Durability properties of ENVISIA® – a lower carbon concrete

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Abstract: Boral has developed a lower carbon concrete, called Envisia®, using a ground slag product. With a typical blend of 60% ZEP and 40% SL cement, and has similar plastic properties to conventional concrete. Unlike traditional high SCM concrete, there is no compromise on early strength and it exhibits much lower free drying shrinkage. These properties have been presented previously at the CIA 2013 conference. Since then, comprehensive research has been carried out to assess the durability properties of Envisia®, in particular chloride resistance, water permeability and alkali silica reactivity (ASR). A 60MPa Envisia® concrete developed for marine applications was compared with an equivalent grade of conventional concretes (SL/FA and SL/GGBFS). In comparison with traditional marine concrete (SL/GGBFS), Envisia® shows much lower chloride diffusion coefficient by both NT492 and NT443 tests, lower water sorptivity by ASTM C1585 method and lower water permeability by DIN 1048 test. Envisia® is far superior to the conventional SL/FA concrete for all the aforementioned durability tests. Secondly the Envisia concretes were soaked in 10% sulphuric acid solutions for 10 weeks. Envisia® has about 41% mass loss versus 61% for the control concrete. The blended ZEP®/SL has an expansion of 160 microstrains after 16 weeks as per the sulphate resistance test AS 2350.14 method, compared to 510 microstrains with SL alone. Finally, Envisia was tested for alkali silica reactivity by the Australian Standard accelerated mortar bar test AS 1141.60.1 method. Three established reactive aggregate sources were selected. The experiment results indicate that Envisia® has a significant mitigating effect on potential alkali silica reaction, reducing the expansion to <0.038% ~0.067%, well below the allowable limits of 0.10% at 21 days, and significantly lower than the controls with SL only, about 0.288% ~ 0.561% at 21 days. The superior durability properties of Envisia® make it suitable for use in demanding applications where lower drying shrinkage, higher chloride resistance and resistance to sulphate or acid attack are required. It is also suitable for use to mitigate ASR potential with potentially reactive aggregates.

Keywords: durability, lower carbon concrete, ASR, Envisia®, ZEP®.

1. Introduction

Boral is committed to creating sustainable solutions for a world-wide building and construction industry (1) including the development and use of fly ash (FA) in concrete in 1966-1968, the development and use of Ground Granulated Blast Furnace Slag (GGBFS) as cement replacement in 1970-1972. In 1995, Boral developed the “Green Concrete” now sold as “Envirocrete” with use of recycled raw materials, and recently the development of Envisia® - a low carbon high early strength concrete.

The most commonly used supplementary cementitious materials (SCMs) in concrete mixes are typically fly ash and/or GGBFS, although others, such as ground glass and metakaolin, have been trialed as well. One issue with the higher use of SCMs is that they can lead to concrete with lower early strength gain and higher shrinkage than standard concretes, potentially compromising construction cycle times and element design outcomes. With this as a background, Boral Cement commenced an R&D program in 2008 to develop a new binder system with a low carbon footprint, but able to provide strength gain similar to conventional concretes and lower shrinkage (2, 3, 4).

2. Envisia® with high performance characteristics

Following review of concrete applications with the lowest use of supplementary cementitious materials (SCM’s) it was evident after studying the markets that post tensioning was a limiting factor due to high early strengths. Efforts were focused on increasing the early strength if high cement replacement concretes were utilized, leading to Envisia ® being launched in 2013, using the new binder ZEP. The key criteria for Envisia®, when compared to “conventional” concretes were(2, 4)

- Compliance with existing relevant Australian Standards AS 3972 and AA 1379 and Design Codes.

- Have the normal hydration products of Portland Cement (mainly mixed hydrates of calcium silicates, aluminates and ferrites) but improved etttringite formation and stabilization (as a result, no compromise on early strength but improved shrinkage and durability).
- Demonstrate plastic properties consistent with conventional concretes.
- Exhibit much lower drying shrinkage at 56 days.
- Exhibit similar setting times and placing and finishing characteristics.
- Exhibit higher early strength for post-tensioned concrete application.
- Exhibit much higher flexural strength for pavement concrete application.
- Exhibit significantly lower creep performance.
- Compatible with existing admixture technology.

