University of Southern Queensland
School of Engineering

Harvested Ash as Pozzolanic substitute in concrete

A dissertation submitted by

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In fulfilment of the requirements of

ENG4111 and 4112 Research Project

Towards the degree of
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ABSTRACT

Fly Ash is produced when coal is burnt to generate energy, for decades the concrete industry has used Fly Ash to improve concrete performance and mitigate long term risks in concrete. Since the energy sector is moving away from coal fired energy in Australia and globally, the production of Fly Ash will cease on our shores forcing Australian Ready Mixed Concrete suppliers to rely fully on the Nations that continue to use coal fired energy for the supply of Fly Ash. Throughout the era of coal fired energy being used in Australia, power plants have stored a percentage of the Fly Ash produced in Ash Dams.

This study makes use of some of the stored Ash, known as Harvested Ash (HA) as a substitute for fine aggregates to investigate the viability of use as sand in achieving a pozzolanic reaction. This is carried out by using a typical set of commercial concrete raw materials and typical S40 MPa mix design to carry out trials substituting varying portions of HA for the Fine aggregate portion replacing on volume basis. By fixing the Water/Total Binder ratio, including the HA addition, while increasing the Water/GP ratio relative to HA addition. Multiple hardened properties tested for comparison between each supplemented percentage of HA to analyse the pozzolanic contribution to the results. The pozzolanic reaction was successfully confirmed and the cement efficiency index was established to be comparable with the fine grade classified fly ash supplied from the same source.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses, and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.
I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

James William Moller
[redacted]

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NOMENCLATURE

AS	Australian Standards
MRTS	Main Roads and Transport Specification
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
CCAA	Cement Concrete and Aggregates Australia
IPWEAQ	Institute of Public Works Engineering Australia Queensland
RMS	Roads and Maritime Services

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Coal ash is produced primarily by burning coal in coal fired power stations. Coal ash (CCP) is made up of two types of ash, referred to as Fly Ash (FA) and Bottom Ash (BA). FA is much lighter and smaller in particle size, whereas BA is heavy and coarse. The Ash that makes up HA is a blend of both. The estimated makeup of the Harvested Ash (HA) used in this study is assumed to be 80% Fly Ash, 20 % Bottom Ash (verbal information provided by Stanwell Corp).

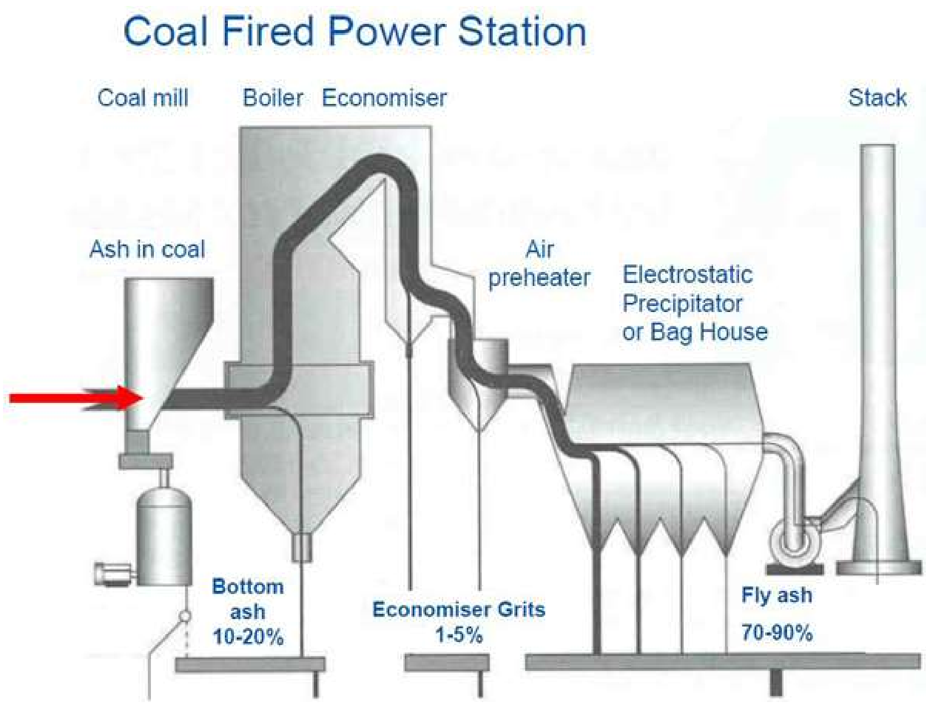


Figure 1.1 Coal Fired Power Station schematic (Fly Ash Australia, <https://flyashaustralia.com.au/WhatIsFlyash.htmllia>,2023)

