Product Evaluation of Great White Halloysite Kaolin Clay (Great White HRM^{TM}) for Andromeda Metals Ltd

by

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February 2023

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Executive Summary

As the year 2030 is fast approaching and with commitment by the Australian government to reduce CO_2 emissions by 43% as compared to 2010 (1) levels, the OPC and concrete industry plays a critical role in this reduction. Globally the industry contributes 8% of global emissions (2). An independent report conducted by VDZ (2), states that one solution is to lower the total binder of concrete, this includes ordinary Portland OPC (OPC) and supplementary cementitious materials (SCMs).

The aim of this project was to evaluate the use of halloysite-kaolin (Great White HRM^{TM}), that is found in South Australia and is referred to as the "Great White Project", and will be mined by Andromeda Metals Pty Ltd, in reducing the total binder in concrete while still maintaining plastic and mechanical properties. The unique properties of the halloysite-kaolin, allow concrete technologists to design concrete with a coarser particle size distribution (PSD), while controlling any segregation and excessive bleeding.

A methodology was adopted that reduced the binder content by 5.5%, then increasing the SCM proportion by 2%. To offset the loss in absolute mix volume, the fine aggregate mass was then increased by 4%, with the manufactured sand mass, increased by 40% in the increased fine aggregate mass, with the remainder of the increased fine aggregate mass being comprised of fine sand. The water/binder (W/B) ratio was increase by 0.1 and the water reducer (W/R) admixture was also increased by 100ml/100kg/binder. Two concrete strengths were used for the evaluation of Great White HRM^{TM}, comprising of a 32Mpa and 40Mpa mix. These mix designs are currently being supplied into the concrete industry and conform to AS1379-2007 (3).

The change in mix design allowed for the slump to be achieved initially for both the control and mixes containing, Great White HRM^{TM}. The flow with Great White HRM^{TM} did show that an additional 20% and 13% drops for 32Mpa and 40Mpa respectively were required. Compressive strength for 32Mpa control and 32Mpa Great White HRM^{TM} at 24hrs, 7days and 28days were, 9/8.3Mpa, 25.8/26.5Mpa and 37/35.8Mpa respectively. Compressive strength for 40Mpa control and 40Mpa Great White HRM^{TM} at 24hrs, 7days and 28days were, 12.3/10Mpa, 30.8/28.3Mpa and 44/44.3Mpa respectively. No changes in rate of bleed to total water content were observed with all mixes achieving 2%. Air contents in the 40Mpa control and 40Mpa Great White HRM^{TM} were 1.5% and 1.6% respectively, and in the 32Mpa control and 32Mpa Great White HRM^{TM} were 2.4% and 3.6% respectively, the increased air did not appear to have any detrimental effects on the plastic and mechanical properties. The plastic densities increased in mixes containing Great White HRM^{TM} by 30kg/m^3 and 80kg/m^3 for 32Mpa and 40Mpa respectively. The initial and final setting times of mortar was comparable for both the control and mixes containing Great White HRM^{TM}, with 20 minutes reduction in the final setting time for 32Mpa Great White HRM^{TM} and an additional 20 minutes in initial setting for 40Mpa Great White HRM^{TM}.

An internally developed life cycle analysis (LCA) tool see annex C, which calculates total CO_2 emissions, referred to as Global Warming Potential (GWP), only using current available environmental product declaration (EPDs) for OPC and aggregates, and calibrated to the Global Cement and Concrete Association (GCCA) EPD for accuracy was adopted. The outcome was a calculated reduction of GWP by 7.2% and 7.25% in 32Mpa and 40Mpa respectively when utilising Great White HRM^{TM} in the concrete mix design, highlighting the potential for Great White HRM^{TM} to assist in reducing GWP in concrete.

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Glossary

CO_2 – Carbon Dioxide
EPD – Environmental Product Declaration
F/S – Macka's Fine Sand
GP – General Purpose
GCCA – Global Cement and Concrete Association
GWP – Global Warming Potential
LCA – Life Cycle Analysis
M/S – Manufactured Sand
MPUV – Mass Per Unit Volume
Mpa - Megapascals
OPC – Ordinary Portland Cement
PSD – Particle Size Distribution
SCMs – Supplementary Cementitious Materials
W/B – Water/Binder Ratio
W/R – Water Reducer

Chapter I – Project Introduction

As the year 2030 is fast approaching, the Australian Government has committed to reducing the CO_2 released into the atmosphere by 43% as compared to the levels in 2010 (1). The Cement industry federation, Cement Concrete and Aggregates Australia, SmartCrete CRC and Race for 2030 CRC, engaged VDZ to compile an independent report on the pathways to decarbonisation for the Australian Concrete and OPC industry (2), As a part of this report Chapter 6.2.2 acknowledges that reducing the total binder of concrete, which includes OPC and SCMs will also play a role in reducing total CO_2 emissions in concrete or as now referred to as GWP. As the OPC and concrete industry emit around 8% of Global GWP, any reduction in GWP in the short term, prior to a sustainable/scalable solution to achieve net-zero, is seen as a positive impact for the industry and will assist with achieving the 2030 targets of 43% reduction in GWP.

Andromeda Metals Pty Ltd has secured the mining rights to extract the halloysite-kaolin clay deposit called Great White that's located near Poochera in South Australia (see figure 1.1a). The halloysite-kaolin has exceptional purity, strength and brightness and can be used as a concrete additive. Halloysite kaolin, is a rare nanotube tubular form which can have various applications in the nanotechnologies arena.

Figure 1.1a – Location of Great White Project in South Australia

The main scope of the work carried out in this evaluation, is to reduce the GWP, of concrete by utilising the halloysite-kaolin as a concrete admixture for reducing the total binder of concrete, as outlined previously in this chapter as solution to the concrete industry in lowering the GWP. A minimum target of 5% GWP reduction was selected, utilisng an internal LCA that was calibrated utilisng the GCCA EPD tool. Two strength grades were used, 32Mpa and 40Mpa concrete, with a maximum nominal aggregate size of 20mm and nominal design slump of 100mm.

Chapter II – Proposed Aims and Objectives

2.1 – Aims

The main aim of the project is to target a minimum of 5% reduction in GWP in concrete by reducing the total binder. When utilising the unique properties of Great White HRM^{TM}, its possible to increase the coarseness of the mix to aid in reducing the water content, increase density while still maintaining the desired plastic and mechanical properties. Two strength grades were used for this evaluation, 32Mpa and 40Mpa concrete, with a maximum nominal aggregate size of 20mm and design slump of 100mm, with a target slump of 120-130mm, this includes the maximum allowable limit and onsite practices as would be expected in the real-life production. Control mixes are those being supplied to the concrete market.

2.2 – Objectives

Objective 1 – Determine a methodology that allows concrete producers to adopt an approach that will assist with lowering the GWP in concrete and still maintain absolute volume, the three options investigated were,

1. Decrease total binder by 5.5%, increase flyash by 2% and reduce OPC by 2%, increase total coarse aggregate only content and maintain the same percentage of 20/14 and 10/7 in the increased mass, maintain the same W/B ratio as the control and check for absolute volume
2. Decrease total binder by 5.5% increase flyash by 2% and reduce OPC by 2%, increase the total coarse aggregate and manufacture sand, maintain the same percentages of material for the new increased mass as the control, maintain the same W/B ratio as the control and check for absolute volume
3. Decrease total binder by 5.5% increase flyash by 2% and reduce OPC by 2%, increase the total fine aggregate only, calculate the same percentage of manufactured sand and fine sand as the control in the increased mass, then increase the manufactured sand mass to obtain suitable workability as the control (determined in objective 2), and subtract the increase in manufactured sand from the new fine aggregate mass for the fine sand mass, maintain the same W/B ratio as the control and check for absolute volume

Objective 2 – Conduct 10L trial mixes from the designs derived from objective 1, additional trials would need to be conducted to find the optimal increase of manufactured sand for option 3, testing of the concrete for suitability was conducted on the following parameters

- Ensuring that while mixing, the concrete appears similar to the control
- Initial slump – ensuring that the slump does not shear
- Air Content

Objective 3 – Once a suitable mix design methodology is developed from objective 2, conduct larger scale trial mixes and test the concrete for the following plastic and mechanical properties,

- Workability and workability retention after 90 minutes
- Initial and final setting times of mortar
- Air content
- Bleed rates
- Compressive strength, tested at 24hrs, 3day, 7days, 28 days and 56 days and cast in duplicate

Chapter III – Experimental Programme

3.1 – Methodology

The Methodology that was adopted for objectives 2 and 3 in the previous chapter follow the requirements set out in AS 1012.2 (4), A drum type mixer was used for both objectives with a 1l and 2l preliminary batch for objective 2 and 3 respectively was utilised prior to conducting the actual trial mix. The mixing sequence is as per the flow chart in figure 3.1a

