microbiological growth and attack.

Some of the epoxy based coatings, however, are able to demonstrate reasonable performance and resistance to microbiological attack. Sikagard 63N/Sikadur 41 in SW showed good conditions after 15 years and Hychem TL5 in Melbourne Water sewer after 9 years of service. The performance is demonstrated through reasonable adhesion and their resistance to acid permeation. Hychem TL5 did show some localised delamination and blistering after 9 year.

- Premature failure (failure in less than 1 year occurring as delamination)

Most epoxy coatings, should they fail prematurely, do so by delamination. Various reasons were put forward for the possible causes of delamination including the coating being too thin (<5 mm) and is thus unable to provide sufficient resistance to the more aggressive sewer gas and the formation of pinholes during application. The use of thicker coatings (20 mm) however has been shown to delaminate and despite adhering to application instructions and holiday testing to avoid and detect pinholes, coatings were still observed to delaminate. Suggesting that other factors may also be contributing to the formation of these defects.

- Defects

After coating application and whilst it is in service, epoxy coating manifest various types of defects including blister formation, sagging, bulging, cracking, partial delamination (*peeling of a partial layer of coating*), full delamination (*peeling of the*

full layer of coating), softening and discolouration. The exact effect of all these defects, with the exception of delamination, on the coating performance and the remaining service life of the coating is unclear to the water utilities.

Cement Based Coatings

Calcium aluminate has been trialed by SW, Melbourne Water, SA Water and Barwon Waters, all with satisfactory results for various periods from 3-19 years. The tests carried out in Barwon Water covering 13 years of trial demonstrated that CAC lost only between 7-8 mm (or rates of 0.5-0.6 mm/yr) from the 50 mm initially installed in the highly corrosive environment (25ppm in winter and 65 ppm H₂S in summer). In SW, the installed Sewperspray lost only 4.5 mm in 15-16 years of service (or the rate of 0.3 mm/yr) in 3-5 ppm H₂S environment. Forecast based on a fitted diffusion controlled model, suggests that CAC under the same environment would lose less than 15 mm of the coating in 50 years. Thus the prescribed 50 mm thick CAC coating would suitably provide protective over this period. These results however need to consider the expansion and also the conversion of CAC with time. Testing in the more aggressive Virginia experimental sewer in South Africa, revealed a slow loss in material for the first 12 years 1-1.2 mm/yr, but this shifted to 1.9 mm/year between 12-14 years. This was attributed to the inevitable mineralogical conversion of CAC to its more reactive phase inducing faster corrosion in the long run. Conversion also results in increased porosity further enhancing the rates of corrosion.

CAC is subjected to the natural softening on its surface as a result of corrosion. However other forms of defects may also become evident after application or whilst the coating is in service and may include cement shrinkage, crazing, cracking and loss of cement strength and hardness. These are attributed to various factors including water:cement ratio, poor mixing, poor curing, conversion (natural mineralogical transformation of CAC to a more reactive phase) and exceeding the shelf life of the cement.

No performance data on *calcareous aggregate cement* was made available to this survey from the water utilities. Published literature suggests however that calcareous aggregate cement is able to extend the life of normal OPC by 2-5 times.

Surface repair material and primer

The coating system may also include surface repair materials and primers. Surface repair materials are used to fill in bug holes in the concrete after the removal of corrosion products and to create an even surface on which protective lining (e.g., epoxy) will be applied. Primers are used to promote better adhesion of polymeric coating on the concrete substrate.

Although surface repair materials are considered as coatings in the US, in Australia these are not considered to offer adequate protection against corrosion.

Primers appear to affect coating adhesion and the formation of blisters. In general, when used, primers appear to improve adhesion. However coatings that have been applied without primer have also been shown to have adequate adhesion. Thus its merit is difficult to judge without controlled testing. It should be noted that epoxy can act as self primer if the substrate is reasonably dry. The effect of primers on blister formation appears to be more consistent. The use of Sikadur 31 and 32 primers on Sikagard 63N/Sikadur 41 showed no blistering even after 15 years of service in SW. Whist Nitomortar ELS and Biocrete in SW and Hychem TL5 in Melbourne Water, which were applied without primers, showed blistering that increased in occurrence and size with time. Primer may therefore function as a sealer and/or modifier of the substrate surface, preventing undesired defects such as blistering in coatings. Again because there is very little known about blister formation, controlled testing is required to confirm the effect of primers on blister formation.

Structure of Review

The review is structured according to the following areas:

1. Review of current coating technologies
2. Coating Systems and Performance
 - i) Polymer
 - ii) Cement Based Coatings
 - iii) Primer and Surface Repair Materials

TABLE OF CONTENTS

SUMMARY OF FINDINGS AND RECOMMENDATIONS	2
STRUCTURE OF REVIEW	5
1.0 COATING SYSTEMS	7
1.1 POLYMER BASED COATINGS	7
1.2 EPOXY AND EPOXY MORTAR	7
1.2.1 <i>Application Methods</i>	10
1.2.2 <i>Coating Purpose</i>	10
1.2.3 <i>Thickness of Coating</i>	11
1.2.4 <i>Performance Assessment of Epoxy Coatings</i>	11
1.2.4.1 Long-term resistance to biogenic acid attack	12
1.2.4.2 Premature failure	12
1.2.4.3 Coating Defects	12
1.2.5 <i>Methods of Performance Assessment</i>	13
1.2.5.1 Visual examination	13
1.2.5.2 Core analysis	13
1.3 POLYURETHANE	14
3.3 POLYUREA	14
2.0 CEMENT BASED COATINGS	15
2.1 CALCIUM ALUMINATE CEMENT (CAC)	15
2.1.1 <i>Suppliers</i>	15
2.1.2 <i>Application</i>	15
2.1.3 <i>Performance Calcium Aluminate Cement (CAC) in Field Trials</i>	15
2.1.4 <i>CAC defects and degradation</i>	18
2.2 CALCAREOUS AGGREGATE CEMENT	19
2.2.1 <i>Performance of Calcareous Aggregate Cement</i>	19
3.0 SURFACE REPAIR MATERIALS	20
4.0 PRIMER/BONDING AGENT	20
4.1 PERFORMANCE OF PRIMERS	20
APPENDIX A. PERFORMANCE OF SPRAY AND TROWEL APPLIED COATINGS IN AUSTRALIAN SEWERS	23
(I) SYDNEY WATER	23
(II) MELBOURNE WATER	32
(III) SOUTH AUSTRALIA WATER	34

1.0 POLYMERIC COATING SYSTEMS

The linings that are used in protecting sewer pipes and related infra-structure are either cement or polymer based. Figure 1 shows the basic spray-on and/or trowelled applied coating technologies available today, including the surface repair material and primer that are often used in preparing the surface of the substrate prior to coating application. The use of surface repair and primer are optional (Sunarho 2012). In certain cases these may not be required or the industry may simply choose not to use them.

1.1 Coating System

A brief description of the various types of coatings is given below. The usage of these coatings in Australian water utilities and performance were collated from the industrial surveys and reports.

