Development and commercialisation of low carbon, low shrinkage, highly durable ENVISIA® Concrete

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Development and Commercialisation of Low Carbon, Low Shrinkage, Highly Durable ENVISIA® Concrete.

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Abstract: The development and commercialization of Boral's low carbon, low drying shrinkage, highly durable ENVISIA® concrete is discussed with reference to specific properties of the concrete as well as performance and perception barriers that have been met. The performance of ENVISIA® concrete is shown to be not as affected by increases in w/c ratio as conventional binder system concrete. The chloride durability of ENVISIA® has outperformed both more conventional concrete designs and the requirements of NSW Roads and Maritime Services Bridge Specification B80 leading to the potential for increased service life of reinforced concrete structures. The reduced Portland Cement content of ENVISIA® concrete makes it less susceptible to sulfuric acid attack to the point where silica fume has little impact. Despite these performance benefits the challenge remains for some specifiers to accept concrete containing old ground granulated blast furnace slag treated in a new way.

Keywords: durability, lower carbon concrete, low shrinkage, ENVISIA®

1. Introduction

ENVISIA® concrete contains a specially milled ground granulated blast furnace slag (GGBFS) which allows concretes that achieve high Portland cement replacement levels without compromising setting time or early strength. After a number of years of research and development, Boral first commercialised this concrete in July 2013 as a low carbon, high early strength concrete with low drying shrinkage aimed specifically at the high-rise post-tensioned market. Over the course of commercialization demand for other grades lead to the development of additional mix designs spanning many applications and for multiple performance benefits including low shrinkage high strength (80MPa+) and durability against chlorides and acid attack.

2. Concrete Properties

2.1 Strength and the Effect of Water

First and foremost in a majority of applications, concrete is required to achieve a specified compressive strength. The upscaling of laboratory work on ENVISIA® to field supply of concrete was relatively straight forward for the initial intended market of post tension slabs with compressive strengths of 32 and 40MPa. Good correlation between lab and field results was observed, including achievement of stressing strengths for post-tensioned concrete and verification of low drying shrinkage. Once customers started requesting variations though, it became apparent that traditional means of achieving higher strengths would need to be rethought and new relationships established.

Conventional wisdom would dictate that to increase strength one must, with all else being equal, decrease water/cementitious ratio by either increasing cement content, decreasing water content through use of high range water reducers or a combination of the two. Such conventional wisdom however did not apply to ENVISIA®. Table 1 compares S40 and S50 ENVISIA® concrete cementitious content with w/c ratio and measured compressive strength in initial supply.

Table 1. S40 and S50 ENVISIA® concrete properties through May 2014 (average)

Grade	Cementitious Content (kg)	W/C Ratio	Average Compressive Strength (MPa)
S40	435	0.44	44.5
S50	500	0.39	48.3

Despite significantly more cement and lower w/c ratio, the compressive results of the S50 concrete were only marginally higher than those of the S40 concrete. Although all supply at this stage was into applications that did not require 50MPa for structural purposes, the difficulty in achieving higher strength caused concern that there may have been an inherent limitation to concrete strength.

During the first year of supply, an anecdotal observation was made that slump and by extension water addition did not appear to be detrimental to strength or shrinkage. In August 2014 a field trial to assess finishing characteristics of ENVISIA® in industrial flat floor applications was conducted. Concrete was designed at 150mm target slump without the use of high range water reducers. Of three loads supplied, the first and third arrived at 140mm slump. The second load had extra water added at the plant and arrived at 180mm slump. It was assessed that this load had approximately 5 litres per cubic metre of extra water added when compared to the other two loads. The w/c ratio of this load was approximately 0.47 compared to 0.46 designed and supplied in the other loads. Table 2 compares compressive strength and shrinkage of the three loads.

Table 2. Slump, Strength and Shrinkage of ENVISIA® concrete – Flat floor trial 4th Aug 2014

Load	Slump (mm)	28 Day Compressive Strength (MPa)	56 Day Drying Shrinkage (μstrain)
Load 1	140	46.8	
Load 2	180	49.5	310
Load 3	140	47.8	280

The load with the higher slump tested as having increased compressive strength and whilst drying shrinkage was marginally higher, it was still very low. This direct comparison seemed to verify the anecdotal findings of earlier supply.