3. Experimental Programs

Envisia® has been used in several projects. The previous papers (3, 4) have reported its properties including the water demand, setting time, compressive strength and free drying shrinkage, flexural strength and creep. This paper focuses on the durability properties such as the water permeability and sorptivity, chloride migration and diffusion coefficient, sulphuric acid and sulphate resistance, and alkali silica reaction migration.

3.1 60 MPa concrete durability tests

The Portland cement content in Envisia® can be varied to adjust properties, however research has focused on concretes with 60% cement reduction for superior durability. Two control concretes include the traditional SL cement/Fly ash combination (SL/FA), and a high SCM "marine" cement blend of SL and GGBFS in the proportions 35:65.

The durability tests chosen include water permeability DIN 1048, water sorptivity ASTM C1585 and RMS T362, and chloride migration/diffusion coefficient tests - Nordtest NT Build 492 and NT Build 443, which now are extensively used to determine the chloride migration/diffusion coefficient of concrete and to estimate the service life of structures exposed to chloride rich environments. The NSW RMS also prescribes NT Build 492 and NT Build 443 chloride test coefficient limits as a durability requirement in its B80 Concrete Work for Bridges specification. Table 1 outlines the trial details.

Table 1. High durability testing mix details.

Properties	Unit	SL/FA Control	High SCM Mix	Envisia®
Total Binder content	Kg/m^3	520	520	520
% Portland Cement Replacement	%	25	65	60
Water/binder ratio	ratio	0.356	0.356	0.343
Slump	mm	150	160	150
3 days Compressive Strength	MPa	43.0	27.0	44.0
7 days Compressive Strength	MPa	55.0	42.0	56.0
28 days Compressive Strength	MPa	71.0	68.0	69.5

It can be seen from Table 1 that all three concretes have same binder content, 520kg/m^3, similar water/binder ratio, and consistent workability in terms of slump 150-160mm. As expected, the SL/GGBFS mix had lower strength gain at early age 3d and 7d. However, all three concretes have equivalent 28 days compressive strength, 68.0~71.0MPa, when the durability tests like the NT Build 492, DIN 1048, sorptivity

ASTM C1585 commenced. The NT Build 443 started at age of 56 days as per RMS B80 Table 6 suggested time, when all concretes would have become relatively mature.

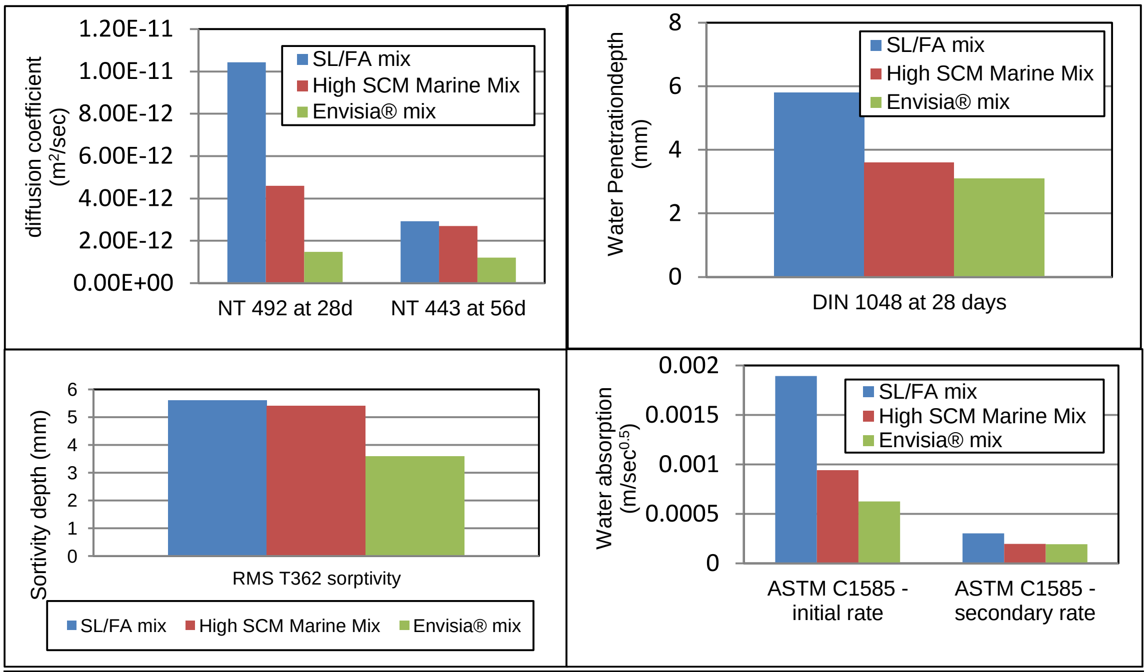


Figure 1. Durability testing data comparison.