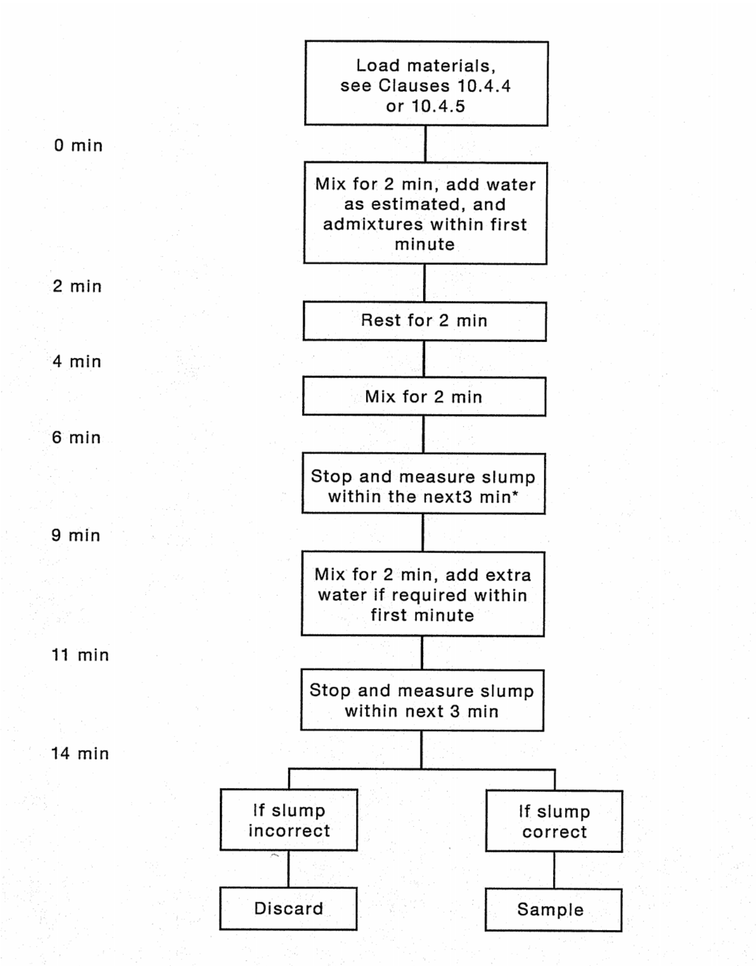

Figure 3.1a – Mixing as per AS1012.2 (4)

Chapter IV – Material Characterisation

The aggregates and chemical admixtures used for the trial mixes were supplied by EasyMix, a small independent ready-mix producer, located on the central coast in NSW. The OPC and flyash were supplied by BORAL from their Kooragang facility located in Newcastle. The OPC and flyash are the same materials that EasyMix currently utilise in their concrete plant.

4.1 – OPC

The OPC was supplied by BORAL and is manufactured at their Berrima plant that's located 207km south of EasyMix and is transported by rail to Newcastle and then trucked from Newcastle to EasyMix by road tanker. The OPC is classed as an shrinkage limited (SL) and general purpose (GP) to AS 3972-2010 (5) and contains up to 7.5% limestone addition. Conformance of the OPC at the time of the trials can be found in figure 4.1a

DATE DESPATCHED: 20/12/2022

PROPERTY	REQUIREMENTS OF AS 3972		RESULT
Compressive Strength (AS 2350.11)			
3 Day			34.5 MPa
7 Day	Minimum	35 MPa	46.7 MPa
28 Day	Minimum	45 MPa	57.8 MPa
Setting Time (AS 2350.4)			
Initial	Minimum	45 mins	105 mins
Final	Maximum	600 mins	150 mins
Soundness (AS 2350.5)	Maximum	5 mm	1 mm
SO_3 (AS 2350.2)	Maximum	3.5 %	2.7 %
Cl (AS 2350.2)	Maximum	0.10 %	0.03 %
Shrinkage (AS 2350.13)			
28 Day Mean	Maximum	750 μstrain	550 μstrain

OTHER REPORTABLE PROPERTIES

CHEMICAL			PHYSICAL		
K_2O	(AS 2350.2)	0.47 %	Normal Consistency	(AS 2350.3)	27.2 %
Na_2O	(AS 2350.2)	0.09 %	Fineness Index	(AS 2350.8)	395 m^2/kg
LOI	(AS 2350.2)	4.1 %			

Figure 4.1a – Conformance testing for Berrima OPC sampled 20-12-2022

4.2 – Flyash

Flyash is supplied by Flyash Australia from its Eraring facility that is located 42.1km north of EasyMix and is transported to EasyMix by road tankers. The flyash is classed as Grade 1 as per AS 3582.1-2016 (6). Conformance of the flyash at the time of the trials can be found in figure 4.2a

Product being certified:	Eraring Monthly Grab Fly Ash
Product sample date:	01-Dec-2022
Sample Identification:	Sample Code: 22120085
Source Power Station:	Eraring Power Station
Sample Condition:	Tested as Received. Testing Commenced on 02-Dec-2022
Certifying Laboratory:	Cement Australia - Darra Laboratory, 18 Station Avenue, Darra Queensland 4076 Australia.

Test Results

Test	Moisture %	Fineness @ 45 micron % Passed	Loss on Ignition %	Sulfuric Anhydride %	Available Alkali %	Chloride Ion %	Chemical Composition %
Result	< 0.1	88	1.8	0.1	n/a	< 0.002	92.5
Test Method	AS3583.2	AS3583.1	AS3583.3	AS2350.2	AS3583.12	AS3583.13	AS2350.2
AS 3582.1	0.5 % Maximum	75% Minimum	4.0 % Maximum	3.0 % Maximum	-	0.1 % Maximum	70% Minimum

Test	Relative Density	Relative Water Requirement %	Strength Index 7 Day Acc. %
Result	2.15	97	95
Test Method	AS3583.5	AS3583.6	AS3583.6
AS 3582.1	-	-	75% Minimum

Reference Cement Details

Identification::	22120254
Source:	Goliath GP
Product Type:	Type GP
Sample Date:	08-Dec-22

Additional Testing - Oxides

Test	CaO by XRF %	SiO_2 by XRF %	Al_2O_3 by XRF %	Fe_2O_3 by XRF %	SO_3 by XRF %	MgO by XRF %	Na_2O by XRF %
Result	1.5	68.3	19.9	4.3	0.1	0.6	0.42
Test Method	AS2350.2	AS2350.2	AS2350.2	AS2350.2	AS2350.2	AS2350.2	AS2350.2

Test	K_2O by XRF %	SrO by XRF %	TiO2 by XRF %	P_2O_5 by XRF %	Mn_2O_3 by XRF %	Total Alkali (NaEQ) %
Result	1.24	<0.1	0.9	0.2	< 0.1	1.24
Test Method	AS2350.2	AS2350.2	AS2350.2	AS2350.2	AS2350.2	AS2350.2

This sample grade conforms to the following requirements of AS 3582.1:2016

Special	Grade 1	Grade 2
	X	

Figure 4.2a – Conformance testing for Eraring Flyash sampled 01-12-2022

4.3 – Aggregates

There are four types of aggregate used in the concrete mix design and these are comprised of a 20mm and 10mm concrete aggregate, manufactured sand and a screened dune sand. The 20mm and 10mm concrete aggregate and manufactured sand are supplied by Hanson from its quarry at Kulnura on the central coast which is located 27.7km northwest of EasyMix and is transported by truck and trailer. The screened dune sand is supplied by Macka's Sand and Soil from its quarry location at Salt Ash and is located 103km north of EasyMix and is also transported by truck and trailer. Typical engineering properties of the aggregates that are used for the design of concrete mixes can be found in table 4.3a

Test Conducted	**Aggregate Size**			
	20/14mm	10/7mm	Man Sand (M/S)	Macka's Sand (F/S)
Particle Size Distribution (PSD)				
Sieve Size	**Percentage passing (%)**			
26.5mm	100			
13.2mm	59	100		
9.5mm	16	99	100	
6.7mm	3	66	100	
4.75mm	1	29	100	
2.36mm	1	1	82	
1.18mm	1	1	42	100
600µm			22	100
425µm			16	95
300µm			12	50
150µm			6	1
75µm		0	4	0.2
Particle Density				
SSD (t/m^3)	2.86	2.91	2.55	2.64
Water Absorption				
%	1.4	0.8	2.6	0.2

Table 4.3a – Engineering properties of aggregate to assist with concrete mix design

4.4 - Chemical Admixtures

The chemical admixture that is utilised in the trials is supplied by GCP Applied Technologies and is classified as a type WR according to AS 1478.1 (7). The sample was collected from the calibration point location, which is located on the discharge hose from the storage tank to discharge point into the concrete mixer. This location of the calibration point ensures that the sample is representative of the product being used for manufacturing of concrete at EasyMix.

4.5 – Great White HRM™

Great White HRM™ was supplied as white odourless powder and meets the requirements of a Type SN when tested to AS 1478 (7). The material is a hydrous alumina silicate, with a particle size on the 2µm sieve by weight of 50±10%. The typical chemical analysis of Great White HRM™ can be found in figure 4.5a

Chemical Analysis

SiO_2 (%)	45.37
Al_2O_3 (%)	38.19
Fe_2O_3 (%)	0. 60
TiO_2 (%)	0.20
K_2O(%)	0.71
Na_2O (%)	0.03
LOI (%)	13.95

Figure 4.5a – Chemical analysis of the Great White HRM™ as per Provisional Technical data sheet

4.5 – Water

The water used in the trials was from a potable source and kept as a consistent source for all trials.