1.2 Epoxy and Epoxy Mortar

Epoxy and epoxy mortars are both thixotropic resin with high chemical resistance. Epoxy mortars are fabricated by incorporating fine particle sized inert aggregates in the epoxy. The aggregates added can vary from 10 to 90% by weight of the coating.

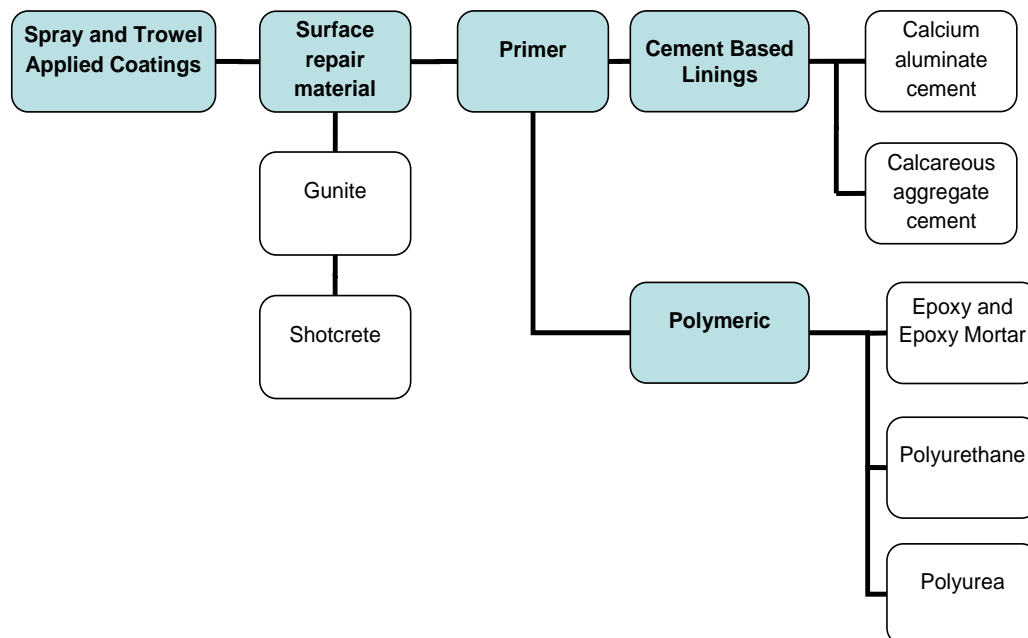


Figure 1. Spray and trowel applied coatings technologies for sewer protection

Prior to 2011, only three of the five industries surveyed appear to have used epoxy and epoxy mortar in the rehabilitation of sewer pipes, SW and Melbourne Water. It is likely that other major industries, for example Brisbane and Gold Coast Water also used epoxy and epoxy mortar, however these water utilities were non-participants in this survey. The list of coatings currently used by the water utilities are summarised in Table 2.

As shown in Table 2, each utility uses specific polymeric products and it appears there are no coating commonly used among the industries. Each industry uses a '*preferred material*' qualified by an in-house assessment process. More details on the industry qualification requirements specific to spray or trowelled coatings are provided in coating specification section of this report.

SW used both epoxy (e.g., Sikagard 63N) and epoxy mortars in their sewers (e.g., Sikadur 41)(Sydney-Water 2009). SW being the heaviest user of epoxy based lining materials (having lined ~20 km of pipeline because they have the most number of box tunnels) (Sydney-Water 2009) has also trialled the greatest number of lining materials. SW predominantly used Sika based coatings (Sikadur 41 +Sikagard 63N, Sikagard 62T) between 1992-early 2000, but from early 2000 till now, the predominant material has been Nitomortar ELS (supplied by Parchem) (SW Epoxy Projects, 2009). SW has used other numerous epoxy coatings from traditional coating suppliers including International, Jotun, Wattyl, PPG, Dulux and others, that have been used in sewer structures(Sunarho 2012). These have been applied at <2 mm thick. No performance data has been supplied for these coatings. Whilst Melbourne Water used epoxy coal tar for 30 years (1970-1999), thereafter it appear to have used only one type of polymeric lining material, Hychem TL5 (Wubben 1999, Connell Wagner, 2004).

The lack of common coatings means that only coating performances specific for each industry is available. General comparison to reflect performances in various corrosive conditions cannot be conducted in this survey.

Table 3 shows the emerging coatings being considered by SW. Other industries have not provided their list but have indicated they are open to submission from manufacturers.

Table 1. SW - Emerging Coatings

Polymer Based Coatings	Cement Based Coatings	Gel Based Coatings
A good polyurethane/polyurea coating	Calcium aluminate cement	Mg(OH) ₂ gel sulfalok

Table 1. Spray and Trowel Applied Coating Used by Water Utility Industries

Industries	Application	Coating System				Purpose
		Polymer	Cement/Sacrificial	Repair Substrate	Primer/Bonding Agent	
SW	Sewer pipes, manholes, treatment plants, pumping stations	Sikadur 31,41,42 Sikagard 62T, 63N Nitomortar ELS MBT Concessive Polyurethane/Polyurea	Biocrete, Sulfalok (Mg(OH) ₂), trialling Calcium aluminate cement	Yes	Yes, some but not all	Protection
Melbourne Water	Manholes	Coal Tar Epoxy (1970-1999) Hychem TL5	Calcium aluminate cement	Yes	NA	Protection
SA Water	Sewer pipes, Manholes	Polyurea	Calcium aluminate cement Calcareous aggregate cement	Yes	No	Protection/ Structural Reinforcement
Barwon Water	Manhole	NA	Calcium aluminate cement	Yes	NA	Protection
Water Corporation	Manholes	Sikagard EpoCem 75 (Considering other polymeric coatings)	Calcium aluminate cement	Yes	NA	Protection
	Air treatment facility	Sikagard 62T				Protection

1.2.1 Application Methods

Three inherent application features that are linked to coating performance are:

- i) Surface preparation
- ii) Method of application
- iii) Atmospheric conditions (temperature and humidity) of application

Surface Preparation

Because surface preparation is common to all types of coating application, this will be covered separately under the decision support system.

Method of application

Epoxy and epoxy mortar coatings are *applied* by brushing, trowelling and/or spraying. The application method is a specific property of the coating. That is some coatings can only be trowel applied. The method of application can influence the speed of application and cost, and thus this feature is often considered when coatings are selected. Spraying provide faster and ease of application and provides greater control in thickness. This in turn facilitates faster turn- around in getting the system back on line and overall may reduce the cost of application. As such spray applied linings that demonstrate suitable performance are often favoured by applicators and water utilities industries in comparison to coatings that must be trowel applied. Most applications in man-entry pipes and manholes for SW since 2000 and Melbourne since 1995 have primarily been applied by spraying (SW Epoxy Projects, 2009, Wubben 1999, Connell Wagner, 2004)

Temperature of application

Most coatings considered in this survey are applied at room temperature with the exception of Ultracoat S301 supplied by Fernco. This coating is applied at 60°C. The benefits or disadvantages of applying the epoxy at higher temperature have not been covered in this study.