It is clear that Envisia® outperformed the conventional SL/FA and SL/GGBFS concretes in terms of chloride migration/diffusion coefficient. In terms of chloride migration coefficient by NT Build 492 test, the value of Envisia® is about 14% and 32% in comparison with SL/FA and SL/GGBFS concretes, respectively. After a relatively longer curing period, for example, the NT Build 443 test at 56 days, the chloride diffusion coefficient of Envisia® is about 41%-45% of the other two conventional concrete mixes.

Furthermore, as per criteria in RMS B80 Table 6, the Envisia® concrete performed the best, meeting both requirements of Classification C limits in terms of NT Build 492 (<4.0E-12m^2/sec) at age of 28 days and NT Build NT443 (<2.0E-12m^2/sec) at 56 days. By contrast, both SL/FA and SL/GGBFS concretes can be classified into Exposure Classification B2.

Figure 1 also demonstrates that the Envisia® concrete performed significantly better than the conventional concretes in both sorptivity by RMS T362 method and ASTM C1585 method, and water permeability results by DIN 1048 method. In each case, the Envisia® is at least 35% better than SL/FA and 15% better than SL/GGBFS control.

3.2 Sulphuric acid resistance

Concrete is the most widely used construction material for sewer structures because of its economic and durable characteristics under normal conditions. Under certain conditions, the environment in some concrete sewer structures can become aggressive owing to the formation of sulphuric acid converted from hydrogen sulphide by aerobic bacterial. The sulphuric acid is responsible for the corrosion and degradation of concrete. Significant deterioration of concrete in sewer environments has been reported worldwide. Some reported cases have been listed in Table 2 (according to the location of the aggressive environment) and is presented in terms of pH values and the corrosion rate of concretes in such situations and is expressed as the deterioration depth of concrete in mm per year.

Table 2. Corrosion cases reported worldwide for concrete sewer structures.

Country	Structure	Corrosion rate	pH	Reference
Australia	Sewer pipe	3.2 mm/year	1.0	Thistlethwayte and Davy (7)
USA	Lift station	1-3 mm/year	3.0	Sarkar (8)
Germany	Sewer pipe	10 mm/year	1-2	Sand and Bock (9)
Japan	Sewer pipe	4.3-4.7 mm/year	1.9	Mori and Nonaka (10)

Acid sulphate soil is another situation that leads to sulphuric acid corrosion when a concrete structure is built in such an area. Acid sulphate soil is the common name given to naturally occurring soil and sediment containing iron sulphides, principally the mineral iron pyrite (FeS_2), or containing acidic products of the oxidation of sulphides. When iron pyrite is exposed to air, oxidation takes place and sulphuric acid is ultimately produced. It has been estimated conservatively that Australia has over 4 million hectares of acid sulphate soils. Along the coast of New South Wales and Queensland, there are 2.9 million hectares of acid sulphate soils (5).

The use of a higher percentage of acid (i.e. 10%) is advantageous for accelerated testing. Researchers in the County Sanitation Districts of Los Angeles (6) prefer to use 10% sulphuric acid as this aggressive media provides the results in eight weeks.

The sulphuric acid resistance of Envisia® was investigated in terms of mass change based on the procedures of ASTM C267. Samples of a SL cement based concrete served as the reference. The acid solution was 10% sulphuric acid concentrations by mass.

The Envisia® mix was 330kg/m^3 cementitious with 40%SL and 60%ZEP® while the control concrete was 330kg/m^3 of SL cement only. Both concretes have 80mm slump. The Envisia® has a 28 day compressive strength of 45MPa while the control concrete has 50MPa. To avoid the influence of the coarse aggregate grains on the mass change, the fresh concrete was sieved through 4.75mm sieve to have the mortar proportion, which was further cast into 150mm diameter and 100mm thick cylindrical samples. After 28 days wet curing by AS 1012.8.1, it was saw cut into three discs, about 33mm thickness. All surfaces were coated with epoxy Sikagard 62 except one face was exposed to 10% sulphuric acid for 10 weeks. The ratio of acid volume (ml) and the sample surface area (cm^2) is about 10 times. The acid solution was refreshed three times during the 10 weeks test period. The use of 10% sulphuric acid is arbitrary, but it represents a more corrosive environment than the actual service situation.