Chapter V Proposed Test Methods

This chapter will outline the test methods used to evaluate the Great White HRM™, with a brief description of the test method.

5.1 – Workability

Workability has multi-function capacity, and the true workability requires testing of the plastic state of the concrete with a selected method that can be easily reproduced in the field. Currently in Australia there is no test method for workability for concrete that is below 240mm in slump. The series of AS 1012.3 refer to differing test methods for consistency with the main test method being AS 1012.3.1 (8) consistency of concrete – Slump Test.

BS EN 12350-5 (9) is used to determine the slump flow of a concrete mix when there is energy applied and if segregation occurs between the paste and the fine aggregate. Typical equipment for this test can be found in figure 5.1a. The size of the slump flow table is $700 \pm 2mm^2$, with a cone height of 200mm as compared to 300mm for the standard slump test and the flow tabletop has a mass of 16±0.5kg. This test is suitable for concrete with medium, high, and very high workability, and is currently being adopted into civil tunnels in Australia for sprayed concrete.

The test is conducted by placing the slump flow table on an even surface free from external vibration. The table should be tested for ease of movement and when the sample is dropped there is minimal bounce. The cone is filled in two equal layers by a tampering rod ten times per layer. Any excess mortar that is present after the second layer is to be removed from the cone and the table. Between ten and thirty seconds after the second layer has been compacted, the cone should be lifted evenly and vertical in a time between one and three seconds, within ten seconds from raising the cone the table should be lifted to the upper stops which are 40mm above the flow tabletop, and freely dropped fifteen times. After the fifteenth time allow the concrete to settle and measure the flow in two directions, see figure 5.1b. Calculate the average by equation 5.1a and record to the nearest 10mm. Check the mortar to see if there is any segregation; if there is, then measure to the nearest mm and make a note.

$$f = (d1 + d2)/2 \quad (5.1a)$$

Figure 5.1a – Typical equipment used for testing to BS EN 12350-5

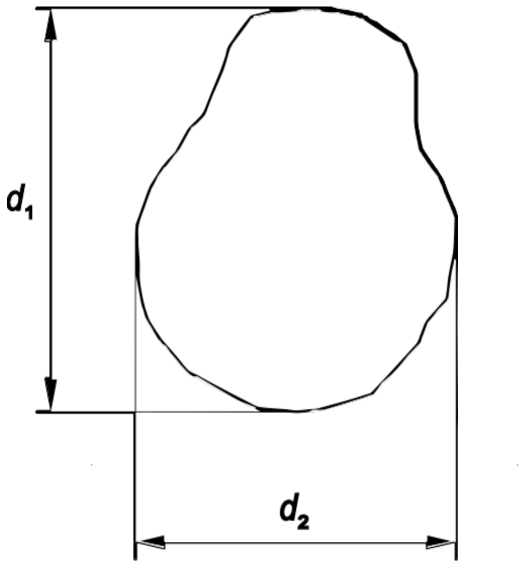

Figure 5.1b – Measurement of spread in two different directions (9)

The equipment described above is not readily available in Australia, so the test method was used as the basis for developing a test that can use equipment readily available in Australia and is able to compare the workability of the concrete. The test uses the standard 300mm slump cone and after the slump is determined, the tray is raised 40mm to the stoppers and freely dropped 15 times for the control, Extra drops are then added for the test specimens to achieve the same flow. The equipment that was used can be found in figure 5.1c

Figure 5.1c – Slump flow table with current available test equipment

Figure 6.4a – Multiple sample testing box for calorimetry testing (10)

5.2 – Air Content AS 1012.4.2 (11)

AS 1012.4.2 (11)measures the reduction in air pressure in a chamber above concrete and is the most widely adopted test method in Australia. Typical configuration of the equipment can be found in figure 5.2a. Air content is calculated by compaction of the mortar into the bowl in three equal layers. Once the mortar is screened off on the surface, the edges of the bowl are cleaned to ensure a secure airtight fit with the lid. Water is filled into the air above the concrete and the lid, until all the air is removed. The chamber is sealed from the outside environment. The air chamber is pressurised to the calibrated zero point, and the air is rapidly introduced to the chamber above the concrete. The corresponding air content is recorded. The procedure is repeated twice, and the average air content of the two readings is determined as being the representative air content. This sample of mortar can be re-used for further testing, if the top 25% is removed carefully and discarded to avoid any contamination with excess water content.

Figure 5.2a – Typical air content equipment used for AS 1012.4.2 (11)

5.3 – Compressive Strength of Concrete

Compressive strength of concrete is usually conducted by using AS 1012.9 (12). This standard requires that the samples be cast as per AS 1012.8.1 (13) and clause 7.3 was used for compaction, which is compaction by rodding. Where the concrete cylinder mould is filled in two even layers, with 25 rods per layer evenly distributed over the cross-section of the mould. The holes are closed in each layer by tapping the sides of the mould with a mallet. Once cast the cylinders are maintained at a temperature of 23 ± 2°C for a period between 18 -36hrs before being stripped and placed into moist curing at a temperature of 23±2°C until the samples are due to be tested.

Once the specimens are ready for testing, they are removed from the curing environment and the striked end will be sulphur capped, while still maintaining the diameter to height ratio of 1.95 to 2.05. Specimens will be weighed and measured to determine the density; the specimens are placed into a compression machine (figure 5.3a) where a constant load of 20Mpa ± 2Mpa per minute is applied until there is no increase in force detected. The maximum force is recorded and used to determine the compressive strength of the concrete by equation 5.3a.

$$\text{Mpa} = \text{Force (n)}/\text{Area (mm}^2\text{)} \qquad (5.3a)$$

Figure 5.3a – Typical Compression machine used for compression testing of cylinders

5.4 – Initial and Final Setting time of Concrete AS 1012.18 (14)

The initial and final setting time of fresh concrete is determined by extracting the mortar from the concrete by sieving the fresh concrete over a 4.75mm sieve. The mortar is placed in containers with a minimum diameter and height of 150mm. The containers will be filled to a depth of at least 140mm, cast in two separate layers with 25 strokes of a tamping rod, with tapping of the sides to close any voids in the surface. Two specimens shall be prepared for each concrete mix.

Removal of any bleed water is conducted before any penetration test is made, by carefully tilting the container to about 10 degrees, for at least 2 minutes, then returning the container to the horizontal position with shock or jarring. The penetration apparatus shall be a spring reaction-type and graduated with a range of 45N to 580N in increments no greater than 25N. There will be circular needles with nominal diameters of 28mm,20mm,14mm,9mm,6.5mm and 4.5mm, typical penetration apparatus can be found in figure 5.4a.

The apparatus will be forced vertically downwards, until the needle penetrates the mortar to a depth of 25mm in a time of 10 seconds. This will be conducted on each of the 2 specimens at the same time to give an average. The force required for penetration will be recorded, and each penetration will be a not less than 15mm from each other and not less than 25mm from the side of the container. Initial setting time is achieved when the penetration resistance is 3.5Mpa (achieved with the 9mm needle with 231N) and 28Mpa for final setting time (achieved with the 4.75mm needle with 449N). Time will be recorded to the nearest 10 minutes. All mortar samples will be maintained at ambient temperature of 23±2°C.

Figure 5.4a – Typical Penetration apparatus for initial and final setting time of mortars

5.5 – Bleeding of Concrete AS1012.6 (15)

The bleeding rate of concrete is determined by placing the concrete into a mould of at least 250mm diameter and at least 280mm in height. There will be a mark set inside the container at least 250mm from the base. The cross-sectional area at the 250mm mark will be determined. The container is filled in 3 even layers with a minimum number of 70 strokes per layer, and each layer is tapped with a mallet to remove any air and close up the surface. Once filled the container and concrete is weighed and the mass of concrete is determined.

Water is drawn from the surface at intervals of 15minutes for the first 60 minutes then every 30 minutes until the bleed water collected is below 5ml. This is facilitated by tilting the container carefully at least 1 minute prior to the withdrawal of bleed water. The rate of bleeding is calculated and reported as $mL/mm^2/min$. The ratio of bleed water to mixing water is reported to nearest %.

Chapter VI – Results and Discussion

6.1 – Objective 1 and Objective 2

As mentioned in chapter 2.2 there were 3 approaches to lowering the GWP and increasing the coarseness of the mix to maintain the same W/B ratio as the control with a reduction of total binder. The 40Mpa mix was used to help determine the most suitable approach to increase the coarseness of the mix. During all the testing the Great White HRM™ was maintained at 1kg/m3 and the WR was kept constant at 300ml/100kg of binder.