To verify this finding a laboratory trial was carried out to assess the effect of adding water to ENVISIA® concrete. A mix was trialed at 80mm slump then repeated at 120mm and 160mm slump using water addition only to achieve the slump growth. A series of control tests using conventional Ordinary Portland Cement (OPC) concrete was also carried out. The results of the trials are shown in Table 3.

Table 3. Effect of Water on ENVISIA® and Conventional Concrete

Mix	Water Content (l)	Slump (mm)	28 Day Compressive Strength (MPa)	Relationship to Low Water Base Result	56 Day Drying Shrinkage (μstrain)	Relationship to Low Water Base Result
ENVISIA® Low Water	188	80	48.0		320	
ENVISIA® High Water	199	160	46.4	-3.3%	290	-9.4%
Conventional OPC Low Water	201	80	66.4		620	
Conventional OPC High Water	213	160	61.4	-7.5%	640	3.2%

The results confirm that the addition of water to ENVISIA® concrete is not as deleterious to compressive strength or drying shrinkage as such addition would be to a conventional concrete binder system. This highlights that higher SCM concretes like ENVISIA® can behave differently than expected from conventional wisdom, and that this reduces variability in concrete performance on site. The insight has allowed us to make high strength, high performing ENVISIA® concretes without drastic water cut, meaning that the rheology is good whilst simultaneously achieving excellent hardened property results.

ENVISIA® is supplied at higher slump than conventional concrete and high strength 80MPa ENVISIA® concrete now[1] uses 13 litres per cubic metre more water than its equivalent conventional design.

The mantra “water is bad” and “low slump makes good concrete” are well ingrained in the industry and fail to take into account developments in concrete technology. Whilst it cannot be said that uncontrolled water addition is acceptable, the data exists proving performance of ENVISIA® concrete containing extra water is not as impacted as with conventional concrete and this should be considered when assessing suitability of concrete mixes.

2.3 Chloride Durability

NSW Roads and Maritime Services (RMS) has strict prescriptive and performance requirements for concrete placed in bridges where conditions are such the exposure classification C is deemed. A summary of some of these requirements is presented in Table 4.

Table 4. Summary of Concrete Durability Requirements[2]

Minimum Cement Content	Maximum w/c ratio	Maximum Rapid Chloride Migration Coefficient NT492 ($x10^{-12}$ m/s)	Maximum Effective Chloride Diffusion Coefficient NT443 ($x10^{-12}$ m/s)
420kg	0.40	4.0	2.0

Initial research[3] by Hocking et al indicated that chloride durability would be improved in ENVISIA®. As the commercialisation of ENVISIA progressed, the need to supply concrete into highly aggressive environments led to bespoke mix designs being created to provide service life improvements to concrete structures. A summary of results is presented in Table 5.

Table 5. Summary of Concrete Durability Trial Results

	Cementitious Content (kg)	w/c ratio	28 Day Strength (MPa)	56 Day Drying Shrinkage (mstrain)	Rapid Chloride Migration Coefficient NT492 ($x10^{-12}$ m/s)	Effective Chloride Diffusion Coefficient NT443 ($x10^{-12}$ m/s)
ENVISIA	543	0.39	72.1	390	2.29	1.04
Conventional	546	0.34	86	570	5.53	1.87
ENVISIA	517	0.39	75.9	350	1.75	1.04
Conventional	517	0.39	76.9	560	5.57	2.13
Conventional	366	0.47	54.7	490	3.42	-
ENVISIA	361	0.52	55.5	330	1.88	-
ENVISIA	367	0.50	52.5	360	1.16	-
ENVISIA	431	0.47	44.5	340	2.93	1.54
ENVISIA	432	0.46	47.6	350	2.62	-
Conventional	540	0.37	78.3	590	3.61	-
Conventional	540	0.37	65.8	600	4.57	1.64
Conventional	535	0.38	64.5	500	3.98	1.47

A direct comparison of the rapid chloride migration coefficient and w/c ratio of the various concretes shows that even at higher w/c ratios ENVISIA® outperforms conventional concrete and the requirements of RMS B80 specification for exposure classification C, even at w/c ratios more commonly associated with non-durable concrete mixes. The numbers are sufficiently low as to greatly increase the service life of a structure and have led to supply into seawall applications as well as other salt water piles and retaining walls. Although specifying engineers have been justifiably conservative in their approach to ENVISIA®, there is now a strong body of evidence supporting its use in aggressive environments, indicating that the service life can be extended, or cover reduced for a given service life. Using ENVISIA® concrete will also significantly reduce the embodied CO_2 content of infrastructure projects.

