EKOPIPE

TECHNICAL MANUAL

RCPA THE AUSTRALIAN PIPE COMPANY | EKOPIPE UTILISING BX3

INTRODUCING EKOPIPE

With over a decade of research and development, EKOPipe is a game-changing eco-friendly concrete pipe, utilising our revolutionary new BX3 technology, and it's here to change the future of our built and natural environment.

EKOPipe meets all performance and durability requirements from the AS4058 concrete pipe standard, and is manufactured using the same manufacturing process as standard SRCPipe. EKOPipe can be used wherever reinforced concrete pipe is required. With the same joint design, installation of EKOPipe can even be done in-line with standard SRCPipes.

ABOUT BX3

BX3 technology uses an innovative approach to produce a low-carbon pipe without compromising the known properties of reinforced concrete pipes.

INTRODUCTION

Steel-reinforced concrete pipes, while out of sight when installed, are a key component in civil construction projects. Stormwater drainage performs a critical function in modern cities, keeping our buildings and roads accessible at all times.

The total supply of concrete in Australia is almost 30 million cubic metres, and while concrete pipes only represent a small % of that total, the impact on global warming cannot be ignored. It is estimated that the concrete used in manufacture of steel reinforced concrete pipes in 2023 was approximately 300,000 cubic metres or 720,000 tonnes– hardly an insignificant number!

Manufacture of steel-reinforced concrete pipes in Australia is governed by the Standard AS/NZS 4058:2007 (AS4058). This is a performance-based standard, which provides the manufacturers in Australia the opportunity to look for innovative methods of meeting the strength and durability requirements.

This performance-based approach is key in allowing the development of EKOPipe, which meets all aspects of the AS4058 standard for strength and durability.

DEVELOPMENT OF **BX3 TECHNOLOGY**

RCPA began the journey to develop a low-carbon concrete pipe over a decade ago. Production of concrete pipes in Australia has historically used highly efficient thin-wall designs when compared to pipes produced in other countries. This efficient design requires a high-strength concrete combined with precisely positioned reinforcement to achieve the load capacity required.

When developing a low-carbon concrete, it wasn't enough to only focus on the strength requirement but also to ensure the achievement of a highly durable concrete that can satisfy the demand for a 100-year service life.

PIPE PRODUCTION **METHOD**

RCPA utilises the packerhead system for casting pipes, this is also referred to as vertical casting or bi-directional casting. This system uses a dry mix concrete with zero slump and is well suited to the BX3 technology mix designs.