Option 1 – When the binder was reduced by 5.5%, to maintain absolute volume the coarse aggregate fraction was increased by 5%, and the percentage of 20/14 and 10/7 was maintained as per the control at 66% and 34% respectively. During mixing of the concrete, it was observed that there was clear segregation of the 20/14 and the mix was not homogenous. At this stage the concrete was not tested any further and this option was rejected. Summary of mix designs can be found in table 6.1a.

Material	40-20B	ADN 40
OPC (kg/m3)	295	271
Flyash (kg/m3)	95	97
GREAT WHITE HRM™ (kg/m3)	N/A	1
20/14mm (kg/m3)	677	711
10/7mm (kg/m3)	348	365
M/S (kg/m3)	258	258
F/S (kg/m3)	535	535
Water (l/m3)	184	174
W/B Ratio	0.47	0.47
OPC (%)	76%	74%
Flyash (%)	24%	26%
20/14 (%)	66%	66%
10/7 (%)	34%	34%
Ratio F/A to Agg	44%	42%
M/s % of F/A	33%	33%
F/S % of F/A	67%	67%
Change in C/A (%)	5.00%	
Reduction in Binder	-5.50%	
Volume assuming 2% Air Content	100.0%	100.1%

Table 6.1a – Summary of mix designs for option 1

Option 2 – To maintain absolute volume with the reduction of the binder by 5.5%, the coarse aggregate and the M/S mass was increased by 3.5%. The same percentage for each material as per the total mass of the 3 materials was also maintained as per the control at 66%, 34% and 20% for 20/14, 10/7 and M/S respectively. While mixing the concrete it appeared to be homogeneous, however during the slump test the slump sheared and this categorised in the standard is a failure, the concrete was rejected from any further testing. Summary of mix designs can be found in table 6.1b.

Material	40-20B	ADN 40
OPC (kg/m3)	295	271
Flyash (kg/m3)	95	97
GREAT WHITE HRM^{TM} (kg/m3)	N/A	1
20/14mm (kg/m3)	677	701
10/7mm (kg/m3)	348	360
M/S (kg/m3)	258	267
F/S (kg/m3)	535	535
Water (l/m3)	184	174
W/B Ratio	0.47	0.47
OPC (%)	76%	74%
Flyash (%)	24%	26%
Total C/A and M/S	1283	1328
20/14 (%), C/A & M/S	53%	53%
10/7 (%), C/A & M/S	27%	27%
M/S (%), C/A & M/S	20%	20%
Ratio F/A to Agg	44%	43%
M/s % of F/A	33%	33%
F/S % of F/A	67%	67%
Change in C/A & M/S (%)	3.50%	
Reduction in Binder	-5.50%	
Volume assuming 2% Air Content	100.0%	99.9%

Table 6.1b – Summary of mix deign for option 2

Option 3 – Maintaining absolute volume in this option required that the total fine aggregate had to increase by 4%. There were 3 levels of increased M/S investigated, with levels increased by 30%, 40% and 50% for the total fine aggregate mass.

At 30% increase the mix required an additional 7l/m3 of water to achieve the required slump, so the mix was rejected and not tested. At 40% increase in the M/S, the additional water to achieve the required slump was only 4l/m3 and the mix appeared to be similar to the control sample when mixing. The concrete was then tested for air content and achieved 1.8% as compared to the control sample of 1.5%. The 50% mix was tested and did not require any additional water to achieve the required slump. However, it did start to show signs of bleeding during the slump test. An additional 1kg/m3 of Great White HRM^{TM} was added in 0.5kg amounts to control the bleeding. The additional Great White HRM^{TM} did reduce the slump by over 20mm. This mix was rejected as you will be consistently fighting competing parameters.

Finally, the 40% was re-tested where additional WR was added, the dose was increased to 400ml/100kg of binder, and a maximum of 2/l/m3 of additional water was allocated. The effect of the additional water could be offset by the increase in density of the concrete. With these changes the mix achieved the required slump and the same air content of 1.5%. Based on the success of the last trial, the methodology was adopted for the 32MPa mix design, and the methodology was transferable to both mix designs. However when tried with a 25Mpa mix the concrete mix cost rose dramatically to over an estimated \$5/m³. Summary of the final mixes to be used in objective 3 can be found in table 6.1c.

Material	32-20B	ADN 32	40-20B	ADN 40
OPC (kg/m3)	240	220	295	271
Flyash (kg/m3)	95	96	95	97
GREAT WHITE HRM™ (kg/m3)				
20/14mm (kg/m3)	660	660	677	677
10/7mm (kg/m3)	335	335	348	348
M/S (kg/m3)	252	367	258	376
F/S (kg/m3)	610	530	535	449
Water (l/m3)	179	172	184	176
W/B Ratio	0.53	0.54	0.47	0.48
OPC (%)	72%	70%	76%	74%
Flyash (%)	28%	30%	24%	26%
Total F/A	862	896	793	825
M/S Mass with same %	N/A	262	N/A	268
F/S Mass with same %	N/A	634	N/A	556
Ratio F/A to Agg	46%	47%	44%	45%
M/s % of F/A	29%	41%	33%	46%
F/S % of F/A	71%	59%	67%	54%
Change in F/A (%)	4.00%		4.00%	
Reduction in Binder	-5.50%		-5.50%	
Volume assuming 2% Air Content	99.3%	99.5%	100.0%	99.9%

Table 6.1c – Final mix designs of 32Mpa and 40Mpa to be used for Objective 3

Once the methodology for altering the mix designs was confirmed calculation of the GWP kg-CO_2-eq for 1m³ of concrete was calculated and can be found in table 6.1d with the following allocations regarding the transport of the raw materials. Internal LCA as calibrated with GCCA EPD, can be found in Annex C.

- OPC - BORAL EPD + Freight of 281km one way from Berrima to Kooragang by rail, 82km from Kooragang to EasyMix by truck, load size of 28t
- Flyash - Aust carbon website includes delivered to plant
- Great White HRM™- Gunlake EPD for Aggregate + Truck freight from Poochera to Port Augusta 40T 329km, Freight of 1549km from Port Augusta to Sydney by rail, Sydney to EasyMix 95km on a truck between 16-28T
- 20/14, 10/7 & M/S - Gunlake EPD + Freight of 29km one way from Hanson Kulnura to EasyMix, load size of 40T
- F/S - Gunlake EPD + Freight of 89km one way from Newcastle sands to EasyMix, load size of 40T
- Batching - Taken from the GCCA EPD tool for OPC and concrete

	32Mpa Control	32Mpa Great White HRM™	40Mpa Control	40Mpa Great White HRM™
GWP kg-CO_2-eq	232	215	277	257
Lowered GWP kg-CO_2-eq (%)	N/A	7.2	N/A	7.25

Table 6.1d – Summary of GWP kg-CO_2-eq and the percentage reduction

If using the GCCA self-declared EPD the default OPC used is the current Australian average as per the AUS LCI database dated May 2022. The GWP kg-CO_2-eq/m^3 is higher than using the internal LCA with locally available EPDs. GCCA produce greater percentage reduction in the 32Mpa, and the 40Mpa as found in table 6.1e. Having EPDs for the materials used is more accurate than using general figures as found in the GCCA self-declared EPD.

	32Mpa Control	32Mpa Great White HRM™	40Mpa Control	40Mpa Great White HRM™
GWP kg-CO_2-eq	261	241	314	290
Lowered GWP kg-CO_2-eq (%)	N/A	7.66	N/A	7.64

Table 6.1e – Summary of GWP kg-CO_2-eq and the % reduction using the GCCA EPD calculator

6.2 – Objective 3

The 40Mpa trial mixes were conducted on the 12th of December 2022, with the 32Mpa trial mixes being completed on the 14th of December 2022, trial mix reports for each batch can be found in annex A. A summary of the plastic properties for each mix can be found in table 6.2a.

Test	32Mpa Control	32Mpa Great White HRM™	40Mpa Control	40Mpa Great White HRM™
Initial Slump (mm)	130	130	120	130
Initial Slump Flow/Drops (mm)	470/15	460/18	420/15	420/17
Slump at 90 min (mm)	100	110	80	100
Slump Flow/Drops at 90min (mm)	420/15	420/17	360/15	370/16
Air Content (%)	2.4	3.6	1.5	1.6
Ratio of Bleed to Water (%)	2	2	2	2
MPUV (kg/m³)	2414	2444	2379	2463
Initial Setting time (hrs/min)	5hrs 20 min	5hrs 20 min	4hrs 20 min	4hrs 40 min
Final Setting time (hrs/min)	7hrs 20 min	7hrs	5hrs 40 min	5hrs 40 min

Table 6.2a – Summary of plastic properties from the trial mixes conducted

The slump achieved for both the 32Mpa trials mixes was the same. However when the slump flow is compared, the 32Mpa Great White HRM™ mix required an additional 3 drops to achieve the similar flow which is an additional 20% as compared to the control. The 40Mpa only required 2 additional drops an (additional 13.3%) as compared to the control to achieve the same flow. It is noted the 40Mpa HRM™ did have a higher initial slump than the control, Photos for the initial slump and flow can be found in annex B.