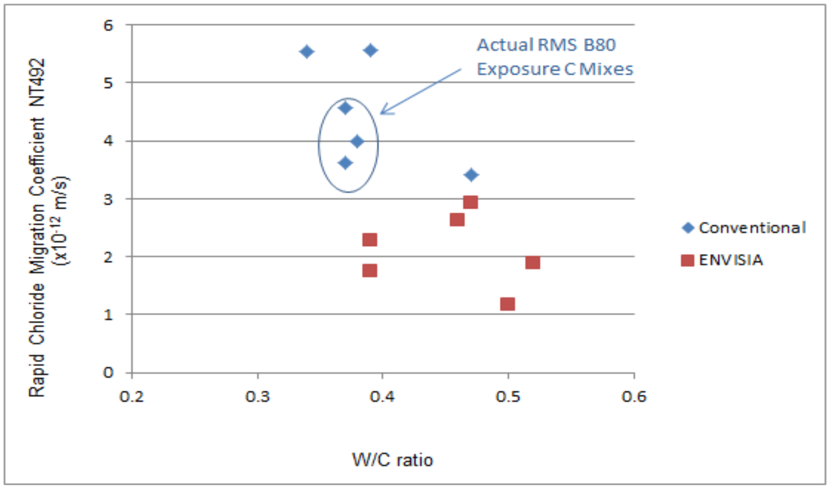

Figure A. Rapid Chloride Migration Coefficient vs W/C ratio

2.4 Resistance to Acid Attack

As concrete is an alkaline material it is known to be susceptible to acid attack. One of the main contributors to such attack is the presence of Calcium Hydroxide ($Ca(OH)_2$) by-product of the cement hydration reaction. The use of silica fume has been proposed by Torii and Kawamura[4] and others as a means of reducing $Ca(OH)_2$. By reducing the amount of $Ca(OH)_2$ produced in the concrete through reduction in Portland Cement content it should also be possible to improve resistance to acid attack. Hocking et al[3] showed that using treated GGBFS in ENVISIA® improved resistance to sulfuric acid attack.

In response to a request to supply concrete for use in a waste management facility, these two theories were combined and trials conducted to assess acid resistance of various concrete mix designs incorporating either or both ENVISIA® and silica fume. As the specification called for 15% silica fume five trial mix designs were formulated, one using conventional supplementary cementitious materials and the other four using different ENVISIA® concretes with varying silica fume and w/c ratios. Highly concentrated sulfuric acid (10%) was used as the destructive medium so as to provide a worst case test. The mix information and strength is shown in Table 6 and the acid resistance in Figure B.

Table 6. Summary of Concrete Properties in Resistance to Acid Attack Trial

Mix description	Conventional High GGBFS 15% Silica Fume	ENVISIA 15% Silica Fume	ENVISIA 7.5% Silica Fume	ENVISIA NIL Silica Fume	ENVISIA 15% Silica Fume + high W/C
Total Cementitious (kg)	457	459	460	457	461
Portland Cement Content (kg)	228	202	202	214	202
Flyash %	23%	0%	0%	0%	0%
untreated GGBFS %	9%	0%	0%	0%	0%
Silica fume %	15%	15%	7.5%	0%	15%
Water/binder ratio	0.354	0.357	0.358	0.362	0.385
Slump (mm)	170	170	160	180	180
Compressive strength (MPa) - 7d	52.0	68	65.0	57.8	62.8
Compressive strength (MPa) - 28d	81.3	83.3	79.5	71	74.5
Drying shrinkage (microstrain) - 56d	460	270	240	290	270