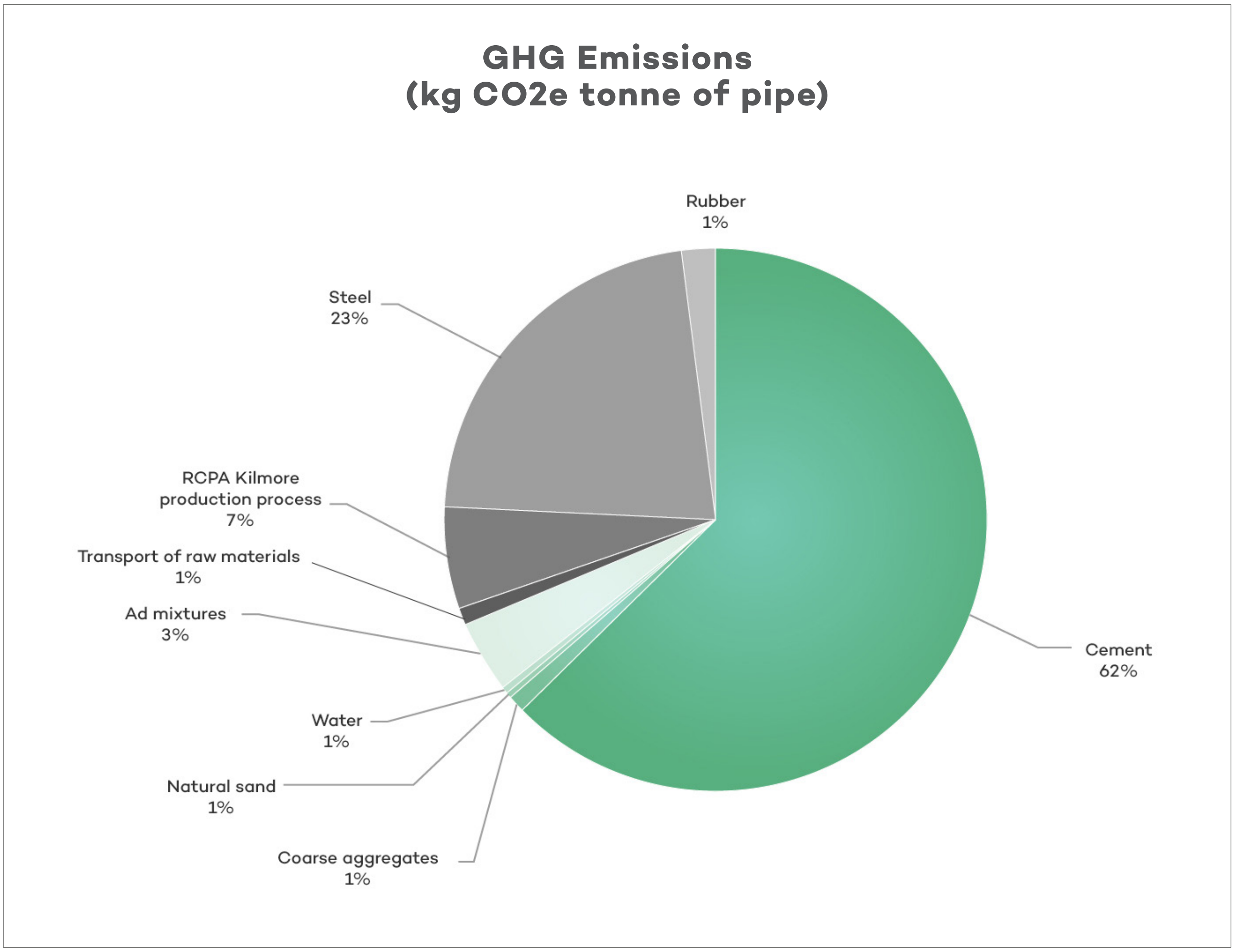
The highly energetic compaction process and ability to instantly strip pipes from the casting moulds allows the use of a low water content concrete, which is known to improve strength and performance.

Concrete is produced in highly accurate batching plants, located on each RCPA site to ensure freshly mixed concrete is available for the pipe casting process as needed.

SUSTAINABILITY

Accurate calculation of embodied carbon, in accordance with internationally accepted benchmarks is key to give confidence to end users. To this end RCPA has developed an Environmental Product Declaration (EPD) for the currently produced steel-reinforced concrete pipes. This has been done in accordance with life cycle assessment processes described in ISO14025 & EN15804, for modules A1 to A3.

The data showed that for currently produced concrete pipes, the key contributor to the embodied carbon is undoubtedly the Portland cement as shown in the following pie chart using a DN300 Class 4 pipe produced at RCPA's Kilmore Victoria site.



While it is not possible to complete an EPD for EKOPipe at time of writing this manual, once sufficient production data becomes available this will be completed. In the interim, a life cycle assessment model has been developed for EKOPipe as a comparison.

Other elements such as reinforcing steel undoubtedly have a substantial contribution to embodied carbon, and RCPA continually strives for efficiency in design for both strength and embodied carbon. The majority of reinforcing steel used in RCPA pipes is sourced from recycled materials, and is part of the circular economy.

AS4058 **TESTING SUMMARY**

PIPE LOAD CAPACITY

The primary goal of any pipe is to withstand the forces applied from the soil surrounding the pipe, and to enable loads such as vehicles to pass above the pipe without causing damage. These loads can vary widely in nature, and there is a detailed methodology outlined in the standard AS/NZS 3725:2007 for calculating the magnitude of the loads for any given installation scenario.

AS4058 provides a table of loads, for both proof (maximum design load) and ultimate (additional load capacity for safety) loadings that a given pipe diameter and class must achieve. Testing is completed using a test apparatus that applies a “crushing” load to the pipe without any additional support.