As to be expected the slump and the slump flow reduced after 90 minutes, with the greatest loss observed in the 40Mpa control with a reduction of 40mm in slump and 80mm in flow. Both the 32Mpa control and 40Mpa Great White HRM™ had the same degree of loss in both slump and slump flow, being 30mm and 50mm respectively. 32Mpa showed the lowest reduction in both slump and slump flow being 20mm and 40mm respectively. This follows the trend with decreasing OPC content which plays a major factor of the workability retention. Due to the lower loss in slump for both the 32Mpa and 40Mpa Great White HRM™ mixes compared to the control mix, the required drops also reduce by a factor of 1 to achieve the same/similar flow.

Air content of the 40Mpa mixes stayed very consistent with only 0.1% difference between the control and Great White HRM™ mix designs. The same can't be said for the 32Mpa mix design where the air content increased by 50% in the 32Mpa Great White HRM™ compared to the 32Mpa control, obtaining 3.6% and 2.5% respectively. The additional air content does not seem to affect the concrete density as can be seen in figure 6.2a. The ratio of bleed to water was consistent over all four mixes with all achieving 2%.

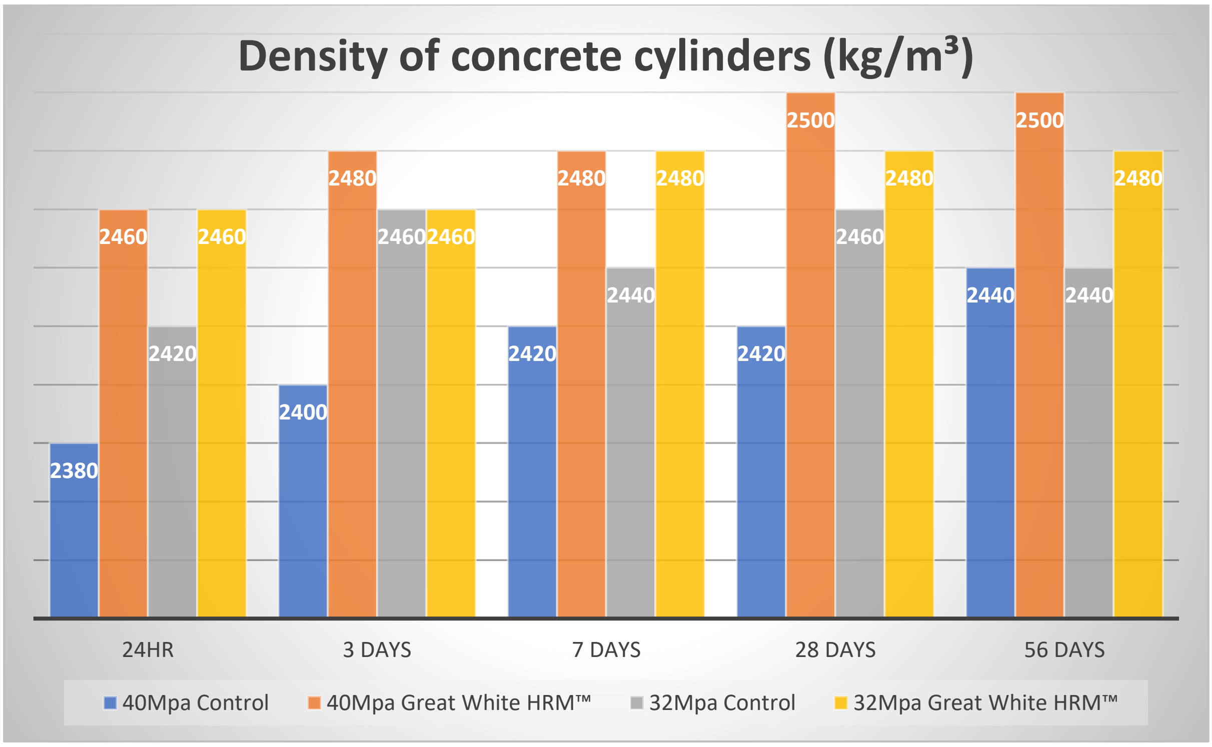

Figure 6.2a – Cylinder density of concrete at the various ages of testing

The bleeding rate of the 32Mpa mix design can be found in figure 6.2b and figure 6.2c for the 40Mpa. The 32Mpa mix designs follow a similar bleed rate profile, and with the lower water content in the 32Mpa Great White HRM™ the overall bleed rate profile is lower than that of the 32Mpa control. The 40Mpa Great White HRM™ follows a similar trend to the control until around 90 minutes. However the 40Mpa Great White HRM™ continues to bleed until

180 minutes as compared to the control that ceases at 150 minutes. This can be seen as an advantage to the mix as it will help protect the surface from rapid moisture loss and could assist with reducing the likely chance of plastic shrinkage cracking. The increased air content in the 32Mpa Great White HRM™ is the likely contributor to not seeing increased bleeding rate over time as is seen in the 40Mpa Great White HRM™ mix design.

