Blu**Cem** ZeoGlass

ACID RESISTANT SHOTCRETE CONTAINING RECYCLED AGGREGATE

Based on industry leading know-how in cement and polymer product development, Bluey has successfully developed Blu**Cem** ZeoGlass. This next generation product is an acid resistant, environmentally sustainable, structural lining system made from more than 60% recycled waste products.

Supplementary cementitious materials have been the preferred rehabilitation system to enhance and prolong the life of sewer pipes and other acid containing structures over the past few decades. In recent years, the sewer rehabilitation industry has undergone rapid transformation as new materials have become commercially available to replace Ordinary Portland Cement (OPC) systems in highly aggressive environments.

The industry now accepts that any form of OPC is unable to survive in acid service conditions. In fact, no OPC, regardless of its composition, will maintain its integrity if exposed to a solution with a pH of 3 or lower. It is important to note, however, that some weak acids can be tolerated, particularly if the exposure is occasional.

Acids react with calcium hydroxide of hydrated OPC. In most cases, the chemical reaction forms water-soluble calcium compounds, which are then leached away by aqueous solutions. In a sewer environment, certain bacteria convert sewage into sulphuric acid. Sulphuric acid is particularly aggressive to concrete because the calcium sulphate formed from the acid reaction further deteriorates concrete through sulphate attack.

Figure 1 - Typical sulphate attack of an OPC sewer showing calcium sulphate deposits.

Figure 2 - Following spray lining.

Various documented test regimes (see references) have shown that, under biogenic acid conditions in sewers, Calcium Aluminate Cement (CAC) concretes clearly outperform OPC concretes. This is ascribed to the ability of CAC to stifle the metabolism of the acid-generating bacteria.

Yamanaka et al (4) prescribe this process to not only sulphur-oxidizing bacteria but also to an acidophilic iron-oxidizing bacteria found in the corroded concrete from sewerage systems in Japan. The surface pH of the concrete test pieces were exposed to an atmosphere containing hydrogen sulphide (of concentrations more than 600ppm) was usually below 2.0 after one month. This was attributed to the the Sulphur oxidizing bacteria growing in a thin water layer which contained hydrogen sulphide. The piece was covered even when the surface of the concrete reached 12-13pH.

A layer of alumina gel (AH_3) is created once the pH falls below 10. AH_3 forms an acid resistant barrier as long as the surface pH is not lowered below 3-4. This somewhat limits the usefulness CAC derived systems.

The performance of sewer pipe CAC concretes with dolomite/non ALAG aggregate did not perform better than similar OPC materials under such conditions, primarily due to of their higher porosity. It is porosity that provides bacteria with a secure area to thrive.

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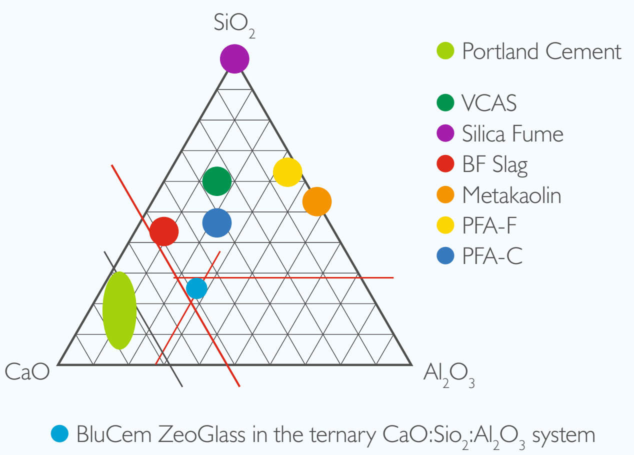
Conventional High Alumina cements (CHA) that undergo conversion will lose compressive strength in service conditions above 40°C. The shrinkage that accompanies conversion, from hexagonal to cubic form, also opens the matrix up to deleterious chemicals and bacteria mentioned above.

Following years of international research and field analysis, Bluey has launched a new binder technology based around calcium aluminosilicates. This advancement allows for the manufacture of a grout, screed, concrete or dry spray shotcrete that can function in a wide range of service temperatures without degradation by acid sulphate attack. BluCem ZeoGlass does not lose compressive strength, with associated microcracking in response to service temperatures over 40°C.

BluCem ZeoGlass also displays excellent resistance to food acids such as citric and gluconic. This has the added benefit of providing alkali passivity to facilitate the protection of steel reinforcements, unlike known 'geopolymer' combinations.