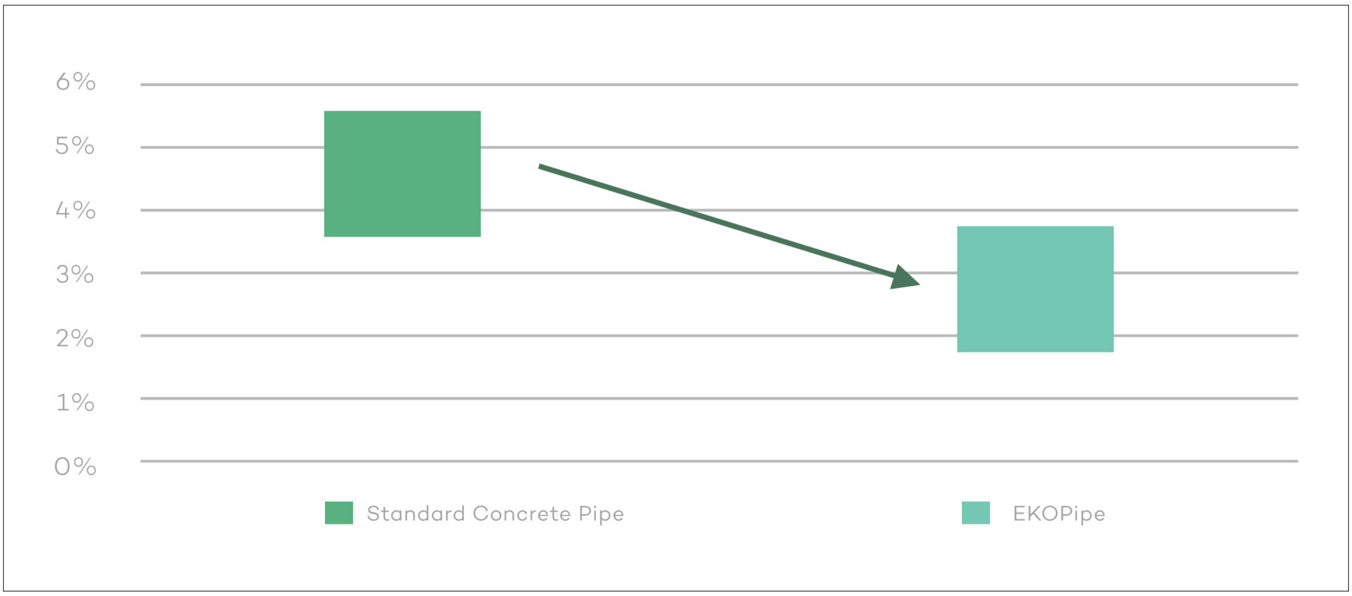
EKOPipe production batches have been tested for both proof and ultimate loads in accordance with AS4058, and all EKOPipes exceed the load requirements listed in AS4058.

DURABILITY – WATER ABSORPTION

The test method in AS4058 for assessing the durability of concrete pipes is known as the water absorption test. This is a test undertaken on cores of concrete taken from the pipe wall, not from separately cast test cylinders.

This gives confidence that it is not just the concrete being evaluated, but also the casting method being assessed for the ability to produce dense, low permeability concrete.

The maximum allowable value for water absorption in AS4058 is 6%. Many tests have been conducted on EKOPipe concrete pipe cores, and all tests have been significantly less than that required by AS4058. In all cases, EKOPipe has performed better than standard Portland cement based concrete tests.



CHEMICAL CONTENT

The Australian Standard for Precast concrete pipes requires that concrete have an acid-soluble chloride and sulphate content below certain limits (AS4058 Table 2.1 – shown below).

AS/NZS 4058:2007 TABLE 2.1

MAXIMUM VALUES OF ACID-SOLUBLE CHLORIDE AND SULFATE ION CONTENT IN CONCRETE AS CAST

Condition	Maximum acid-soluble chloride ion content (kg/m^3)	Maximum acid-soluble sulfate ion content percent (by mass of cement)
Concrete cured at ambient temperature	0.8	5.0
Steam-cured concrete	0.8	4.0

Previous testing results for standard OPC pipe concrete and EKOPipe concrete are shown in the following table, it can be observed that all test results including EKOPipe concrete are less than the allowable limits.