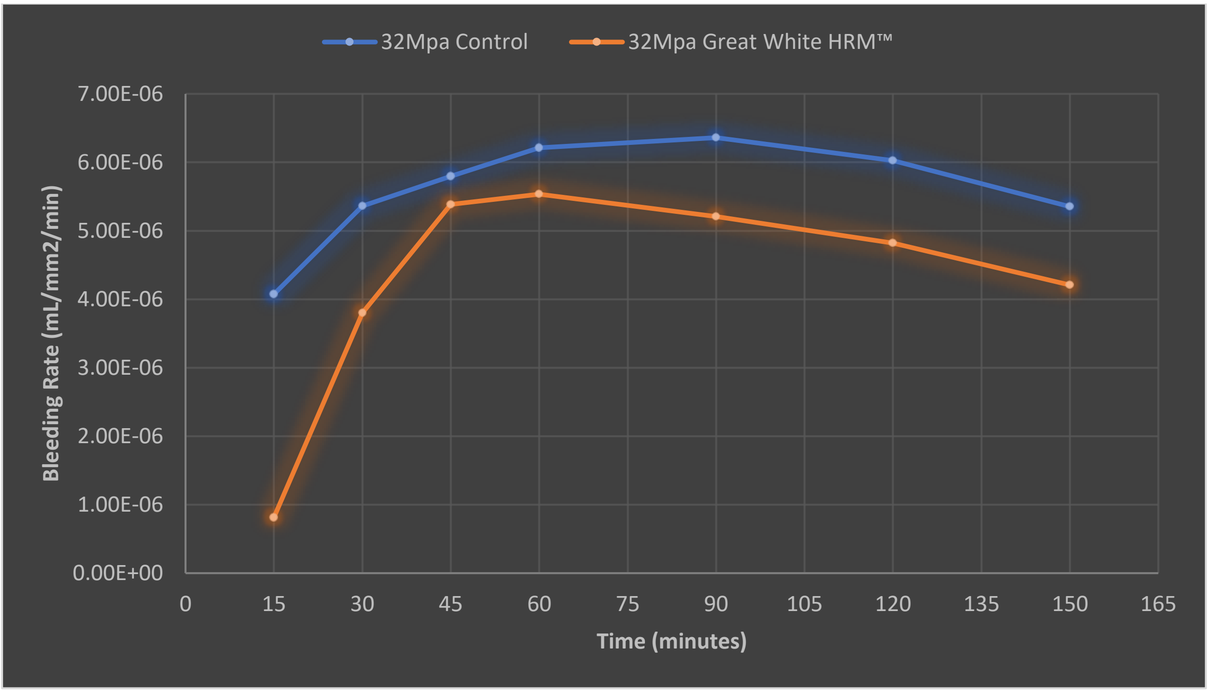

Figure 6.2b – Bleeding rate profile for the 32Mpa mix designs

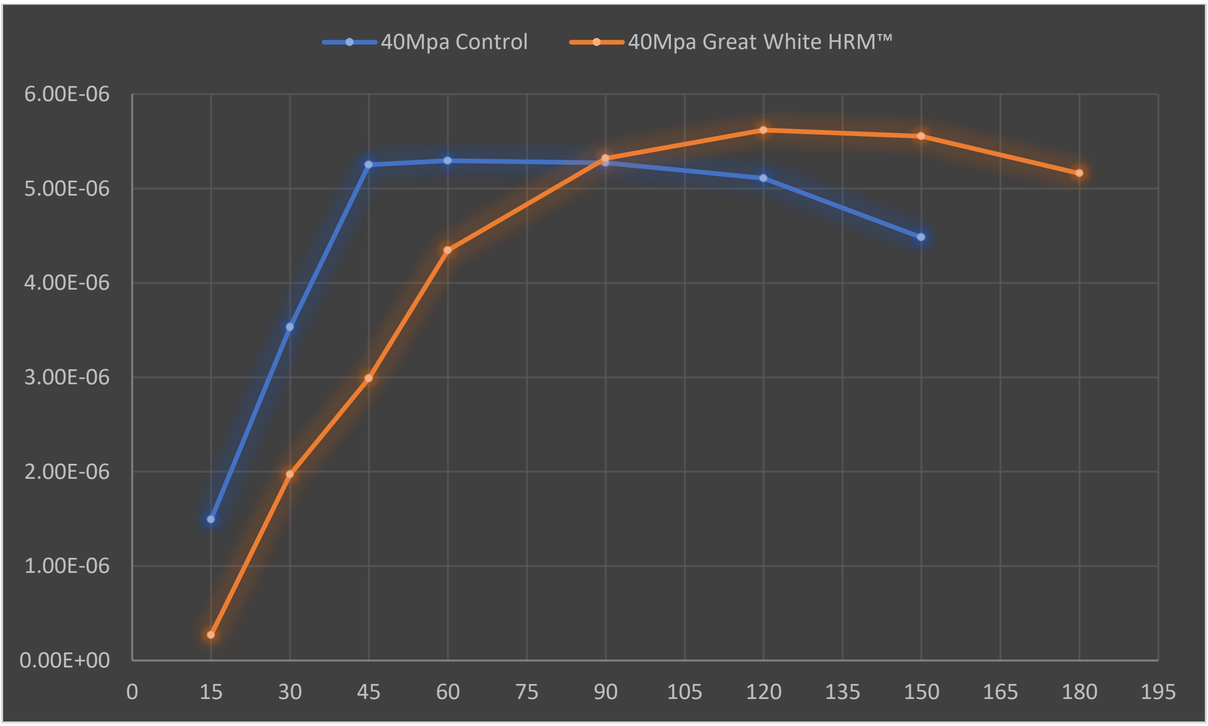

Figure 6.2c – Bleeding rate profile for the 40Mpa mix designs

The mass per unit volume (MPUV) increased with the use of Great White HRM™ in both the 32Mpa and 40Mpa mix design. This may be attributed to better packing density of the aggregates as both the mix designs exhibit a more linear mix design PSD than compared to the control, see figure 6.2d. The better packing density of the fine aggregate would also be a contributing factor as to why the setting times are similar when comparing the control to Great White HRM™ mix designs.

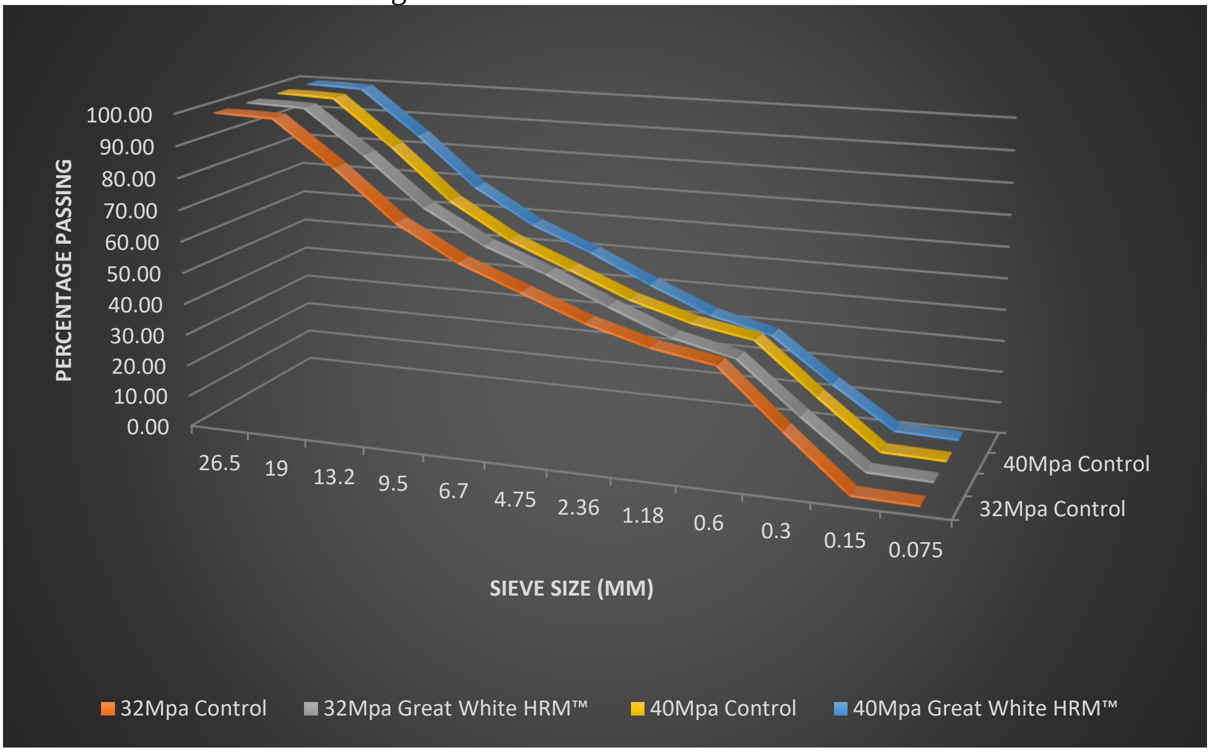

Figure 6.2d – Mix design PSD for control and Great White HRM™ for both 32Mpa and 40Mpa mix designs

When comparing the compressive strength of the concrete mixes, although there is likely an increase in the packing density on the fine aggregate, the strength of concrete is still ultimately controlled by the binder content and the W/B ratio. As both Great White HRM™ mixes had lower OPC contents than the control, it is expected that the early age strengths will be affected. This is seen at 24 hours in both mixes where the 32Mpa Control mix, 32Mpa Great White HRM™, 40Mpa control mix and 40Mpa Great White HRM™ achieved, 9Mpa, 8.3Mpa, 12.3Mpa and 10Mpa respectively.

The 40Mpa Great White HRM™ mix achieves lower strengths than the control mix until 28 days where the strength growth from 7 days to 28 days increases by 36% as compared to the control mix that only increases by 30%, this could be attributed to the increase in flyash reacting with the calcium hydroxide from OPC hydration.

The same trend is not seen in the 32Mpa where the growth in the control mix from 7days to 28 days is 30% as compared to 32Mpa Great White HRM™ that achieved a 26% growth in strength. This may be attributed to a balance of the level of flyash and OPC and free calcium hydroxide.

The strength gain from 28 days to 56 days is similar for the control and Great White HRM™ for both mix designs, however the 32Mpa experiences growth of 20% and 21% for 32Mpa Control and 32Mpa Great White HRM™ respectively and the 40Mpa Control and 40Mpa Great White HRM™ both achieve 13% growth. The larger percentage of flyash in the 32Mpa concrete could be the contributing factor. However more work and data is required to establish that theory. It is also noted that all concrete passed minimum strength requirements as set out in AS 1379-2007 (3). Strength results can be found in figure 6.2e

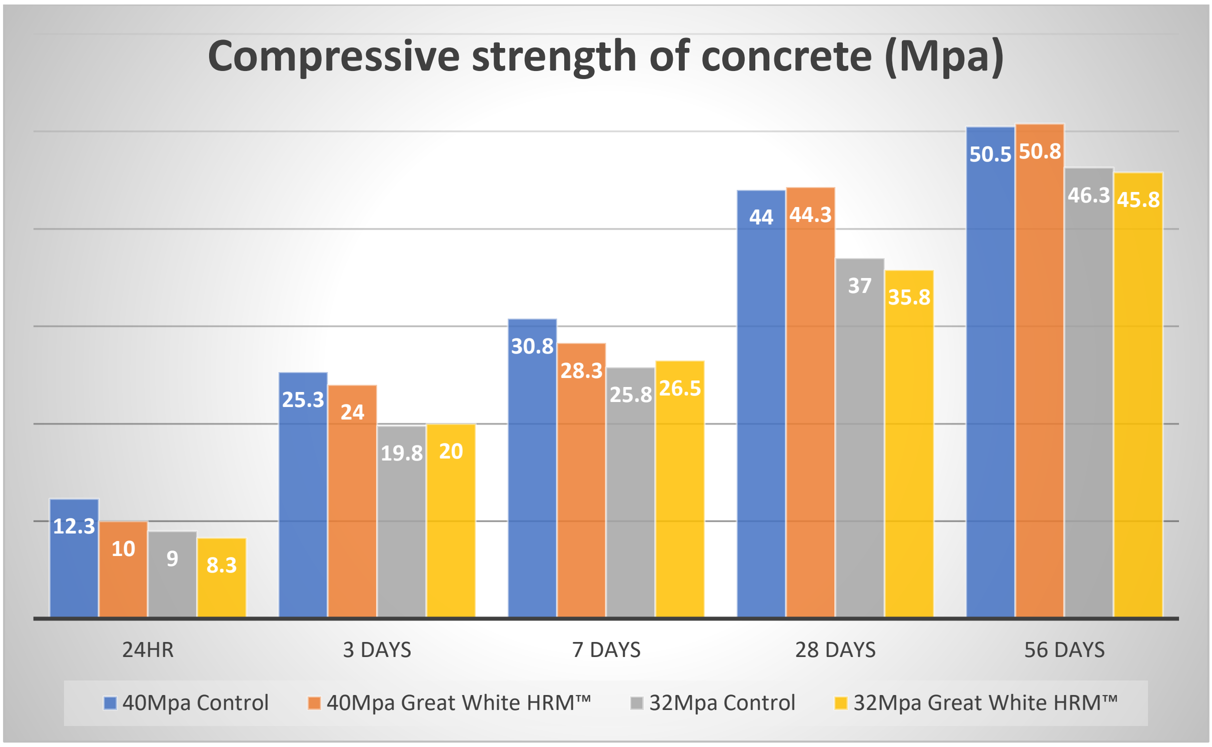

Figure 6.2e – Compressive strength results for 32Mpa and 40Mpa concrete mix designs (Strengths are reported in Mpa)

Chapter VIII – Potential Commercial Opportunities

This chapter will highlight the potential commercial objectives of utilising Great White HRM™ for the concrete producer and the potential global opportunity. This chapter can only indicate the potential and the figures presented are based on the materials used for the trial work, these figures may not be fully achieved with other raw materials, locations within and abroad of Australia, so care must be taken when using the figures presented.