1.2.2 Coating Purpose

The purpose of the coating for the water utilities, whether it is be for protection and/or to provide structural integrity to the failing pipes dictates the nature of the coatings selected (see Table 2).

Epoxy and epoxy mortars have in general been applied only for protective purpose. As such their ability to adhere to the substrate is an important feature in their performance.

SW has used epoxy/epoxy mortar preferentially in the repair and rehabilitation of non-circular man-entry sewer pipes and manholes. The use of epoxy for SW began in the protection of treatment plant and pumping stations, and this followed on to the

protection of sewer tunnel. Melbourne Water has only use the lining materials in repair and protection of manholes. Water Corporation is now considering the lining of their manholes with spray applied coatings.

1.2.3 Thickness of Coating

The thickness that must be applied has always been a contentious issue. In general most industries have observed that thinner polymer lining (< 5mm) are unable to provide adequate protection in the more aggressive conditions found in Australian sewers today (Wubbem , 1999, SW Survey response, 2009). Prior to 1992, Sydney Water applied < 2mm epoxy coatings. These have failed by delamination prematurely (< 2 years) despite claims from suppliers that these would last 10-15 years (SW Survey response, 2009). Since then SW have used various thicknesses, from 10-30 mm, with a preference for 20 mm thick linings (SW Epoxy Projects, 2009), however performance continue to be variable (see Appendix A for coating performance).

Melbourne Water applied 0.5-1.0 mm epoxy tar coating prior to 1999 on concrete surface of manholes and related structures, which performed well, but there after demonstrated significant deterioration over time because of increased aggressiveness of the gas environment (Wubben, 1999). Melbourne Waters began applying 3 mm and 5 mm thick Hychem TL5 in 1995. Condition assessment of these coating in 2004 revealed the thicker 5 mm coating, which was also one year younger than the 3 mm coating, provided better performance than the thinner coating (Connell Wagner, 2004). Both coatings were found to have suffered localised delamination and blisters, but the occurrence of defects in the 3 mm coating was greater than the 5 mm coating. An exceptional advantage for this particular coating is that it did not appear to have suffered from premature delamination. The report did not include concrete assessment so there is no indication if localised delamination resulted in concrete deterioration.

The thickness of coating that is appropriate for certain environmental conditions and that would provide required service life, whilst still providing the most economical option is still a difficult decision for water utility industries. SW has introduced a new qualification for determining the minimum thickness based on the epoxy content of the coating (AM SS204, 2009) based on research carried out at the University of Sydney. However, in general, there is still a strong general reliance on manufacturers to prescribe appropriate coating thickness.

1.2.4 Performance Assessment of Epoxy Coatings

The only assessments of epoxy based coatings were received from SW and Melbourne Water. Appendix A shows the list of polymeric coatings used by water utilities and their condition assessment over time. The list covers coating that have been applied since 1992 in SW and in Melbourne Water since 1995.

The performance of polymeric coatings has been observed to be characterised by one or more of the following features (see Appendix A):

- Long-term resistance to biogenic acid attack (*for some coatings only*)

- Premature failure (failure in less than 1 year occurring as delamination)
- Defects including pinholes, blisters formation, sagging, bulging, cracking, partial delamination, full delamination, softening and discolouration.

The following summarises the industry experience with respect to the above characteristics.

1.2.4.1 Long-term resistance to biogenic acid attack

It is apparent that polymeric coatings that are able to adhere show reasonable degree of performance. In SW this has been demonstrated by the Sika based coatings (Sikagard 63N/Sikadur 41) with 15 years of service (SW Epoxy Projects, 2009).

In Melbourne Waters, Hychem TL5, which was also applied as a thin coating (3, 5 mm) has been shown to perform as a protective coating for over 8-9 years. Earlier trials with high build epoxy and vinyl esters installed in the sewers also showed reasonable performance within the 3 year trial period (Wubben, 1999). Longer term performance was not available to this review. Trade names of the coatings were also withheld in the reports.

1.2.4.2 Premature failure

Premature defects will often occur in less than one year. Failure most often occur by delamination.

Coatings including Biocrete, Nitomortar ELS and Sikagard 62T showed premature failure by delamination and softening and were inundated by defects primarily the formation of blisters which grew in frequency with time (SW Epoxy Projects, 2009).

The industry has primarily attributed this form of failure to thin coatings (<5 mm) that are unable to provide sufficient resistance to greater aggressiveness of the sewer gas and to the formation of pinholes, resulting during the application of coating (Survey Response 2009). To avert the formation of pinholes, suppliers recommend the application of several layers of the coatings, each applied in opposite directions and some water utilities implement a holiday test after the installation of coatings as part of their QC to detect pinhole defects. The relative impact of such practices could not be established in this study because no reports documenting their effect were submitted in this survey.

1.2.4.3 Coating Defects

In general polymer based coatings degrade with service. The degradation often occurs as localised defect observed to result on edges, handrails, roofs, upper walls of pipes, and access holes to manholes. The degradation is manifested through defects including: i) softening or loss of hardness, ii) discolouration, iii) increased formation and size of blisters, iv) bulging and sagging of the coating and v) delamination (complete, localised spalling). The impact of microbiological attack on the coatings

are also characterised by the lowering of surface pH (~0-2) and permeation of acid through the coating.

1.2.5 Methods of Performance Assessment

Two approaches are used in the condition assessment of coatings. The first method, which has been the primary method used by the water utilities, is based on visual examination. The second more recent method is based on a destructive test involving coring of the coating and subjecting the coating to a series of chemical and physical testing.

1.2.5.1 Visual examination

Accurate assessment of epoxy conditions has challenged many water utility industries and this was attributed to lack of appropriate tools. Currently most water utilities and consultants use visual examination and tapping method to detect coating defects. Some consultants may also use hardness test. Unlike cement, which softens on corrosion accompanied by a significant drop in pH (<7.0), polymers tend to hold their structure. Its degradation or its failure to resist acid permeation is therefore difficult to detect by visual inspection alone. The lack of appropriate analytical tests to fully assess acid permeation and adhesion has hampered the ability of the industries to accurately compare coatings, assess the installation, monitor the stage of the coating and in general design suitable protective systems. At present the ability of the industries to design, monitor and maintain the polymeric based protective system has been challenged by two factors:

- i) The water utility industries do not have the technical understanding of the mechanism or factors that contributes to the formation of defects in the coatings (Survey Response 2009).
- ii) The industries cannot correlate the defects observed to the state of the coating or the substrate these coatings are protecting.

Although there is much conjecture primarily around the effect of environmental conditions (temperature, moisture, H₂S) on these defects, there is little fundamental understanding of the mechanism of coating deterioration. This is largely because of the dynamic nature of the deterioration that is difficult to capture unless monitored continuously. It is also difficult to decouple the effects of multiple factors that could affect coating deterioration including organism, surface preparation, application, environmental conditions, and the aging of coating that introduces its own chemical and mineralogical transformation with time.