Site/Concrete	Chloride Ion Content (kg/m^3)	Sulfate Ion content (% by mass of cement)
ALLOWABLE LIMIT	<0.80	<4.00
Kilmore/standard OPC	0.14	3.42
Melton/standard OPC	0.48	1.91
Melton/standard OPC	0.48	1.08
Yatala/standard OPC	0.24	1.25
Somersby/standard OPC	0.48	0.97
Kilmore/EKOPipe	0.24	1.07

ADDITIONAL **TESTING**

While not required for manufacture and testing of steel reinforced concrete pipes, RCPA has conducted additional testing for EKOPipe concrete to validate the performance of this innovative concrete. Testing conducted has evaluated the performance of EKOPipe concrete for compressive strength, shrinkage, chloride exposure, corrosion resistance, permeability of the concrete, and resistance to alkali-silica reaction. Many of these tests were undertaken using internationally recognised test methods, and where relevant the tests were adjusted to provide a comparison of standard OPC pipe concrete with EKOPipe concrete.

CONCRETE COMPRESSIVE STRENGTH

While not a required test parameter for AS4058, it is common for concrete to be tested for characteristic compressive strength using the test methods outlined in Australian Standards suite AS1012. This testing involves casting a test cylinder of concrete 100mm diameter by 200mm tall. For the dry concrete mix used by RCPA, these test cylinders must be produced using either intense external vibration or mechanical compaction to achieve a representative test sample.

Once cast, the test cylinders are cured in accordance with AS1012 requirements prior to compressive testing at the required timeframes.

Typical concrete strengths achieved for both conventional pipe concrete and EKOPipe concrete using BX3 formulation achieve greater than 50MPa compressive strength when tested after 28 days curing.

SHRINKAGE

Concrete shrinkage is not assessed for precast concrete pipes as this attribute does not affect the structure of a concrete pipe. As a reference study, two sets of standard shrinkage beams were cast at RCPA Kilmore and tested by an independent, NATA registered Laboratory, one set for standard OPC concrete on the 22nd of February 2023 and a set of EKOPipe concrete shrinkage beams on the 15th March 2023. Results for these beams are shown in the following table:

	21-day shrinkage	56-day shrinkage
OPC pipe concrete (22/2/2023)	430μm	580μm
EKOPipe concrete (15/3/2023)	440μm	570μm

While there are no requirements for shrinkage of concrete used for drainage pipes, the values recorded for both OPC pipe concrete and EKOPipe concrete are very similar indicating equivalent performance. In addition, the drying shrinkage values obtained in both tests are significantly less than typical limits required for structural concrete in Australia.

CHLORIDE MIGRATION

It is considered by industry that resistance to chloride ingress is a critical parameter for steel reinforced concrete, due to the assumption that once a certain chloride threshold value is reached within the concrete then corrosion of the reinforcing will take place. Hence testing of a concrete's resistance to chloride penetration into the mass of the concrete, also known as chloride migration, is conducted to determine this value.