The estimated costs of materials can be found in table 8a. Based on the mix designs used, the potential savings for the concrete producer are $2/m^3 and $3.16/m^3 for 32Mpa and 40Mpa respectively. This represents 1.11% and 1.64% mix cost savings for 32Mpa and 40Mpa mixes respectively.

Material	***Cost***
OPC (t)	$ 280.0
Flyash (t)	$ 140.0
GREAT WHITE HRM™ (kg)	$ 3.0
20/14mm (t)	$ 50.0
10/7mm (t)	$ 54.0
M/S (t)	$ 42.0
F/S (t)	$ 60.0
Admixture (l)	$ 1.6

Table 8a – Estimated costs of raw materials used in the trial mixes

Based on the global concrete report 2023 (16), which is based on the most recent recorded full year (2021), there was 9.42Bnm^3 of concrete produced globally, with 48.5% (4.58Bnm^3) produced in 10 countries, of which 35% of global production (3.29Bnm^3) was produced in China. The other 9 countries by percentage are USA – 3.5%, India – 2.3%, Indonesia – 1.5%, Russia – 1.3%, Turkey – 1.2%, Egypt – 1.1%, Vietnam – 1%, Brazil – 0.9% and Saudi Arabia – 0.7%. Based on the VDZ report (2) Australia accounts for 0.31% of global production

If assuming that the split of concrete is similar to that stated in the VDZ report, the potential global volume of concrete excluding China for commercial use is 1.84Bnm^3 of concrete per annum, that which Great White HRM™ could be potentially marketed towards. This will vary as the Great White HRM™ is in Australia and shipping globally may not bring the desired outcome commercially and more importantly in lowering GWP kg-CO_2-eq to similar levels as reported in this document. So, if only 10% of the potential concrete was targeted with Great White HRM™ this equates to 184Mm^3 of concrete that Great White HRM™ could be marketed towards per annum. Using the dose rate of Great White HRM™ as utilised in this report, this equates to an extrapolated potential market size of 184Kt of Great White HRM™ per annum.

According to the Roadmap to Net Zero by the GCCA (17), the contribution by altering the mix design of concrete is 11%, so by reducing the GWP in the concrete by over 7% as found in this evaluation, is a major contribution in achieving net zero by 2050. More importantly is a reduction that could be made within the next 12 to 18 months once the Great White HRM™ becomes commercially available.

Chapter IX – Conclusion

Based on the results of the trial mixes the following conclusions can be made

- A methodology has been developed with these materials that can reduce the GWP of the concrete mix design by 7.25% for the 40Mpa mix and 7.2% for a 32Mpa mix, the methodology could not be used for strengths below 32Mpa without increasing the cost of the concrete dramatically. Further work with other materials and designs needs to be investigated to ensure that the methodology, and the lowering of GWP is repeatable
- Increasing the percentage of flyash in the concrete has a small effect on the 24 hour strength of concrete with reductions of 2.3Mpa and 0.7Mpa for 40Mpa and 32Mpa respectively, which may only be of concern in the colder months. The industry typically uses accelerators to assist with setting time and early age strength development so this may not be a major factor
- Setting times of the concrete remain unaffected with the lower total binder systems as compared to the control mix. This can be attributed to better packing density of the fine aggregate
- Increasing the flyash content from 28% to 30% in the 32Mpa concrete generated better strength growth between 28 days and 56 days than the control but was lower than the control for ages 7 days to 28 days. This could be attributed to the balance of flyash and the readily available calcium hydroxide that is required for pozzolanic reaction to occur
- Increasing the coarseness of the mix had no effect on the air content in 40Mpa concrete, however a 50% increase was observed in the 32Mpa. The air content does not appear to have affected the strength of the concrete as confirmed by the cylinder density and strengths
- The ratio of bleed to water was consistent at 2% for all 4 mixes.
- The rate of bleed was lower initially for the both the Great White HRM™ mixes, and at 90 minutes the 40Mpa Great White HRM™ mix exceeded the bleed rate of the control. The increase is attributed to a coarser fine aggregate fraction and packing density allowing for a slower release of the excess water

The author declares receipt of the following financial support for the research, authorship, and publication of this report: This work was supported by Andromeda Metals Pty Ltd. The author also declares that Andromeda Metals Ltd did not have any role in the design of the study, in the analysis and interpretation of the data. The results and views are completely independently reported by the author.

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Annex A – Laboratory Trial Mix Reports

LABORATORY TRIAL MIX REPORT

Client:	**Andromeda Metals**	**Report Issue Date:**	**19-12-2022**
Project:	**Great White HRM^{TM} Evaluation**	**Trial Mix Date:**	**14-12-2022**

All tests were carried out in accordance with the relevant test methods of AS 1012 unless noted otherwise

Trial Mix Details					
Mix Identification	**Sample ID**	**Sample Time**	**Mixer Type**	**Batch Size (l)**	**Compaction[1]**
32 Mpa Control	**SFD – 3**	**07:05**	**Drum**	**45**	**Rodding**

Note 1 – Compaction method = R- Rodding, EV – External Vibration and IV – Internal Vibration

Trial Mix Design				
Constituent Material	**Source**	**Design Weight SSD (kg/m^3)**	**Trial Batch Weight SSD (kg)**	**Moisture Content (%)**
OPC	Berrima	240	10.800	
Flyash	Erraring	95	4.275	
Coarse Aggregate - 20/14	Kulnura	660	29.953	0.85
Coarse Aggregate - 10/7	Kulnura	335	15.351	1.83
Fine Aggregate – Manufactured Sand	Kulnura	252	11.927	5.18
Fine Aggregate – Dune Sand	Macka’s	610	28.067	2.25
WRDA PN	GCP	1 (l)	53.76 (g)	
Total Allowable Water	Potable	179	6.321	

Plastic Properties of Mix Design Details							
Nominated Slump (mm)	**100**	**Nominated W/B ratio (%)**	**0.53**	**Air Content (%)**	**MPUV (kg/m^3)**	**Setting Time (hr/min)**	
Slump (mm)	**130**	**Actual W/B ratio (%)**	**0.53**	**2.4**	**2410**	**Initial**	**5hs/20min**
Flow (mm) – 15 drops	**470**	**Ambient Temp (°C)**	**21.2**	**Concrete Temp (°C)**	**22.6**	**Final**	**7hrs/20min**
Ratio of Bleed to Water (%)	**2**						

Mechanical Properties of Concrete					
UCS 1 – Day (Mpa)	**UCS – 3 Days (Mpa)**	**UCS – 7 Days (Mpa)**	**UCS – 28 Days (Mpa)**	**UCS – 56 Days (Mpa)**	**UCS – 90 Days (Mpa)**
9.0	**19.8**	**25.8**	**37.0**	**46.3**	**N/A**
Shrinkage Initial (µm)	**Shrinkage 7 Days (µm)**	**Shrinkage 14 Days (µm)**	**Shrinkage 21 Days (µm)**	**Shrinkage 28 Days (µm)**	**Shrinkage 56 Days (µm)**
N/A	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Cl Diff NT443	**N/A**	**Cl Diff NT 492**	**N/A**	**Cl/SO**	**N/A**

LABORATORY TRIAL MIX REPORT

Client:	**Andromeda Metals**	**Report Issue Date:**	**19-12-2022**
Project:	**Great White HRM™ Evaluation**	**Trial Mix Date:**	**14-12-2022**

All tests were carried out in accordance with the relevant test methods of AS 1012 unless noted otherwise

Trial Mix Details					
Mix Identification	**Sample ID**	**Sample Time**	**Mixer Type**	**Batch Size (l)**	**Compaction[1]**
32 Mpa Great White HRM™	**SFD – 4**	**08:15**	**Drum**	**45**	**Rodding**

Note 1 – Compaction method = R- Rodding, EV – External Vibration and IV – Internal Vibration