The mass change is presented in Figure 2 while some photos in Figure 3. The samples after acid exposure were split and sprayed with the phenolphthalein solution to check the pH values.

As showed in Figure 2, Envisia® specimens have approximately 41% mass loss, lower than the control of 61% after 10 weeks in the same acidic environment, though the surface of Envisia® has similar appearance, for example, the lost paste and residual siliceous sand grains.

In addition, all specimens have the initial thickness approximately 33mm. After 10 weeks acid test, the control SL has its residual layer of about 14mm thick while the Envisia® being 19mm. This comparison demonstrates that the Envisia® is superior to Portland cement paste in resisting sulphuric acid attack. Accordingly it is expected that Envisia® can significantly prolong the service life if it is used in the same condition to replace the normal concrete.

It is obvious from Figure 3 that the specimens of SL and Envisia® concretes were seriously eroded. However, after spraying a 1% phenolphthalein on the freshly fractured section of each sample, the colour is shown in Figure 3c). There is about 2mm neutralized layer, showing grey, but most of the fractured cross section on the sample of both SL and Envisia specimens was still in pink indicating that the concrete behind the corroded surface layer still had a pH above 9 after sulphuric acid attack.

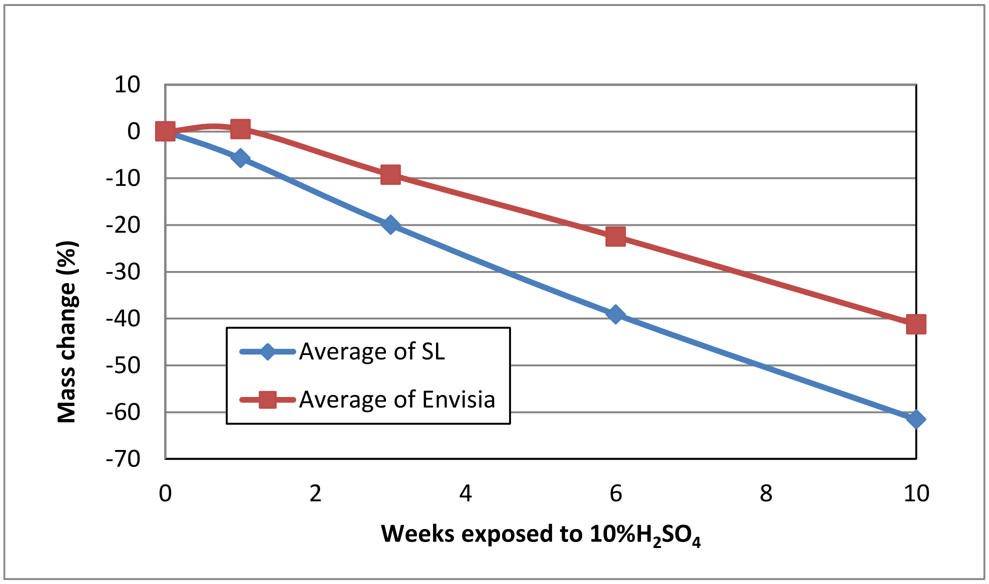
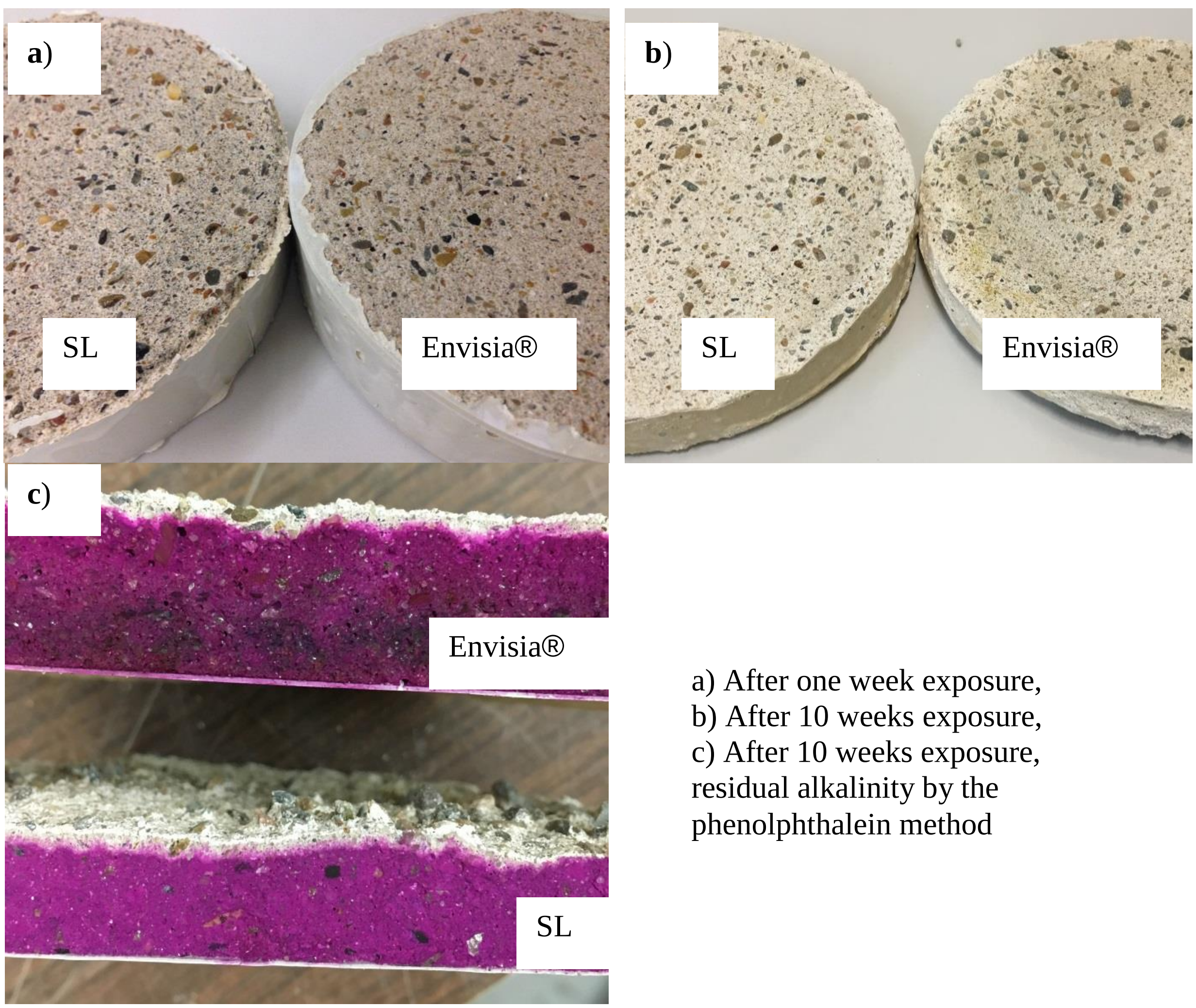