Notes
VCAS and metakaolin are pozzolans, meaning they react with the calcium hydroxide generated during cement hydration. Both VCAS and metakaolin are manufactured mineral admixtures. VCAS is a trademarked name for vitreous calcium alumino-silicate, and metakaolin is an amorphous alumino-silicate. VCAS is manufactured using post-industrial ingredients, while metakaolin is manufactured using mined kaolin clay.

Figure 3 - Ternary diagram showing the position of BluCem ZeoGlass in relation to other cementitious and geopolymer binders.

What is BluCem ZeoGlass and Why is it Different?

The term Geopolymer is today too broad a term to describe specific materials. Since Viktor Glukovsky, USSR, developed concrete materials originally known under the name "soil silicate concretes" in the 1950's and the subsequent introduction of the geopolymer concept by Joseph Davidovits, the terminology and definitions of 'geopolymer' have become more diverse and often conflicting.

BluCem ZeoGlass is a Calcium (Sodium) Aluminosilicate. One of the unique features of BluCem ZeoGlass is the incorporation of Calcium in the structure. Conventional Geopolymer technology will not work in the presence of Calcium ions, yet Calcium is one of the more abundant elements on the planet and is an integral part of many potential raw material sources. BluCem ZeoGlass is a Calcium (Sodium) Aluminosilicate. The incorporation of Calcium in the structure provides additional benefits and also makes BluCem ZeoGlass inherently unique.

BluCem ZeoGlass is an inorganic polymer synthesised from components that include a source of 'available' aluminium. That is, aluminium that is taken up into the structure of the inorganic polymer. This allows for sufficient alumina gel to remain at the surface to offer bacterial protection for the life of the product.

Silica sources include a wide range of raw materials including slags, fly ash, waste glass, hydrothermal silica deposits, clays or other silicate containing materials. This permits a large percentage of recycled materials to be incorporated into the formulated product.

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Recycled Silica Sources

Silica sources include a wide range of raw materials such as recycled glass, slags, fly ash, hydrothermal silica deposits, clays and other silicate containing materials. This allows for a large percentage of recycled waste materials to be incorporated into the formulated product.

The quality of the aggregates allows for the creation of a combined grading, ideal for spray application with maximised compaction. The Calcium Alumino-silicate binder ensures no risk of alkali aggregate reaction together with maximum acid resistance.

Figure 4 - Application showing low rebound benefits of graded aggregates.

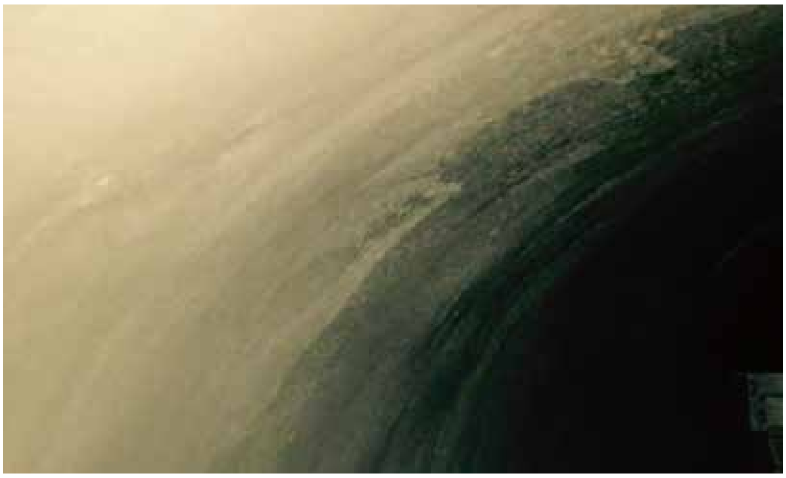

Figure 5 - Compact and dense finish of well graded dry-spray lining.

Glass Aggregates

BluCem ZeoGlass is unique in that the aggregate used is recycled glass and as such totally inert to corrosion in acid sewer environments.

The proprietary binder system used in BluCem ZeoGlass is very low in alkalinity and does not induce any form of ASR (Alkali Silica Reaction) or AAR (Alkali Aggregate Reaction) with such aggregates.

The minimal water demand of this aggregate means very low water cement ratios can be achieved with dry spraying whilst still ensuring proper cement binder hydration and compaction. This greatly enhances the durability of cured BluCem ZeoGlass.