1.2.5.2 Core analysis

SW and Water Corporation have begun the use of destructive method involving the coring of the coating and concrete substrate. A suite of tests are applied to the cores according to the recommendations of the Tender report on the assessment of epoxy conducted at Sydney University and may include (Valix 2008):

- Bond strength tests
- Surface pH
- Hardness
- Bioacid analysis
- Acid/water permeation
- FTIR (functional group analysis to examine polymeric breakdown)
- TGA/DSC (thermal degradation analysis to examine polymeric breakdown)

1.3 Polyurethane

This is a two-component poly-isocyanate formulation, which is known for its fast reactivity, resistance to moisture and excellent adherence to concrete and steel. Polyurethane is used widely in UK for lining pressurised water mains. (EPA/600/R-11/017). The advantage of polyurethane over epoxy is its rapid cure time (30 minutes). However adhesion, as is the case with epoxy, is dependent on the surface preparation of the substrates that requires surface dry condition and cleanliness, which can be a challenge for sewer environment. High build or thicker application have been developed as structural liner that is less dependent on a good bond (EPA/600/R-11/017). The first commercial product was introduced by E. Wood in the United Kingdom for the water market. This product was called Copon Hycote 169HB.

It appears that no polyurethane lining materials are used within the Australian water utilities today. SW trialled its use in lining sewers 1998 and it failed. The coating delaminated within hours because of the moisture present on the concrete substrate (SW Survey response, 2009). No further trials on sewers have been conducted since. This is mainly due to lack of understanding of the product characteristics. SW has trialled the Copon Hycote 169HB in 2008 (Valix. 2009, Valix. 2009) on water mains. This too has failed, failing to adhere, although other defects could be attributed to application problems.

A polyurethane that has been in the market called Polibrid 705E and supplied by International Protective Coatings has been used extensively in the US. International Protective Coatings has recently bought a licence to market it here in Australia. This uses a geotextile backing material, which the supplier claims allows the polyurethane to adhere to damp concrete, as long as there is no condensation on the surface (Polibrid TDS). This coating is currently being tested under the SP2 program of the ARC Odour and Corrosion project.

1.3 Polyurea

Polyurea also belongs to the poly-isocyanate family of spray on polymers. It is finding acceptance for lining manholes, wet wells, and other structures exposed to corrosive environments. Its key advantage is its very rapid cure. With gel times of 5-40 seconds

and 80% cure in just 5 minutes. Structures can be returned to service 30 minutes after applying the polyurea. Full cure is achieved in 24 hours. It also has a good crack bridging ability (> 3mm). Polyurea has been applied in the UK and US both in the sewers and protection of fresh water pipes (EPA/600/R-11/017). However it appears that polyurea has had no application within the larger Australian water utilities, although they are popular among the smaller utilities (Sunarho 2012). SW is considering this as an emerging coating (SW Survey Response, 2009)

2.0 CEMENT BASED COATINGS

2.1 Calcium aluminate cement (CAC)

Calcium aluminate cement is a specialty cement principally made up of lime (C or CaO) and alumina (A or Al₂O₃). These components are reacted to generate calcium aluminates (CA or CaAl₂O₄). CAC is characterised by high strength, lower porosity in comparison to Portland cement and higher neutralisation capacity. These properties and the release of Al³⁺ ions, which are toxic to most organisms, have been proposed to provide the protective system for CAC against MIC (microbiologically induced corrosion). Calcium aluminate has been used widely as protective lining for internal surface of new steel/ductile iron sewer pipes. In late 1980s, it started to be used in Europe as a rehabilitation material and protective coating for existing sewer concrete assets, in particular manholes.

2.1.1 Suppliers

Prior to 2010, only Kerneos (previously traded under the name Lafarge) supplied CAC in Australia. It supplied two types of CAC that are intended for sewer rehabilitation purpose, Sewpercoat® (100% CAC or 40% Al₂O₃) and Sewperspray® (16% Al₂O₃). BASF entered the market in 2010 supplying a coating similar to Sewpercoat. More recently in 2011, Parchem acquired a licence from Kerneos to supply Sewpercoat in Australia.

2.1.2 Application

Being a cementitious product, CAC is applied using similar equipment to other ordinary cement material, including shotcreting machine. It can be applied wet and dry shotcrete. Some products have also been developed to be hand applied/trowelled and poured.

2.1.3 Performance Calcium Aluminate Cement (CAC) in Field Trials

SW first applied the CAC supplied by Lafarge Fondu Australia (Kerneos) in 1991-92 in SWSOOS 1, with the designated trade name RC 130, which was later known as Sewperspray®. RC 130 is a calcium aluminate cement product with silica sand aggregates. The applied product soon developed cracking/crazing after application, and hence it was not selected for further use. An inspection, however in 2007 revealed the CAC coating previously applied was still adhering well to the substrate i.e. no drummy area. Based on core sampling, it was estimated that the material loss rate was

around 0.3 mm/year (Sunarho 2012). That is within 15-16 years, approximately 4.5 mm of the coating has been lost out of the 50 mm previously applied. Further inspection of the 2007 SW CAC application in the SWSOOS 1 in 2010 appear to have performed well with only minor crazing and little loss of thickness (see Figure 2).

In the late 1990s, Kerneos developed calcium aluminate cement product that used calcium aluminate aggregates/clinker, with the designated trade name of Sewpercoat®. Around 2000, a small trial application was undertaken in SW in Herbert St, NSOOS. Unfortunately, there is no further information available about this trial or its field performance. In 2007, a site of SWSOOS2 North, adjacent to Hayden Place, was selected for a demonstration project for Sewpercoat. A larger project in BOOS (Bondi Ocean Outfall Sewer) followed in 2010 with the application of both CAC from Kerneos and BASF.

Barwon Waters have applied CAC in a trial project earlier in 1995 and only in manholes. It appears that SA Water have only recently applied CAC in their system in 2009.

Melbourne Water performed trial testing of Sewpercoat (100% CAC or 40% Al₂O₃) and Sewperspray (16% Al₂O₃) in 1995, supplied by then by Lafarge, to combat the rising corrosivity of the gas in its sewer (Wubben, 1999). Blocks of type D sulphate resistant concrete coated with CAC were installed in Melbourne Water Spotswood North Drop structure. This site is particularly aggressive with H₂S content of 25ppm in winter and 65 ppm in summer in addition to the chemical cocktail of domestic and industrial discharges. The performance of two types of CAC were compared with an experimental alternative mortar, UHB epoxy, vinyl ester, epoxy coal tar and water impermeable membrane (see Figure 3). Concrete blocks coated with water impermeable membrane showed 15 mm corrosion in 3 years and coal tar epoxy (0.5-1.0 mm) showed blistering in 18 months, which subsequently increased in occurrence and some bursts by 3 years resulting in 10 mm of concrete deterioration. Alternative experimental mortar also failed in 3 years. One of the UHB epoxy failed after 18 months, polyester failed in 3 years, the remaining UHB epoxy and vinyl esters were in satisfactory condition in 3 years. Sewpercoat and Sewperspray that were applied with 30 mm thickness showed minimal deterioration in 3 years. Sewpercoat deteriorated by 2mm and Sewperspray by 4 mm.