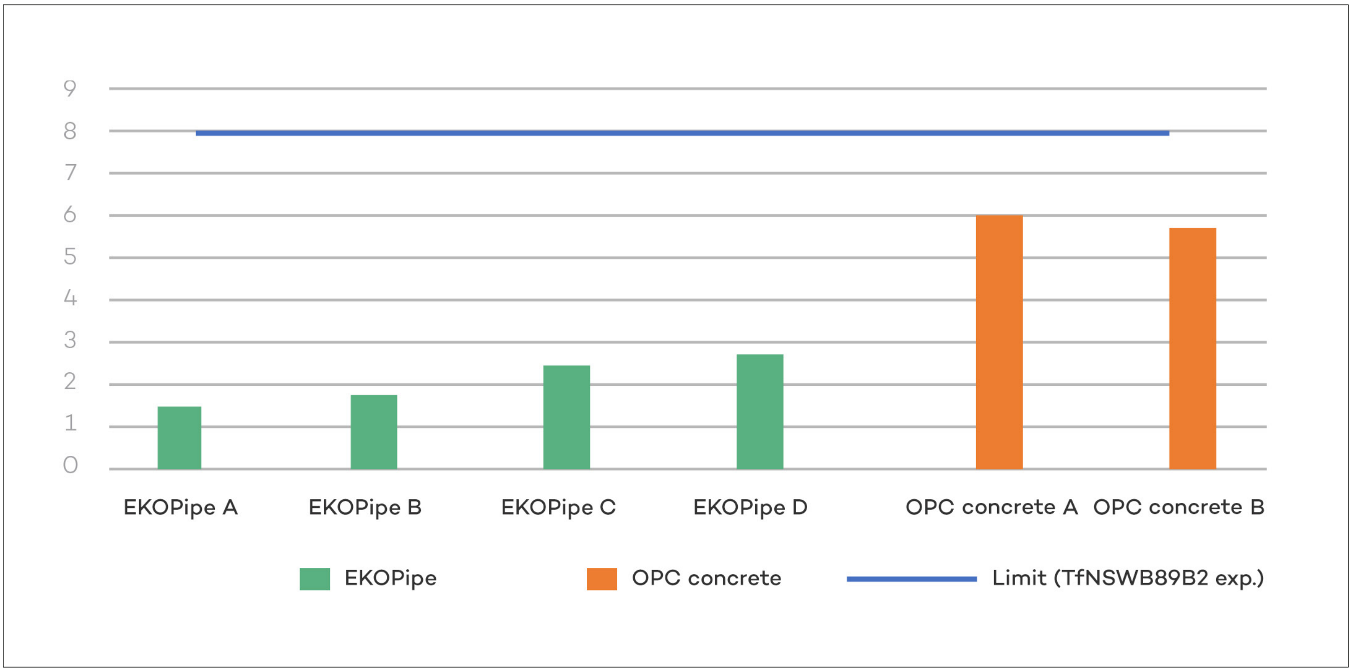
A recent study has challenged this concept, with a report by Sleep et al showing that reinforced concrete pipes with high chloride levels in the concrete around the reinforcement bars had little or no corrosion of the steel reinforcement [1]. This study, along with other investigations of concrete in marine environments, questions the conventional wisdom around acceptable chloride concentrations in concrete and suggests that other factors may also influence corrosion of reinforcement in concrete exposed to chlorides.

Nevertheless, RCPA has conducted testing of chloride resistance using the NordTest NT Build 492 method to determine typical chloride ingress coefficients for EKOPipe concrete. Some of the tests did not strictly conform to the NT Build 492 test requirements with the concrete specimens being older than the 28 day age, but the test results do provide indication that EKOPipe possesses excellent resistance to chloride migration.

Results for chloride ingress testing conducted on EKOPipe and OPC concrete samples are shown in the chart below, with EKOPipe concrete having chloride ingress coefficients half that of standard OPC concrete. A reference to the Transport for NSW B80 concrete requirements for maximum chloride ingress coefficient limit (B2 exposure classification) is included in the chart for reference.

CHLORIDE MIGRATION TEST RESULT

($\times 10^{-12}$ m^2/sec)



PERMEABILITY/VPV

The primary test for durability of concrete in AS4058 is the water absorption test detailed in Appendix F of the standard. In Victoria, a similar test is used to evaluate the permeability of concrete known as the VPV (Volume of Permeable Voids) test.

The test methods used in the AS4058 water absorption test and the VPV test are very similar, consisting of a drying phase where a concrete sample is placed in a 105 degree C oven and heated until the sample reaches an equilibrium weight. The sample is then removed from the oven and cooled to ambient temperature in a desiccator to prevent absorption of moisture from the atmosphere. The sample weight is recorded at this point.

After cooling, the sample is placed in a water bath. The water containing the sample is heated to boiling point and maintained in this state for a specified period of time. After completion of the boiling phase the sample is cooled by replacement of the hot water with cold water. Once cool, the sample is removed from the water, dried to a saturated-surface dry condition and weighed once again. If reinforcing steel is present in the sample, this is removed and weighed separately.

A calculation is performed to determine the absorption of water by the concrete during the boiling phase, allowing for any reinforcing steel present. This test subjects the concrete samples to extreme conditions, and debate exists as to the relevance of such a test to actual performance of concrete in service. Regardless, it is a long-standing measure of permeability of concrete in Victoria and reference values exist in the VicRoads Section 610 concrete specification.

Date of casting	Test specimen type	Testing laboratory	EKOPipe VPV Average Value
3/2/2023	Cylinders	Construction Sciences	8.3%
15/3/2023	Cylinders	Construction Sciences	10.2%

VicRoads Section 610 specifies a maximum VPV value of 12% (50MPa concrete cylinder compacted by vibration). While this test is not a requirement of the Australian Standard 4058 for steel reinforced concrete pipes, the results above confirm that EKOPipe concrete has low permeability and meets VicRoads requirements for VPV.