Figure 1.1 above shows the coal burning process at a coal fired power station. The CCP are extracted from the system at two separate stages. A portion of the CCP produced at some power stations is extracted and processed directly for use in varying industries, while the remaining CCP are then transported to storage facilities, typically Dams or Ponds as the Ash is slurrified at the plant and then pumped to the landfill storage sites or transported by tipper truck. These Dams are typically then capped with soil fill and either planted with vegetation or not planted to leave the cap undisturbed, (Public Works Committee NSW 2021) As an example, the site that was used for this study, Tarong power station, has an estimated 40 million tonnes in landfill storage comprised of approximately 80 to 90% FA and 10 to 20 % BA. (Information provided by Stanwell Corp during sampling)

Figure 1.2 Image taken while sampling HA at Tarong Power Station showing the surface of the CCP Dam and on right hand side stockpiled BA.

1.2 The problem

Classified FA is used as a supplementary cementitious material in commercial concrete supply as material to improve the plastic and hardened properties of concrete *(ADAA 1991).* FA's use is well established and it's testing, and minimum performance is detailed in *AS/NZS 3582.1:2016 Supplementary cementitious materials Part 1: Fly Ash*. Multiple Australian and global standards specify the use of FA to mitigate the expansion caused by reactive aggregates in concrete.

As Energy generation in Australia and Globally is moving away from Coal Fired power there has been a reduction in the supply capacities of available FA. Australian Ash production in 2008 was estimated to be 14.5 million tonnes, dropping to 10.2 million tonnes in 2021. (ADAA, 2014 p12 & 2021 p5) In recent years the reduction was recorded to be 10 per cent per annum, and the rate of reduction in availability is predicted to increase annually as more coal fired power stations are closed and renewable energy sources are employed. (ADAA, 2021 p3) Table 1.1 below gives some insight to the trending of closures globally by region. This data clearly shows the number of Coal Fired Power Stations on decline, which will contribute to the declining capacity for FA in concrete.

Table 1.1 Record of Coal fired Power Station construction, cancellations, and retirement from operation globally. (Global Energy Monitor, https://globalenergymonitor.org/projects/global-coal-plant-tracker/summary-tables/,2023)

Region / Subregion	Pre-construction	Construction	Shelved	Operating	Cancelled 2010-2022	Retired 2000-2022
Africa	21	3	18	39	76	2
Northern Africa	0	0	0	4	7	0
Sub-Saharan Africa	21	3	18	35	69	2
Americas	3	1	4	270	87	345
Latin America and the Caribbean	3	1	3	43	41	9
Northern America	0	0	1	227	46	336
Asia	280	187	95	1,819	1,287	439
Central Asia	4	1	1	25	6	5
Eastern Asia	200	119	35	1,287	527	388
South-eastern Asia	30	32	39	165	175	3
Southern Asia	34	34	17	304	466	40
Western Asia	12	1	3	38	113	3
Europe	15	4	6	310	143	264
Eastern Europe	9	2	3	190	72	83
Northern Europe	0	0	0	16	12	43
Southern Europe	6	2	3	34	33	44
Western Europe	0	0	0	70	26	94
Oceania	1	0	4	20	11	15
Australia and New Zealand	1	0	3	20	11	15
Melanesia	0	0	1	0	0	0
Global Total	320	195	127	2,458	1,604	1,065

Annually in Australia the construction industry consumes close to 30 million cubic metres of concrete. To achieve this supply the concrete industry consumes 200 million tonnes of aggregates, both coarse and fine. (CCAA, 2018) Of these aggregates it is estimated that over 190 million tonnes are virgin materials supplied by extractive industries and due to this demand, the natural sand and gravel resources available are depleting and decentralising from metropolitan areas where the material is required for use. (ADAA, 2021, p3) As each materials in a concrete mix plays a role in and has influence on the plastic and hardened performance of concrete, it is important to understand any impact of the substitution of the HA as fine aggregate. Due to the particle size of the Ash, typically greater than 70 % is finer than 45 μm (ADAA, 2014, p55) the impact of this additional fine material and its characteristics must be assessed against that of a typical fine aggregate.

Currently in Australia there is estimated to be more than 400 million tonnes of HA in storage in Australia. (ADAA, 2014 p154) This material has potential to be introduced as a replacement for fine aggregate doubling as a replacement for current FA used as a Supplementary Cementitious Material. As there is a real and present issue in rehabilitating sites that are current storage facilities of HA, in terms of cost, resourcing and environmental impact (Public Works Committee NSW 2021) it is an opportunity to develop a solution to both problems by commercialising the utilisation of landfilled CCP that is readily available in the region, with large enough quantity to keep up supply for the increasing demand due to the reduction in Coal Fired Power Generation, giving time for the industry to determine a long term replacement for FA all together.