A parallel trial of Sewpercoat was carried out by Barwon Water (Wubben. 2008). The Corcon 2008 report on Sewpercoat CAC performance in Barwon water covered 13 years of service life (Wubben, 2008). The loss of thickness over this period is shown in Figure 4. Superimposed on this correlation is the prediction of over 50 years, assuming the loss of thickness over this period is dependent only on diffusion. The predictive model was determined and fitted to the thickness loss (x) and period of service (t) to the equation $x = k t^{0.5}$ with an R² of 0.96. It appears based on this prediction than in 10 years only 13.7 mm of the coating would be lost. That is 50 mm thick CAC would be able to provide protection over the 50 years service life of the



Figure 2. CAC Application Trial in SWSOOS 2007, SW showing minor crazing after 18-19 years of service, otherwise intact and in good conditions.



Sewpercoat, 3 years, 4 mm corrosion



Polyester, 3 years, flaking and cracking



Water impermeable membrane, 3 years, 15 mm corrosion



Epoxy coal tar, 3 years, blister, 10 mm concrete corrosion

Figure 3. Comparison of performance of coating systems in Melbourne Spotswood North Drop structure (Wubben 1999).

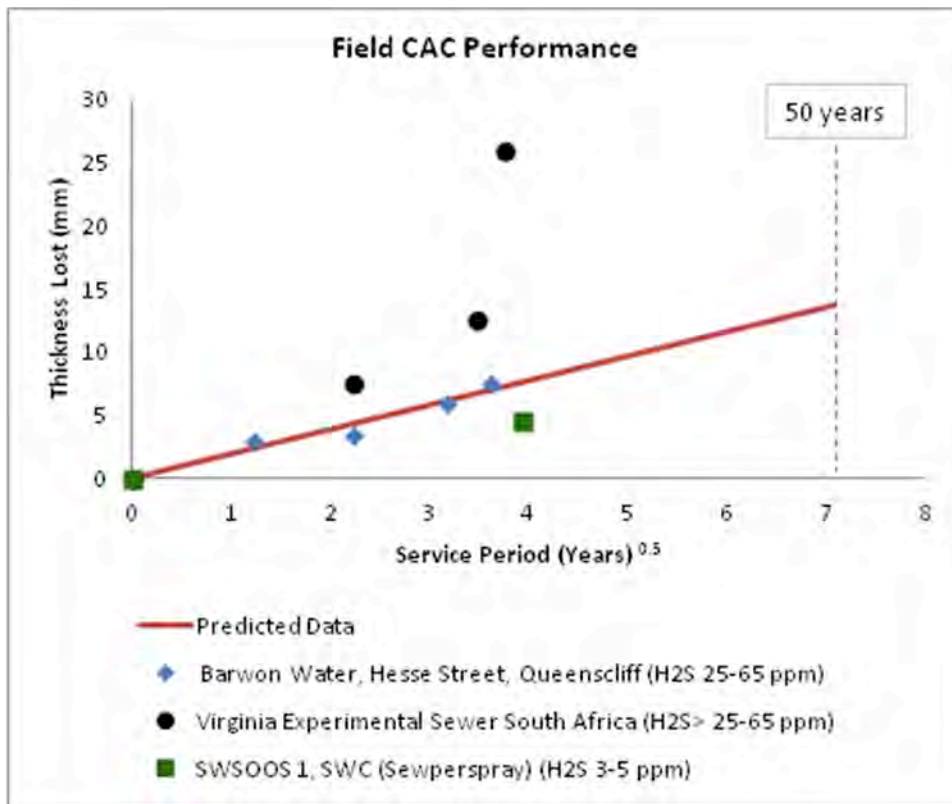


Figure 4. CAC current and predicted performance in Barwon Water (Hesse St, Queenscliff) (Wubben. 2008), Virginia Experimental Sewer, South Africa and SWSOOS 1, SWC. (Note thickness measurements in Barwon Waters were corrected for expansion of CAC e.g. actual thickness loss of 20-40 mm is equivalent to 4-8 mm. Measurements were confirmed by actual remaining thickness left).

coating. Similar field test result from Virginia experimental sewer in South Africa (Goyns 2008) and in SWSOOS1, SW are included in Figure 4. The lower CAC thickness loss in SWSOOS 1 and higher loss in Virginia sewers are consistent with the H₂S concentrations in these sites. SWSOOS1 typically has between 3-5 ppm of H₂S and although Virginia sewer conditions were not reported, the higher material loss suggest the H₂S here is > than 25-65 ppm experienced in Barwon Water. At the Virginia site, OPC was corroding 4 times faster than CAC at the rate of 7.5 mm/yr. The two interesting features of these results are one the early performance of CAC in SW and Virginia sewer and their close fit to the low rate of material loss in Barwon Water. This suggests that CAC could reasonably provide adequate protection within 12-13 years when H₂S concentrations are at least below 65 ppm. The later performance, particularly in Virginia shows rapid corrosion, indicative of the challenge in using early data to predict the long term performance of CAC. The rapid

corrosion is attributed to CAC conversion. The conversion of CAC, which is inevitable, converts its mineralogy to the more reactive phase.

These results show that both short (3 years) and long term (13-19 years) trials of CAC appear to demonstrate the ability of this lining material to provide adequate performance as protective barrier against corrosion in the sewers, in particular between the period of up to 12-13 years. Longer term performance is an area that is still not well defined, but it appears to be highly dependent on CAC conversion.

2.1.4 CAC defects and degradation

The main sign of CAC degradation is the formation of softened corrosion products (gypsum, CaSO_4). Although other defects including loss of strength ($< 48\text{MPa}$), cracking and crazing and cement shrinkage may occur after application and/or during service. The occurrence of these defects depends on various factors including the water to cement ratio, mixing of water and cement, curing and cement batch shelf life. The typical shelf life of CAC is less than one year. The manufacturers claim that CAC is able to bridge the gap formed by crazing as CAC expands with service. The performance of Sewperspray® in SW for 15-16 years despite initially showing minor crazing provide some supports to this claim. Cracks will need to be repaired, although if cracks form the underlying reasons should be examined as defects that introduced the cracks (e.g., poor curing, shrinkage) may impact the service life of the coating. There appears to have been no reported premature failure of CAC by delamination.

2.2 Calcareous Aggregate Cement

Calcareous aggregate cement is fabricated by the addition of limestone or calcareous aggregate into Portland cement to increase its alkalinity. Limestone is an inexpensive alkaline mineral and its use is qualified by the only standard for this material in Australia, TS3C (TS3C 2007). Its incorporation into Portland cement can therefore provide a cost effective sacrificial material promoting a higher neutralisation capacity to normal OPC. The effectiveness of calcareous aggregate as a sacrificial coating has been tested in South Africa (Barnard 1967, Goyns 2008) and Australia (Thistlethwayte 1972) both in laboratory and applied engineering practices since early 1960. It appears that today only South Australia Water uses calcareous aggregate cement in the rehabilitation of their manholes.