AUTOGENOUS HEALING

Hairline cracks in concrete have long been shown to heal without external intervention, often known as autogenous healing. The word autogenous comes from the Greek “autogenetos” meaning self-born, and in the concrete world refers to the ability of concrete structures to fill cracks and effectively repair itself.

This phenomenon occurs due to the interaction of environmental moisture with residual calcium hydroxide in the concrete matrix to create calcium carbonate, or limestone, which fills the fine cracks.

In stormwater drainage pipes, which may have fine cracks present at the pipe invert, silt or other small particles present in the water flowing through the pipe may also aid in self-healing of hairline cracks. In a report prepared for RCPA by durability consultants BG&E [4], it is noted that in low-carbon concretes such as EKOPipe, the use of supplementary cementitious materials (SCM’s) “does not adversely affect the occurrence of autogenous healing”. The mechanism of autogenous healing remains the same as for standard OPC concrete, although there may be greater contribution from hydration products over the formation of calcium carbonate.

Testing of EKOPipe concrete for its ability to undergo autogenous healing is difficult to do in a laboratory condition, as the process of autogenous healing is slow and cannot be hastened. Experience and time will show that EKOPipe demonstrates the same self-healing ability as standard OPC concrete pipes.

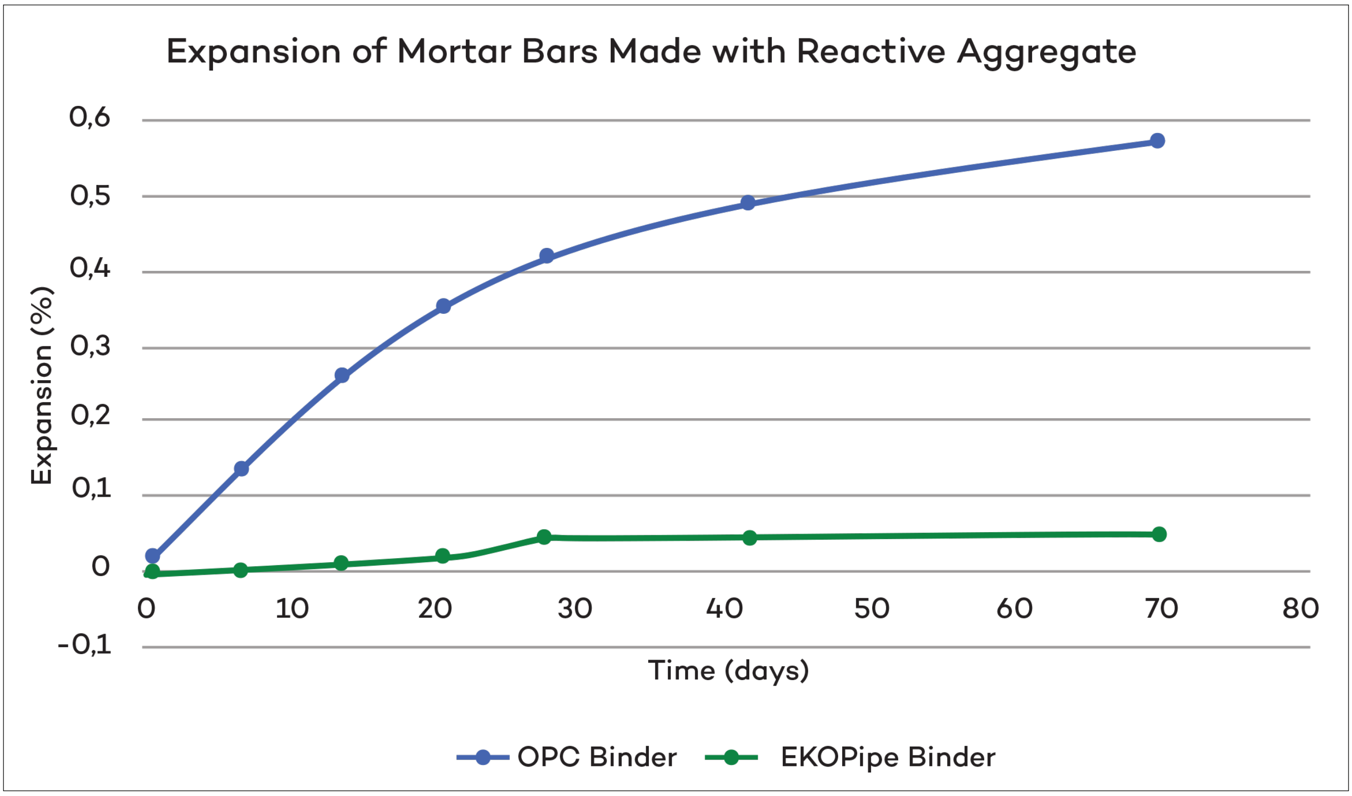
ALKALI SILICA REACTIVITY MITIGATION

Alkali-silica reactivity (ASR) is a phenomenon where the alkali present in cement can react with silica containing minerals present in aggregates and cause damage to the concrete matrix over time. Many aggregate sources in Australia are deemed to be have unacceptably high alkali-silica reactivity, and control measures such as the use of supplementary cementitious materials are well known.

To evaluate the ability of EKOPipe concrete binder design to mitigate the effects of ASR, a modified test was conducted where an aggregate source known to be reactive was tested with two cementitious blends, one consisting of a straight Portland cement binder and another consisting of the EKOPipe binder formula. The results of this report are detailed in report reference [2].

The test was conducted in general accordance with AS1141.60.1 "Potential alkali-silica reactivity: Accelerated mortar bar method", with slight modifications to permit testing of the low water to binder ratio used for dry-cast concrete. The test evaluates the expansion of test specimens made with the various binders, caused by exposure of the specimens to a highly alkaline solution. Normally, this accelerated test allows rapid evaluation of aggregates. In this test, RCPA sought to verify that an aggregate that was known to be reactive would not undergo expansive reaction when used in a concrete made with the EKOPipe binder design.