1.3 Project Aim

Commercialisation and industrialisation must be established in stages. This study aims to prove that while the technology is developed for processing of the HA to a dried and powder medium that the ready-mix supply industry is accustomed to using and has the required infrastructure to handle and process, there is benefit in the use of HA as a pozzolanic material via fine aggregate replacement. This is intended to be proven through the trial procedure of comparing the tested properties of the control mix using only GP cement, against multiple mixes utilising varied percentages of replacement of fine aggregate with raw HA. This study intends to prove the use of HA in concrete will provide enhanced hardened properties through the pozzolanic reaction. In addition to this the use of chemical admixture in conjunction with HA will further enhance the reaction due to the dispersion of the fine material.

The plastic and hardened properties of 9 different concrete mixes will be tested to confirm the impact of the addition of the HA to understand the impact of the addition of this material to the concrete.

1.4 Objectives

1. Conduct comprehensive literature review on the use of HA as substitute in concrete
2. Establish research significance.
3. Develop testing plan and mix trial program to best eliminate as many variables as possible.
4. Establish mix design and percentage of sand replacement by HA for trials.
5. Source materials and prepare samples and complete testing.
6. Analyse data linking with available literature, draw conclusions, answer initial question, look for future opportunities.
7. Prepare thesis/ present findings at Project Conference

1.5 Ethical responsibility

With any work in the professional environment, it is critical to consider the ethical responsibility of that work.

If this project is successful, it will offer an opportunity for further and future research into the use of HA in Concrete. This objective provides all stakeholders at direct or indirect level of involvement a sustainable solution to what is a global and local issue without any immoral or unethical implications.

CHAPTER 2: LITERATURE REVIEW

A literature review has been undertaken to identify gaps in current knowledge as well as develop the background theory, mixture design, and methodology for the project.

2.1 Ash Reuse

Products produced through the burning of coal are known as Coal Combustion Products (CCPs). ADAA 2014 lists the possible use of CCP as the below:

- Cement/ Concrete industry
- Structural fill
- Flowable fill
- Waste stabilisation
- Agriculture – soil treatment
- Manufacturing
- Ponding or storing

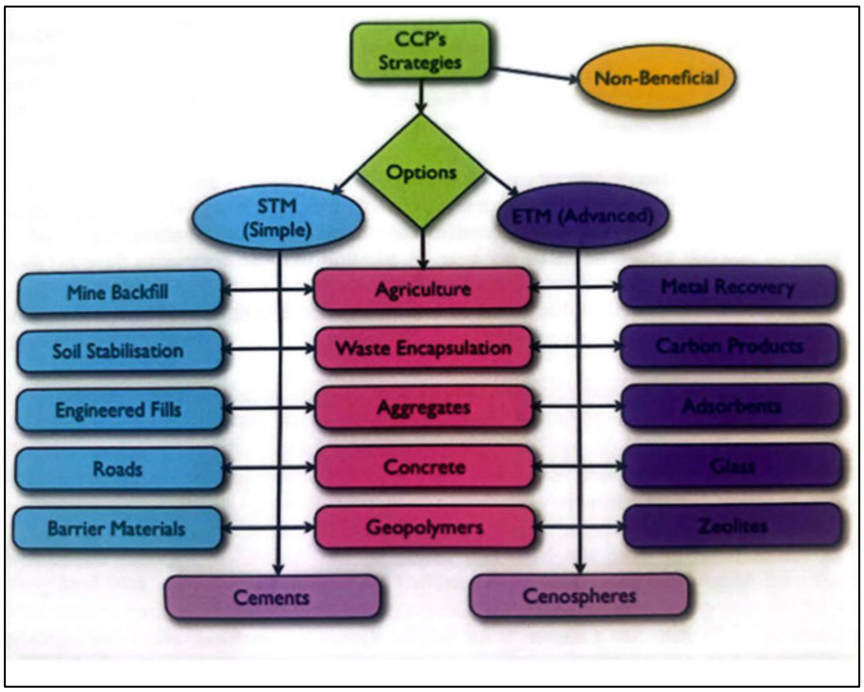


Figure 2.1 Schematic for reuse of CCP options (ADAA 2014 p13)

This project will focus on the Ponded or stored Ash portion, noted as Non-beneficial in Figure 2.1 above, and the validity of extracting and utilising the massive amount of stored Ash.

2.1.1 Global CCP Reuse

Of the CCP produced Globally only between 50 and 60 % is effectively utilised, feeding the remaining into storage. It is typical that countries with a larger geographic footprint (more space) and that have not advanced their energy production away from Coal Fired Power have larger contributions going to storage facilities.