2.2.1 Performance of Calcareous Aggregate Cement

Calcium aggregate cement is used both as a protective liner and structural material. No report or data were supplied in this survey on the performance of calcium aggregate cement in Australian sewers. Previous trials have shown the addition of limestone is able to impart a longer service life to OPC. Testing in South Africa showed calcium aggregate cement extended the service life of siliceous aggregate cement by 3-5 times (Goyns 2008). An Australian study showed limestone cement increased the cement life by 1.9 times (Barnard 1967, Thistlethwayte 1972).

3.0 SURFACE REPAIR MATERIALS

Concrete substrates that have been heavily corroded will exhibit a highly uneven surface often accentuated by the presence of large exposed aggregates. Surface restoration is achieved using less expensive lining materials to repair the substrate surface. This has included rapid curing cement such as ‘shotcrete’ and ‘gunite’. Gunite typically refers to a spray-applied dry cement mortar mix with the water added at the nozzle. Shotcrete refers to any spray-applied concrete mix applied over a reinforcing mesh or reinforcing fibers.

Gunite and shotcrete are used as lining materials in the US (EPA/600/R-11/017 2011), however it appears that these materials continue to be used only as surface repair material in Australian Water industries. That is it is not anticipated these surface repair materials will provide significant protective layer.

4.0 PRIMER/BONDING AGENT

Primers are used as a preparatory coating material that is applied to ensure better adhesion of the coating and the concrete substrate. The primers themselves offers no protection against corrosion, however they are engineered to fill in porous structures and for adherence. By filling into the porous structure, the primer therefore creates a strong bond between the primer and substrates whilst providing a smooth surface on which the lining material could adhere. Primers can also be used to seal the damp concrete surface to allow coatings to cure and thus adhere without being affected by the moisture present in the substrate (Comyn 1997). Solventless epoxies have poor pore filling abilities. Addition of solvents may improve this property, however at the risk of affecting the curing. If epoxy is used in coating dry substrates, epoxy could be self priming demonstrating good adherence. Most coating manufacturers provide a standard recommendation on the use of primer prior to the application of lining materials on moist concrete substrate. Utilities often leave the decision to use primers to suppliers/contractor and consultants (Sunarho 2012).

4.1 Performance of primers

It appears the Australian water industries do use some primers with the coating applications, however it is not done consistently with all applications (Sydney-Water 2009). This is generally attributed to the higher cost introduced by the addition of primers to the coating system and because no adequate trials have been conducted to demonstrate their efficacy. Also epoxy has been known to be self priming.

Condition assessment of coatings appears to suggest that primers may have some effect on adhesion of the coating and in preventing blister formation. However without documentation of the state of the substrate and controlled test conditions, these could not be validated.

In general the overall merit of using primers in improving the adherence of the lining materials is still unclear. Sydney Water’s use of Sikadur 31 and 32 as primers for the

Sika based coatings such as Sikagard 63N/Sikadur 41 showed the coating had good adhesion after 15 years of service. However Nitomortar ELS which were applied without primers also demonstrated good adhesion after 7 years of service. Although SW experienced more defects in Nitomortar in terms of blister formation and Sikagard 62T that has been applied without primer delaminated prematurely. The use of certain primers, on the other hand, had been shown to have detrimental effect on the performance of the coating. For example the use of Renderoc FC primer for Nitomortar resulted in premature delamination for a 2008 application in SW. Whereas the use of Nicote EP primer on similar coating did not promote premature delamination (Sydney-Water 2009).

Melbourne Water did not appear to use primers on their coating system based on Hychem TL5 (Connell-Wagner 2004). It appears without primer, Hychem TL5 was able to demonstrate suitable adherence within 8-9 years of service. Some delocalised delamination (1-30% of the area) was observed after 8-9 years of service, however no premature delamination was observed.

Without historical measure of the moisture content of the substrate prior to the application of the coating materials, it is difficult to accurately assess if primer had impact on the adhesion of the coating material.

The effect of primers on the formation of blister is also unclear but it does appear to have some merit. Assessments of coating system based on Sikagard 63N/Sikadur 41 that have been applied with primer in SW sewers showed no defects including blisters even after 15 years of service apart from changes in hardness. Nitomortar and Hychem TL5 in SW and Melbourne sewers, which were applied without primers, consistently showed the formation of blister that grew in size and occurrence with service (Wubben 1999, Sydney-Water 2009). These observations suggest that primer may function as a sealer and/or modifier of the substrate surface tension, preventing undesired defects such as blistering in coatings. This evidence suggests the potential benefit of primers. However because the formation of blisters is a complex process, controlled testing must be conducted to resolve its effect on the coating system.

References

1. Barnard, J. L. (1967). Corrosion of sewers. South Africa, Council for Scientific and
2. Industrial Research (CSIR) Research Report 250
3. Comyn, J. (1997). Adhesion science. UK, UK: Herts, UK : The Royal Society of Chemistry.
4. Connell-Wagner (2004). Review of Epoxy Sewer Lining. Melbourne, Connell Wagner Pty Ltd. .
5. EPA/600/R-11/017 (2011). Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains

- <http://www.epa.gov/nrmrl/pubs/600r11017/600r11017.pdf> (accessed November 22 2011).
6. Goyns, A. M., Alexander, M.G., and Fourie, C.W., (2008). Applying experimental data to concrete sewer design and rehabilitation. Calcium Aluminate Cements: Proceedings of the Centenary Conference. C. H. Fentiman, Mangabhai, R.J., and Scrivener, K.L. Avignon, IHS BRE Press.
 7. Sunarho, J. (2012). Sydney Water.
 8. Sydney-Water (2009). Epoxy Projects, (spreadsheet).
 9. Thistlethwayte, D. K. B. (1972). The Control Of Sulphides In Sewage Systems. Sydney, Butterworths.
 10. TS3C (2007). Technical Standard - Fine and coarse calcareous aggregates (marble) for concrete sewerage structures (excluding lightweight aggregate), SA Water Corporation.
 11. Valix., M. (2009). Assessment of Spray-lined Watermain that have been in Service and Under Pressure, Sydney Water Corporation.
 12. Valix., M. (2009). Report on the Testing of Pipes with a Copon Hycote 169HB Semi-Structural Polyurethane Spray Lining, report, Sydney Water Corporation.
 13. Wubben, R. (1999). Evaluation of Lafarge 'Sewper Mortars' for Aggressive Sewer Environments, ConCorr Pty. Ltd. (submitted to to Lafarge Aluminates).
 14. Wubben., R. (2008). Assessment of Service Life Performance by Core Sampling on Kerneos 'Sewperspray' Application, ConCorr Pty. Ltd. (submitted to Kerneos Aluminate Technologies).

APPENDIX A. PERFORMANCE OF SPRAY AND TROWEL APPLIED COATINGS IN AUSTRALIAN SEWERS

(i) Sydney Water

Table 1. Performance of Sikadur 41/Sikagard 63N in Sydney Water Sewers.