The combined glass aggregate grading allows for a controlled void space of 36% in the blended BluCem ZeoGlass product which permits the formulation to be adjusted for maximum compaction with minimum water demand; further enhancing durability. BluCem ZeoGlass utilises 3mm recycled glass aggregates following extensive testing of various cement and aggregate combinations.

Figure 6 - Shows the carefully graded and crushed recycled glass aggregates utilised in BluCem ZeoGlass.

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BluCem ZeoGlass Test Program

This report focusses on the performance of BluCem ZeoGlass against several leading proprietary cementitious coatings for sewer lining applications. The four products are described by the manufacturers as follows:

Golden Bay AR - Acid resistant cement blended with aggregate

Kerneos Sewpercoat - CAC using calcium aluminate cement and calcium aluminate aggregates

Millikan Geospray - Geopolymer cement system

BluCem ZeoGlass - Calcium (Sodium) Aluminosilicate with recycled glass aggregates

TABLE 1 - MIXING DETAILS AND INITIAL SAMPLE PROPERTIES

Materials	Golden Bay AR	Kerneos	Geospray	BluCem ZeoGlass
Date Mixed	10/11/17	10/11/17	10/11/17	29/3/18
Aggregate to Cement Ratio	1:1	As supplied	As supplied	1.3:1
Water	21%	15%	15%	14%
Set Time	140 minutes	135 minutes	17 minutes	45 minutes
Shrinkage 24 Hours in Water Cure	-0.01%	-0.005%	-0.012%	-0.01%
Shrinkage 28 Days in Water Cure	+0.00%	+0.03%	+0.04%	+0.2%

Notes:
Water % is by weight and added to give equivalent workability and is typical of minimum needed to place by hand.
Dry spraying would achieve a lower W/C ratio.

TABLE 2 - MANUFACTURERS DECLARED SPECIFICATIONS

Materials	Golden Bay AR	Kerneos	Geospray	BluCem ZeoGlass
Quoted Shrinkage	NA	Less than 0.6%	0.07%	Less than 0.5%
24 Hours UCS	NA	40MPa	17MPa	45MPa
7 Days	NA			50MPa
28 Days	NA	70MPa	55MPa	65MPa

Figure 7 - Prisms ready for testing.

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Test Methodology

The selected acid testing regime mirrors a more aggressive version of BRANZ testing for concrete durability under sewer conditions.
In accordance with BRANZ, samples are cured in water for 28 days, weighed, measured and then immersed in an acid solution. The solution is changed every 2 weeks. However, for the purpose of this testing, the BRANZ nominated 1% solution was increased to 2% by volume.

ASTM C250 prisms were adopted has they have a large surface area to volume ratio and allow for measurement of dimension change. In addition to the prisms, 50mm cubes have been cured alongside them for compressive strength testing.

6 Months Acid Exposure

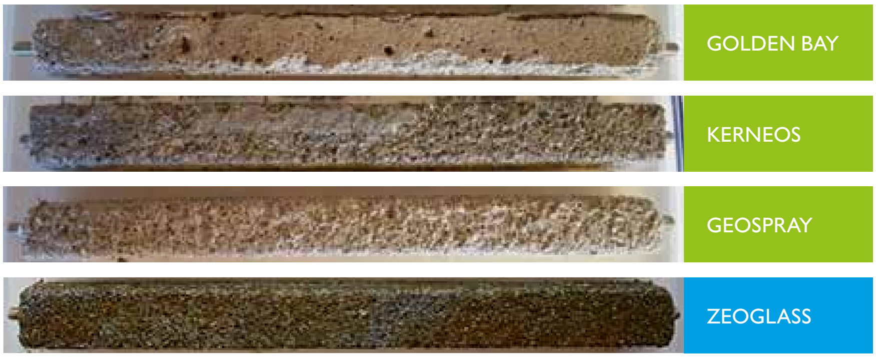

Figure 8 - Prisms at 6 months.

6 Months Exposure Observations

Golden Bay AR Cement is in a very poor condition. Reference pieces are now too exposed to measure length accurately. The prism sides have swollen with material lost to spalling. Expansion of the prism sides is greater than 20% in volume but difficult to be accurate due to the lost material. A weight loss of 5.3% was recordedbut much of the lost material has been replaced by acid sulphate reaction product (which is causing the spalling).

Kerneos CAC started to lose its alumina gel coating; previously evident as a 'surface slime'. Surface now heavily eroded. Prism sides indicate +8% expansion with a +0.02% length change.

Millikan Geospray has lost 22% of its original weight through surface erosion. 12% of the material has been lost from the prism sides. Interestingly the length change is minimal and the same as recorded at 4 months.