Figure 2. Mass change of Envisia® and SL concretes after 10% H_2SO_4 exposure.



a) After one week exposure,
b) After 10 weeks exposure,
c) After 10 weeks exposure, residual alkalinity by the phenolphthalein method

Figure 3. Images of Envisia® and SL mortar specimens after 10% H_2SO_4 exposure.

3.3 Sulphate resistance test

Concrete exposed to sulfate solutions can be attacked and may suffer deterioration to an extent. Sulphate may be present in industrial effluents and wastes such as industries associated with the manufacture of chemical batteries, aluminum and in the mining industry (11).

The sulphate resistance test was carried out in accordance with AS 2350.14 – Length change of cements mortar exposed to a sulphate solution for 16 weeks. The blended SL-ZEP® (40%:60%) was compared directly with 100% SL cement. The control SL mix had 28 days strength of 57.8MPa while the SL-ZEP® blended cement has achieved 50.1 MPa. The graph in Figure 4 demonstrates the sulphate resistance performance of SL-ZEP® blended cement relative to Type SL cement.

Australia Standard AS 3972 specifies an upper limit of 750 microstrains for mortar bar expansion for Type SR cement. The control mortar with SL cement has the expansion of about 510 microstrains. By contrast, the SL-ZEP® blended cement performed well, having the expansion of only 160 microstrains after 16 weeks exposure to standard sulphate solution. This comparison indicates that Envisia® with SL/ZEP® blend cement would have much better sulphate resistance.