Industry	Coatings	Infrastructure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (years)	Conditions Assessment	Assessment Report
	Sikadur 41/Sikagard 63N	Pipe	Trowel	20 mm Sikadur 41, 1.5 mm Sikagard 63N	none	none	NA	NSOOS, Section 3	1992	2007	15	Multilayered epoxy mortar in good conditions, Shore Hardness 75.6	
	Sika (type not specified) Used PVC panel and epoxy	Pipe	Trowel	NA	none	concrete	NA	NSOOS, Section 3	1993	2007	14	Good conditions, Shore hardness 65.6	NA
Sydney Water	Sikadur 41/Sikagard 63N	Pipe	Trowel	20 mm Sikadur 41, 1.5 mm Sikagard 63N	Yes	none	NA	Manly Section 1	1996	2006	10	Good condition compared to non-repaired section. Sikagard 63N chipping off. Black to grey growth, Shore Hardness 65.7	NA

Table 2. Performance of Sikadur 41/Sikagard 63N in Sydney Water Sewers

Industry	Coatings	Infrastructure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (years)	Conditions Assessment	Assessment Report
Sydney Water	Sikadur 41/Sikagard 63N	Pipe	Trowel	20 mm Sikadur 41, 1.5 mm Sikagard 63N	Yes	none	NA	NSOOS West Ryde	1998	NA		None	NA
	Sikadur 41/Sikagard 63N	Pipe	Trowel	20 mm Sikadur 41, 1.5 mm Sikagard 63N	Yes	none	NA	NSOOS section 1 Amiens Rd to Eustace St	1999	2006	7	Good condition, no sign of deterioration , Shore hardness, black stains suspected biological	KBR
	Sikadur 41/Sikagard 63N	Pipe	Trowel	20 mm Sikadur 41, 1.5 mm Sikagard 63N	Yes	none	NA	NSOOS Spit siphon upleg	2000	2006	6	Good condition, no sign of deterioration , Shore hardness 75.5	KBR

Table 3. Performance of Sikadur 41/Sikagard 63N in Sydney Water Sewers

Industry	Coatings	Infrastructure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (years)	Conditions Assessment	Assessment Report
	Sikadur 41/Sikagard 63N	Pipe	Trowel	20 mm Sikadur 41, 1.5 mm Sikagard 63N	Yes Sikadur 31		NA	NGRS Section 4, 8	2002	2004	2	Good condition	NA
	Sikadur 41/Sikagard 63N	Manhole	Trowel	20 mm Sikadur 41, 1.5 mm Sikagard 63N	Yes Sikadur 31	none	NA	NGRS Smith field	2002	None	NA	None	NA
	Sikadur 41/Sikagard 63N	Pipe	Trowel	10, 20 mm Sikadur 41	Yes Sikadur 32	none	NA	Oaks flat, submain	2008	None	NA	None	NA

Table 4. Performance of Sikagard 62T in Sydney Water Sewers

Industry	Coatings	Infrastructure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (years)	Conditions Assessment	Assessment Report
	Sikagard 62T	Pipe	Sprayed	20	No	none	NA	SWOOS 2 Twin Barrell	2003	None	NA	None	NA
	Sikagard 63N/Sikadur 42	Pipe	Trowel	20	Yes Sikadur 31	none	NA	SWOOS 2 Twin Barrell	2002	2004	2	Good condition	NA

Table 5. Performance of Nitomortar ELS in Sydney Water Sewers

Industry	Coatings	Infrastructure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (years)	Conditions Assessment	Assessment Report
	Nitomortar ELS	Pipe	Sprayed	20	No	SS mesh	NA	NSOOS, Section 1	1999	2006	7	Good conditions compared to unrepaired section. Contain snottites (yellow), Shore Hardness 65.7)	NA
	Nitomortar ELS	Pipe	Sprayed	20	No	none	NA	NSOOS Morrison Creek	1999	None	NA	None	
	Nitomortar ELS	Pipe	Sprayed	30	No	Shotcrete, Gunites + SS mesh	NA	NSOOS, Section 7	2002	None	NA	None	NA
	Nitomortar ELS	Pipe	Sprayed	20/10	No	proprietary gunite	NA	SWSOOS 2Sth	2005	None	NA	None	NA
	Nitomortar ELS	Pipe	Sprayed	20	No	none	NA	NGRS aqueducts Oatley & Renown	2005	None	NA	None	NA

Table 6. Performance of Nitomortar ELS in Sydney Water Sewers.

Coatings	Infra-structure	Appli-cation Method	Nominal Thickness (mm)	Primer	Substrate Repair Materials	Surface Prep	Sewer Site	Yr Applied	Date of Condition Assess-ment	Age (yrs)	Conditions Assessment	Assess -ment Report
ELS	Pipe	Sprayed	10 roof and walls	No	Nitomortar HB	NA	SWSOOS 2 Sth and North	2006	2007	1	Blistering in some areas , repairs carried out on section after inspection	SASTTI JV in November 2007
ELS	Pipe	Sprayed	10 roof and walls	No	Nitomortar HB	NA	SWSOOS 2 Sth and North	2006	2010	4	Generally good condition. Increase in size and occurrence of blisters since the 2007 inspection. Reduction in hardness and surface pH 0-1. Acid ingress 3-5 mm.	SASTTI JV in April 2011
ELS	Pipe	Sprayed	10	No	proprietary gunite	NA	SWSOOS 2Sth	2006	2007	1	Blistering in some areas , repairs carried out on section after inspection	SASTTI JV in November 2007
ELS	Pipe	Sprayed	10	No	proprietary gunite	NA	SWSOOS 2Sth	2006	2010	4	Generally good condition. Blistering in some areas , repairs. Surface pH 0-2. Loss of hardness. Acid ingress 2-5 mm.	SASTTI JV in April 2011
ELS	Pipe	Sprayed	10 wall, 20 mm roof	No	Nitomortar HB	NA	SWSOOS Site 2 and 3	2007	None	NA	NA	NA
ELS	Pipe	Sprayed	20	No	Shotcrete	water blast and grit blast if necessary to get back to sound non acid effected concrete.	SWSOOS 2 Between Hayden Pl and Exell St - Barrel 1 & 2	2007/2008	None	NA	NA	NA
ELS	Pipe	Sprayed		Yes Renderoc FC			SP1148 Ropes Crossing	2008	2010	2	Delamination	SW
ELS	Pipe	Sprayed	5 mm on brick and 20 on concrete	Yes Nicote EP	Shotcrete	water blasting, then priming	Stage 2A, 2C & 2D - MH 31 at Hercules St Dulwich Hill to MH 38 at Illawara Rd, Murrickville	2008	None	NA	None	NA

Table 7. Performance of MBT Concessive coating in Sydney Water Sewers.

Industry	Coatings	Infrastructure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (years)	Conditions Assessment	Assessment Report
	MBT Concessive coating	Pipe	Trowel	30	No	none	NA	NSOOS LC Siphon upleg	1999	2007	8	Coating experiencing deterioration in various locations. Finish coat is blistering and delaminating and epoxy mortar below has softened. Gas attack on unlined concrete is upto 20mm on walls and 30-40mm on roof, pH on wall and roof 1.0.	NA
	MBT Concessive coating	Pipe	Trowel	30	No	none	NA	NGRS/SWOOS	NA	2004	NA	none	NA

Table 8. Performance of Biocrete in Sydney Water Sewers.