BluCem ZeoGlass has retained its dimensions.

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12 Months Acid Exposure

Figure 9 - Prisms at 12 months.

TABLE 3 - 12 MONTH PRISM CONDITION REPORT

Materials	Golden Bay AR	Kerneos	Geospray	BluCem ZeoGlass
Weight Loss/Gain	-25%	-7.43%	-33.8%	-1%
Swelling or Shrinkage	+0.081%	+0.05%	-0.61%	+0.10%

12 Months Exposure Observations

Golden Bay AR Cement lost 25% of its original weight at 1year. Reference pieces are now loose therefore testing discontinued. The increase in length was +0.081% and it appears much of the swelling and spalling was from the sides of the prism.

Kerneos, after 12 months acid exposure, recorded a mean weight loss of 7.43%. This appears to be primarily a loss of alumina gel. Exposed fibres are clearly evident. The water cured control material increased in length by -0.13% which is surprising as it was not a positive expansion and may indicate a degree of conversion to the cubic crystalline form common in high alumina cement (CAC) mortars.

Millikan Geospray recorded a 33.8% weight loss, over the 12 months. Another alarming feature is the -0.61% shrinkage after 12 months acid sulphate cure and a +0.39% expansion under regular water cure over the same period, suggesting a relatively unstable binder. The sample has a strong odour (which may be hazardous in confined spaces). Testing has been discontinued on this sample.

BluCem ZeoGlass shows a slight 1% loss in weight after 12 months in acid cure conditions. A slight gain in weight was noted in the plain water cured sample. Expansion under acid sulphate cure is 0.1% and virtually the same as recorded in plain water cure (0.12%) over the same period. Prisms were in excellent condition and showed no alumina gel dissolution. After 12 months, no changes were observed.

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18 Months Acid Exposure

Figure 10 - Prisms at 18 months.

TABLE 4 - 18 MONTH PRISM CONDITION REPORT

Materials	Golden Bay AR	Kerneos	Geospray	BluCem ZeoGlass
Weight Loss/Gain	Discontinued	-6.8%	Discontinued	+1.8%
Swelling or Shrinkage		+0.05%		+0.10%

18 Months Exposure Observations

Golden Bay AR Cement Testing stopped at 12 months.

Kerneos lost 6.8% weight over original 28 days age due to loss materials and alumina gel from surface. Dimension is only 22/23mm square.

Millikan Geospray Testing stopped at 12 months.

BluCem ZeoGlass stabilised in conditions with very little change observed since 12 month measurements. The prism retained original 25/26mm square dimensions.

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24 Months Acid Exposure

Figure 11 - Prisms at 24 months.

TABLE 5 - 24 MONTH PRISM CONDITION REPORT

Materials	Golden Bay AR	Kerneos	Geospray	BluCem ZeoGlass
Weight Loss/Gain	Discontinued	-14.4%	Discontinued	-1.78%
Swelling or Shrinkage		+0.046%		+0.065%

24 Months Exposure Observations

Golden Bay AR Cement Testing stopped at 12 months.

Kerneos lost 14.4% weight over original 28 days age due to loss materials and alumina gel from surface.

Millikan Geospray Testing stopped at 12 months.

BluCem ZeoGlass lost 1.78% in weight over the original 28 day age. BluCem ZeoGlass lost less sufrace material than the Kerneos sample at the same age.

TABLE 6 - SUMMARY OF COMPRESSIVE STRENGTHS

Materials	Golden Bay AR	Kerneos	Geospray	BluCem ZeoGlass
Water:Powder	21.0%	15%	15%	14% (12%)
24 Hour in Water		47.0MPa	19.5MPa	27.0MPa (47.5MPa)
3 Days in Water		51.0MPa		30.0MPa
7 Days in Water	22.0MPa	53.0MPa		31.0MPa (50.4MPa)
28 Days in Water		57.0MPa	64.5MPa	43.0MPa (72MPa)
56 Days in Water	33.0MPa	62.0MPa	61.0MPa	51.5MPa
12 Months in Water				55MPa
28 Days in Acid	n/a	58.5MPa	48.0MPa	43.0MPa
56 Days in Acid	n/a	55.5MPa	n/a	43.5MPa
90 Days in Acid				39.9MPa
6 Months in Acid	n/a	40.1MPa	n/a	
10 Months in Acid				30.5MPa
12 Months in Acid		19.8MPa		32.0MPa

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