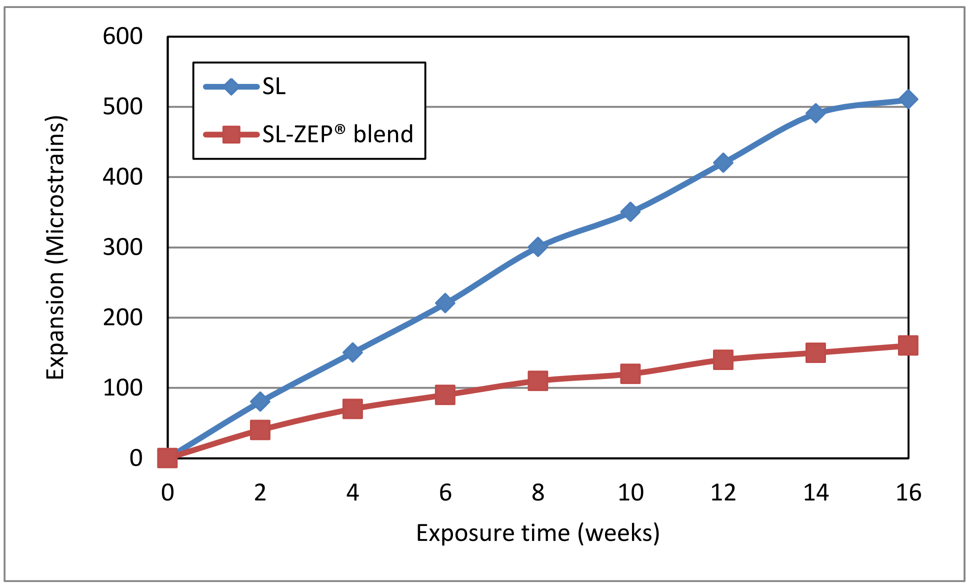


Figure 4. Sulphate resistance of Blended SL-ZEP® cement as per AS 2350.14 test.

3.4 Alkali Silica Reactivity (ASR)

A well-documented positive attribute of the inclusion of SCM's in concrete is their potential to mitigate alkali silica reactivity caused by reactive aggregates. Two mortars, one with SL cement and one with an SL/ ZEP® at 40:60 blend, were tested by the Australian Standard accelerated mortar bar test (AMBT) method, AS1141.60.1. Three known reactive aggregates (reactive agg A, B, C) were used in the mixes.

Table 3. Alkali silica reaction mortar bar test by AS 1141.60.1.

Test days	3	7	10	14	17	21	28
Reactive agg A - 100% SL	0.031	0.121	0.187	0.263	0.311	0.370	0.444
Reactive agg A - 40% SL-60%ZEP	0.003	0.014	0.022	0.031	0.041	0.053	0.073
Reactive agg B - 100% SL	0.017	0.071	0.130	0.199	0.239	0.288	0.340
Reactive agg B - 40% SL-60%ZEP	0.003	0.013	0.018	0.026	0.033	0.038	0.042
Reactive agg C - 100% SL	0.023	0.198	0.299	0.373	0.417	0.461	0.561
Reactive agg C - 40% SL-60%ZEP	0.003	0.021	0.033	0.043	0.053	0.067	0.088

The ASR results are shown in table 3. As expected, the expansion of three reactive aggregates with SL only was significant, about 0.288% ~ 0.561% at 21 days. However, the Envisia® has a dramatic mitigating effect on potential alkali silica reaction, reducing the expansion to <0.038% ~0.067%, well below the allowable limits of 0.10% at 21 days. This demonstrates that the incorporation of ZEP® in the binder has a significant mitigating effect on potential ASR expansion, reducing the expansion to well below the allowable limits (essentially < 0.10%) at 21 days.

4. Conclusions

Durability properties of Envisia® concrete in terms of water permeability, water sorptivity and chloride migration/diffusion coefficient are also significantly improved in comparison with equivalent strength grade of conventional SL/FA and SL/GGBFS concretes.

It is expected that Envisia® has superior sulphuric acid and sulphate resistance in comparison with standard concretes.

Envisia® concrete efficiently mitigates the alkali silica reaction impact of highly reactive aggregates.

5. Acknowledgement

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