Industry	Coatings	Infra-structure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (years)	Conditions Assessment	Assessment Report
	Biocrete	Pipe	NA	25	No	none	NA	SWOOS 2 South	2006	2007/2008	1-2	Softer around the flow line compared to upper wall and roof . Varying degrees of bubbling, drumminess and bulging was observed.	KBR (July 2007) and SASTTI November 2008
	Biocrete	Pipe	NA	25	No	none	NA	SWOOS 2 North	2006	2007/2008	1-2	Epoxy is sound. Varying degrees of defects ranging from minor, blisters, bubbling and drumminess and patch of delamination. High concentration of defects around the expansion joints	KBR (July 2007) and SASTTI November 2008
	Biocrete	Pipe	NA	25	No	none	NA	SWOOS Site 1 & 2S Airport Grit pit 2006 25mm thick roof	2007	2007/2008	~1	Softer around the flow line compared to upper wall and roof (5 mm). Varying degrees of bubbling, drumminess and bulging was observed.and bulging was observed.	KBR (July 2007) and SASTTI November 2008
	Biocrete	Pipe	NA	25	No	none	NA	SWOOS Site 1 & 2S Airport Grit pit 2006 25mm thick roof	2007	2011	4	Softening has increased from 5 mm to 8-15 mm and greater formation of blistering. Surface pH 3.0 Few of the sections have delaminated.	SASTTI JV in April 2011

Table 9. Performance of CAC in Sydney Water Sewers.

Industry	Coatings	Infra-structure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (years)	Conditions Assessment	Assessment Report
	CAC (Kerneos)	Pipe	NA	50	NA	NA	NA	SWOOS	2007	NA	4	None	
	CAC (Kerneos + BASF)	Pipe	NA	50	NA	NA	NA	BOOS	2010	NA	1	None	

(ii) Melbourne Water

Table 10. Performance of Hychem TL5 in Melbourne Water Sewers.

Coatings	Infrastructure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (years)	Conditions Assessment	Assessment Report
Hychem TL5	Manhole	Sprayed	3	No	None	NA	WTS	Sept 1995	10 th May 2004	~ 9	Mezannine landing- 20-30% of the coatings have delaminated with large blisters on the walls, roof floor, near vents and where concrete joined steel structure in access hole (30-40%). Delamination and blistering less in the sewer level.	Connell Wagner Pty Ltd
Hychem TL5	Manhole	Sprayed	5	No	None	NA	NDS	April 1996	7 th May 2004	~ 8	Mezannine wall , areas behind stairs and wall on top of manhole– coating good conditions, some minor delamination on the floor otherwise good adhesion (checked by tapping). Vent, access hole- coating has delaminated concrete showing corrosion Overall 1% of coating has failed on the wall Floor- showed greater delamination and cracks around access hole (5%)	Connell Wagner Pty Ltd

Table 11. Performance of CAC in Melbourne Water Sewers.

Coatings	Infrastructure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (yrs)	Conditions Assessment	Assessment Report
Sewpercoat	Manhole	trowelled	50 mm on wall, ceiling and structures but thicker on bottom	NA	NA	NA	Hesse Street, Queenscliff, Melbourne (575367)	June 1995	December 1996	1.5	10 mm of soft deteriorated material (corrected thickness of 3 mm if expansion taken into account)	Wubben Pty Ltd Submitted to Kerneors August 12 2008
Sewpercoat	Manhole	trowelled	50 mm on wall, ceiling and structures but thicker on bottom	NA	NA	NA	Hesse Street, Queenscliff, Melbourne (575367)	June 1995	April 2000	~5	10-15 mm of soft deteriorated material (corrected thickness of 3-4 mm if expansion taken into account)	Wubben Pty Ltd August 12 2008
Sewpercoat	Manhole	trowelled	50 mm on wall, ceiling and structures but thicker on bottom	NA	NA	NA	Hesse Street, Queenscliff, Melbourne (575367)	June 1995	June 2005	10	10-20 mm of soft deteriorated material (corrected thickness of 4-8 mm if expansion taken into account)	Wubben Pty Ltd August 12 2008
Sewpercoat	Manhole	trowelled	50 mm on wall, ceiling and structures but thicker on bottom	NA	NA	NA	Hesse Street, Queenscliff, Melbourne (575367)	June 1995	August 2008	13	Typically 5-30 mm of soft deteriorated material (this is equivalent to 10-20% of the nominal thickness was lost)	Wubben Pty Ltd August 12 2008

(iii) South Australia Water

Table 12. Performance of CAC in South Australian Water

Coatings	Infrastructure	Application Method	Nominal Thickness (mm)	Bonding Bridge or primer	Substrate Repair Materials	Surface Prep	Sewer Site	Year Applied	Date of Condition Assessment	Age (years)	Conditions Assessment	Assessment Report
Sewpercoat (accelerated using Lithium borate)	Manhole	trowelled	NA	NA	NA	Pressure wash, grit removed using sludge pump	Cnr Lowana Tee and Aldinga St , Taperoo, SA (MH4196 426)	2009	NA		NA	
Sewpercoat	Manhole	trowelled	NA	NA	NA		Francis St Wingfield SA (MH 4217101)	2009	NA		NA	

Barnard, J. L. (1967). Corrosion of sewers. South Africa, Council for Scientific and Industrial Research (CSIR) Research Report 250

Comyn, J. (1997). Adhesion science. UK, UK: Herts, UK : The Royal Society of Chemistry.
 Connell-Wagner (2004). Review of Epoxy Sewer Lining. Melbourne, Connell Wagner Pty Ltd. .

EPA/600/R-11/017 (2011). Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains <http://www.epa.gov/nrmrl/pubs/600r11017/600r11017.pdf> (accessed November 22 2011).

Goyns, A. M., Alexander, M.G., and Fourie, C.W., (2008). Applying experimental data to concrete sewer design and rehabilitation. Calcium Aluminate Cements: Proceedings of the Centenary Conference. C. H. Fentiman, Mangabhai, R.J., and Scrivener, K.L. Avignon, IHS BRE Press.

Sunarho, J. (2012). Sydney Water.

Sydney-Water (2009). Epoxy Projects, (spreadsheet).

Thistlethwayte, D. K. B. (1972). The Control Of Sulphides In Sewage Systems. Sydney, Butterworths.

TS3C (2007). Technical Standard - Fine and coarse calcareous aggregates (marble) for concrete sewerage structures (excluding lightweight aggregate), SA Water Corporation.

Valix., M. (2009). Assessment of Spray-lined Watermain that have been in Service and Under Pressure, Sydney Water Corporation.

Valix., M. (2009). Report on the Testing of Pipes with a Copon Hycote 169HB Semi-Structural Polyurethane Spray Lining, report, Sydney Water Corporation.

Wubben, R. (1999). Evaluation of Lafarge 'Sewper Mortars' for Aggressive Sewer Environments, ConCorr Pty. Ltd. (submitted to to Lafarge Aluminates).

Wubben., R. (2008). Assessment of Service Life Performance by Core Sampling on Kerneos 'Sewperspray' Application, ConCorr Pty. Ltd. (submitted to Kerneos Aluminate Technologies).