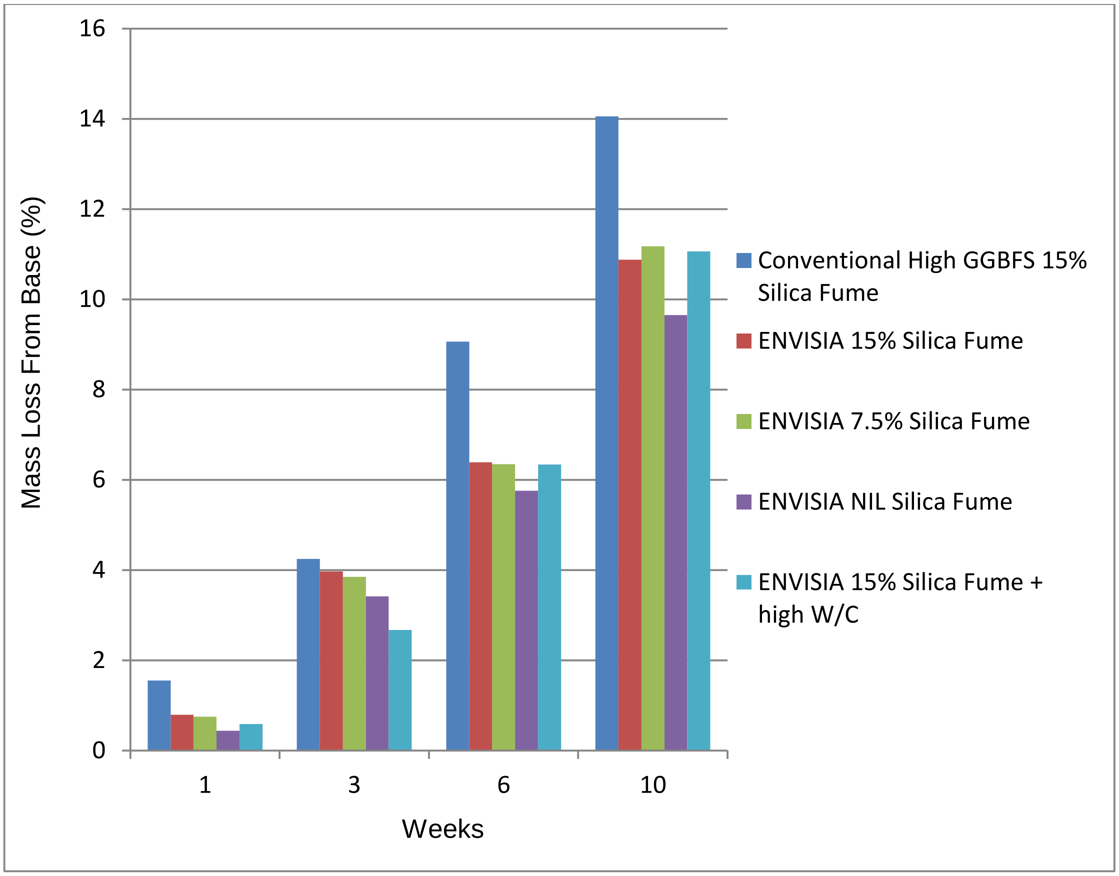

Figure B. Acid Resistance of Concrete (10% H_2SO_4)

It is evident that at each time interval the acid resistance performance of the ENVISIA® mixes were superior to the conventional concrete control mix and that at 10 weeks the concrete which exhibited the lowest mass loss was the ENVISIA® concrete not incorporating any silica fume.

Despite these trials an alternate design was prescribed and supplied into the project. The design had a higher cement content in the hope that the extra $Ca(OH)_2$ would react with the 15% silica fume to form a more impervious barrier to the acid attack. A field sample of the concrete was exposed to the same testing regime. The average mass loss on the sample at 10 weeks was found to be 30.03%. The concrete supplied had a lower resistance to acid attack due to reliance on silica fume in isolation.

3. Conclusions

The development and commercialization of ENVISIA® concrete has led to a new generation of higher performing, low carbon concretes. As with any product introduction there have been opportunities to learn and refine mix designs to the point that ENVISIA® concrete is now available across a wide range of strength grades with performance attributes that cannot be matched by conventional concretes. The adoption of ENVISIA® has followed the typical cycle of diffusion of innovation, where early adopters who understand the performance benefits use it before wider spread adoption by the market in general. Data gained from these early adopters has proven the performance benefits of Envisia in the field.

4. Acknowledgement

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5. References

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