The test results indicated that, as expected, the concrete specimens made with a straight Portland cement binder underwent unacceptable expansion when subjected to the alkaline solution. The specimens made with EKOPipe binder had minimal expansion, confirming that EKOPipe concrete can utilise reactive aggregates within the concrete mix design and effectively mitigate any alkali-silica reaction.



CORROSION RESISTANCE

To evaluate the ability of EKOPipe concrete to withstand corrosion of reinforcement steel in comparison to standard OPC concrete, testing was conducted at the University of Melbourne.

Given the lack of a standardised test method for this purpose, a test program was devised using a principle similar to that used in an accelerated chloride diffusion test where an electric field is used to enhance the migration of chloride ions from an electrolyte solution (cathode) into the concrete mass using an embedded reinforcement bar (anode).

The concrete samples tested consisted of two standard OPC concrete cylinders and two EKOPipe concrete cylinders, both with N12 reinforcement bars centrally positioned with the bar ends approximately 50mm from the base of the cylinder. Full details of the test are contained with the Project report [3].

Cylinders containing the specially placed reinforcement bar (anode) were positioned in a container with 5% sodium chloride solution, and a DC electrical charge was applied to create a voltage potential. The cylinders were then observed for signs of corrosion, typically shown as rust stains forming on the external surfaces of the concrete.

In this test, one of the OPC concrete cylinders displayed signs of corrosion after 35 days, at which time all cylinders were removed from the solution and cracked open along the central axis of the cylinders to allow inspection of the reinforcement bar. Both OPC concrete cylinders displayed signs of corrosion on the steel bar, where the EKOPipe concrete cylinders showed no sign of steel corrosion.

The accelerated corrosion resistance testing demonstrated that EKOPipe concrete cylinders had superior resistance to chloride-induced corrosion when compared to standard OPC concrete used in steel reinforced concrete pipes.

References:

[1] Sleep et al, Durability of Steel Reinforced Concrete Pipe in Below Ground Conditions, 2023

[2] San Nicolas, Resistance of RCPA EKOPipe to Alkali-Silica Reaction (ASR), 2022

[3] San Nicolas, Steel corrosion testing for EKOPipe…, 2023

[4] BG&E, EKOPipe Durability Assessment, 2023

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