Trial Mix Design				
Constituent Material	**Source**	**Design Weight SSD (kg/m³)**	**Trial Batch Weight SSD (kg)**	**Moisture Content (%)**
OPC	Berrima	220	9.900	
Flyash	Erraring	96	4.320	
GREAT WHITE HRM™	Andromeda	1	45 (g)	
Coarse Aggregate - 20/14	Kulnura	660	29.953	0.85
Coarse Aggregate - 10/7	Kulnura	335	15.351	1.83
Fine Aggregate – Manufactured Sand	Kulnura	367	17.370	5.18
Fine Aggregate – Dune Sand	Macka's	530	24.386	2.25
WRDA PN	GCP	1.27 (l)	67.54 (g)	
Total Allowable Water	Potable	172	5.819	

Plastic Properties of Mix Design Details							
Nominated Slump (mm)	**100**	**Nominated W/B ratio (%)**	**0.54**	**Air Content (%)**	**MPUV (kg/m³)**	**Setting Time (hr/min)**	
Slump (mm)	**130**	**Actual W/B ratio (%)**	**0.54**	**3.6**	**2440**	**Initial**	**5hrs/20min**
Flow (mm) – 18 Drops	**460**	**Ambient Temp (°C)**	**21.3**	**Concrete Temp (°C)**	**22.6**	**Final**	**7hrs**
Bleeding Rate (%)		**2**					

Mechanical Properties of Concrete					
UCS 1 – Day (Mpa)	**UCS – 3 Days (Mpa)**	**UCS – 7 Days (Mpa)**	**UCS – 28 Days (Mpa)**	**UCS – 56 Days (Mpa)**	**UCS – 90 Days (Mpa)**
8.3	**20.0**	**26.5**	**35.8**	**45.8**	**N/A**
Shrinkage Initial (μm)	**Shrinkage 7 Days (μm)**	**Shrinkage 14 Days (μm)**	**Shrinkage 21 Days (μm)**	**Shrinkage 28 Days (μm)**	**Shrinkage 56 Days (μm)**
N/A	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Cl Diff NT443	**N/A**	**Cl Diff NT 492**	**N/A**	**Cl/SO**	**N/A**

LABORATORY TRIAL MIX REPORT

Client:	**Andromeda Metals**	**Report Issue Date:**	**19-12-2022**
Project:	**Great White HRM™ Evaluation**	**Trial Mix Date:**	**12-12-2022**

All tests were carried out in accordance with the relevant test methods of AS 1012 unless noted otherwise

Trial Mix Details					
Mix Identification	**Sample ID**	**Sample Time**	**Mixer Type**	**Batch Size (l)**	**Compaction[1]**
40 Mpa Control	**SFD – 1**	**09:00**	**Drum**	**45**	**Rodding**

Note 1 – Compaction method = R- Rodding, EV – External Vibration and IV – Internal Vibration

Trial Mix Design				
Constituent Material	**Source**	**Design Weight SSD (kg/m^3)**	**Trial Batch Weight SSD (kg)**	**Moisture Content (%)**
OPC	Berrima	295	13.275	
Flyash	Erraring	95	4.275	
Coarse Aggregate - 20/14	Kulnura	677	30.440	-0.08
Coarse Aggregate - 10/7	Kulnura	348	15.943	1.81
Fine Aggregate – Manufactured Sand	Kulnura	258	11.997	3.34
Fine Aggregate – Dune Sand	Macka's	535	24.562	2.02
WRDA PN	GCP	1.17 (l)	53.76 (g)	
Total Allowable Water	Potable	184	7.148	

Plastic Properties of Mix Design Details							
Nominated Slump (mm)	**100**	**Nominated W/B ratio (%)**	**0.47**	**Air Content (%)**	**MPUV (kg/m^3)**	**Setting Time (hr/min)**	
Slump (mm)	**120**	**Actual W/B ratio (%)**	**0.47**	**1.5**	**2380**	**Initial**	**4hs/20min**
Flow (mm) – 15 drops	**420**	**Ambient Temp (°C)**	**25**	**Concrete Temp (°C)**	**25**	**Final**	**5hrs/40min**
Bleeding Rate (%)		**2**					

Mechanical Properties of Concrete					
UCS 1 – Day (Mpa)	**UCS – 3 Days (Mpa)**	**UCS – 7 Days (Mpa)**	**UCS – 28 Days (Mpa)**	**UCS – 56 Days (Mpa)**	**UCS – 90 Days (Mpa)**
12.3	**25.3**	**30.8**	**44**	**50.5**	**N/A**
Shrinkage Initial (µm)	**Shrinkage 7 Days (µm)**	**Shrinkage 14 Days (µm)**	**Shrinkage 21 Days (µm)**	**Shrinkage 28 Days (µm)**	**Shrinkage 56 Days (µm)**
N/A	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Cl Diff NT443	**N/A**	**Cl Diff NT 492**	**N/A**	**Cl/SO**	**N/A**

LABORATORY TRIAL MIX REPORT

Client:	**Andromeda Metals**	**Report Issue Date:**	**19-12-2022**
Project:	**Great White HRM™ Evaluation**	**Trial Mix Date:**	**12-12-2022**

All tests were carried out in accordance with the relevant test methods of AS 1012 unless noted otherwise

Trial Mix Details					
Mix Identification	**Sample ID**	**Sample Time**	**Mixer Type**	**Batch Size (l)**	**Compaction[1]**
40 Mpa Great White HRM™	**SFD – 2**	**10:25**	**Drum**	**45**	**Rodding**

Note 1 – Compaction method = R- Rodding, EV – External Vibration and IV – Internal Vibration

Trial Mix Design				
Constituent Material	**Source**	**Design Weight SSD (kg/m^3)**	**Trial Batch Weight SSD (kg)**	**Moisture Content (%)**
OPC	Berrima	271	12.195	
Flyash	Erraring	97	4.365	
Great White HRM™	Andromeda	1	45 (g)	
Coarse Aggregate - 20/14	Kulnura	677	30.440	-0.08
Coarse Aggregate - 10/7	Kulnura	348	15.943	1.81
Fine Aggregate – Manufactured Sand	Kulnura	376	17.484	3.34
Fine Aggregate – Dune Sand	Macka's	449	20.614	2.02
WRDA PN	GCP	1.47 (l)	67.54 (g)	
Total Allowable Water	Potable	176	6.689	

Plastic Properties of Mix Design Details							
Nominated Slump (mm)	**100**	**Nominated W/B ratio (%)**	**0.48**	**Air Content (%)**	**MPUV (kg/m^3)**	**Setting Time (hr/min)**	
Slump (mm)	**130**	**Actual W/B ratio (%)**	**0.48**	**1.6**	**2460**	**Initial**	**4hrs/40min**
Flow (mm) – 17 Drops	**420**	**Ambient Temp (°C)**	**25**	**Concrete Temp (°C)**	**26.2**	**Final**	**5hrs/40min**
Ratio of Bleed to Water (%)	**2**						

Mechanical Properties of Concrete					
UCS 1 – Day (Mpa)	**UCS – 3 Days (Mpa)**	**UCS – 7 Days (Mpa)**	**UCS – 28 Days (Mpa)**	**UCS – 56 Days (Mpa)**	**UCS – 90 Days (Mpa)**
12	**24.0**	**28.3**	**44.3**	**50.8**	**N/A**
Shrinkage Initial (µm)	**Shrinkage 7 Days (µm)**	**Shrinkage 14 Days (µm)**	**Shrinkage 21 Days (µm)**	**Shrinkage 28 Days (µm)**	**Shrinkage 56 Days (µm)**
N/A	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Cl Diff NT443	**N/A**	**Cl Diff NT 492**	**N/A**	**Cl/SO**	**N/A**

Annex B – Photos Slump and Slump/Flow

32Mpa Control Slump

32Mpa Control Flow

32Mpa Great White HRM™ Slump

32Mpa Great White HRM™ Flow

40Mpa Control – Slump

40Mpa Control - Flow

40Mpa Great White HRM™ – Slump

Annex C – Internal LCA table

Material	GWP kg/m³	32Mpa Ctrl	GWP - GHG kg/m³	40Mpa Ctrl	GWP - GHG kg/m³	32Mpa Great White HRM™	GWP - GHG kg/m³	40Mpa Great White HRM™	GWP - GHG kg/m³
Cement	0.835	240	200.4	295	246.325	220	183.7	271	226.285
Flyash	0.02	95	1.9	95	1.9	96	1.92	97	1.94
HRM	0.119		0		0	1	0.119	1	0.119
20/14mm	0.01	660	6.6	677	6.77	660	6.6	677	6.77
10/7mm	0.01	335	3.35	348	3.48	335	3.35	348	3.48
M/S	0.01	252	2.52	258	2.58	367	3.67	376	3.76
F/S	0.016	610	9.76	535	8.56	530	8.48	449	7.184
Batching	0.00742	1000	7.42	1000	7.42	1000	7.42	1000	7.42
Water	N/A	179		184		172		176	
GWP-GHG kg-CO_2-eq			232		277		215		257
Lowered GWP - GHG kg-CO_2-eq						ECO2 Reduction	7.20%	ECO2 Reduction	7.25%