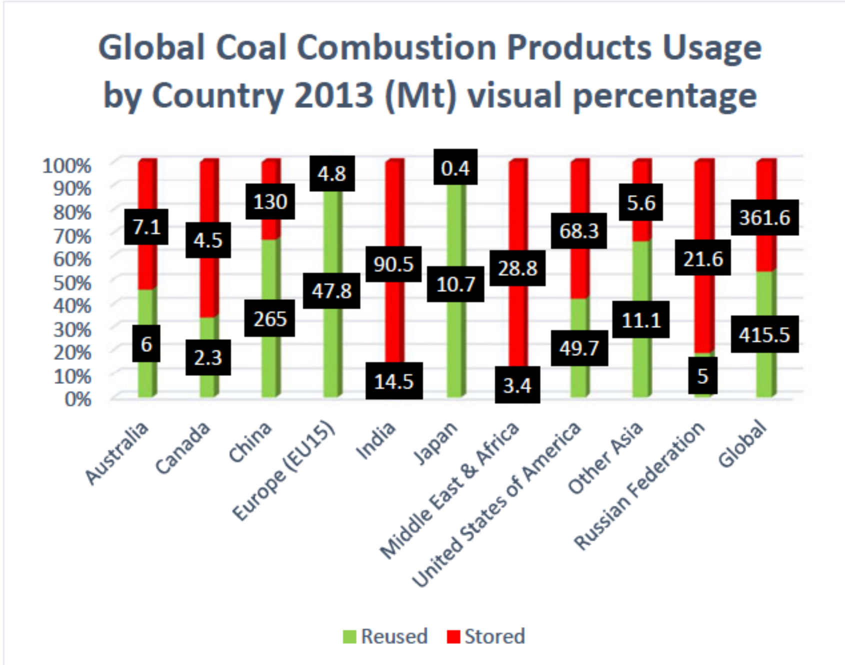


Figure 2.2 Global CCP figures of 2013, extracted from ADAA 2014 p11

2.1.2 Australian CCP reuse

Australia historically has stored greater than 50 % of CCP produced per annum, in some years close to 80% of CCP produced went to storage, which has results in coal fire power station sites with massive Ash Dams. (ADAA 2014) Figure 2.3 below shows that as CCP production increased, use of CCP products trended downwards.

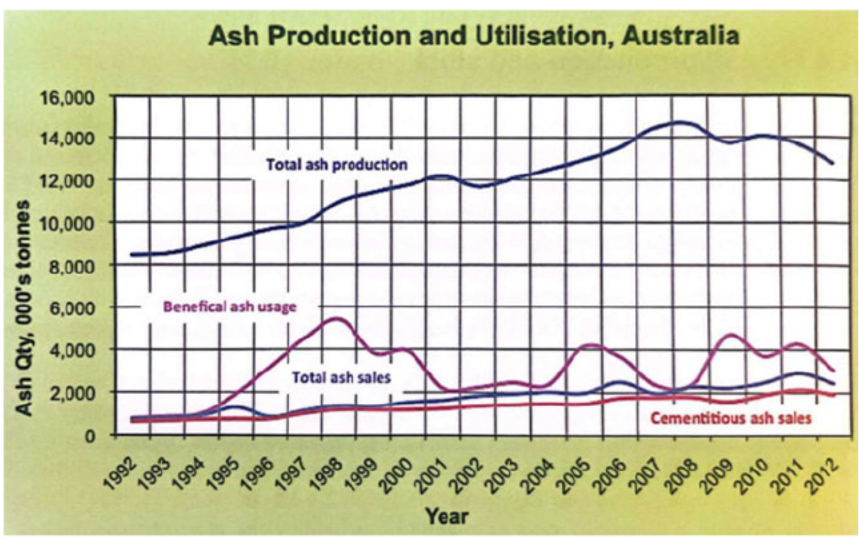


Figure 2.3 Historical CCP production (ADAA 2014 p12)

2.2 Queensland and Australian Standards

MRTS70 Main Roads Technical Standard for Concrete details that all concrete shall include cements either produced as blends, Type GB (Blended Cement per AS3972) or blended at a concrete plant from a silo of Type GP (General Purpose Cement per AS3972) with a silo of either FA or Ground

Granular Blast Furnace Slag (GGBFS) to meet specified minimum percentages as defined in *AS3972 General Purpose and blended cements.* Blends either use FA at minimum of 25% replacement by weight of cement, GGBFS of varying proportions depending on the blend type and Amorphous Silica Fume (SF), 4% - 8% by weight. This use of blends for all concrete shows that any infrastructure that is to be constructed will require FA to be built.

SA HB 79:2015-2007 provides the guidance for use of FA for the purpose of mitigating the risks associated with Aggregate Alkali Reaction AAR and Alkali Silica Reaction ASR.

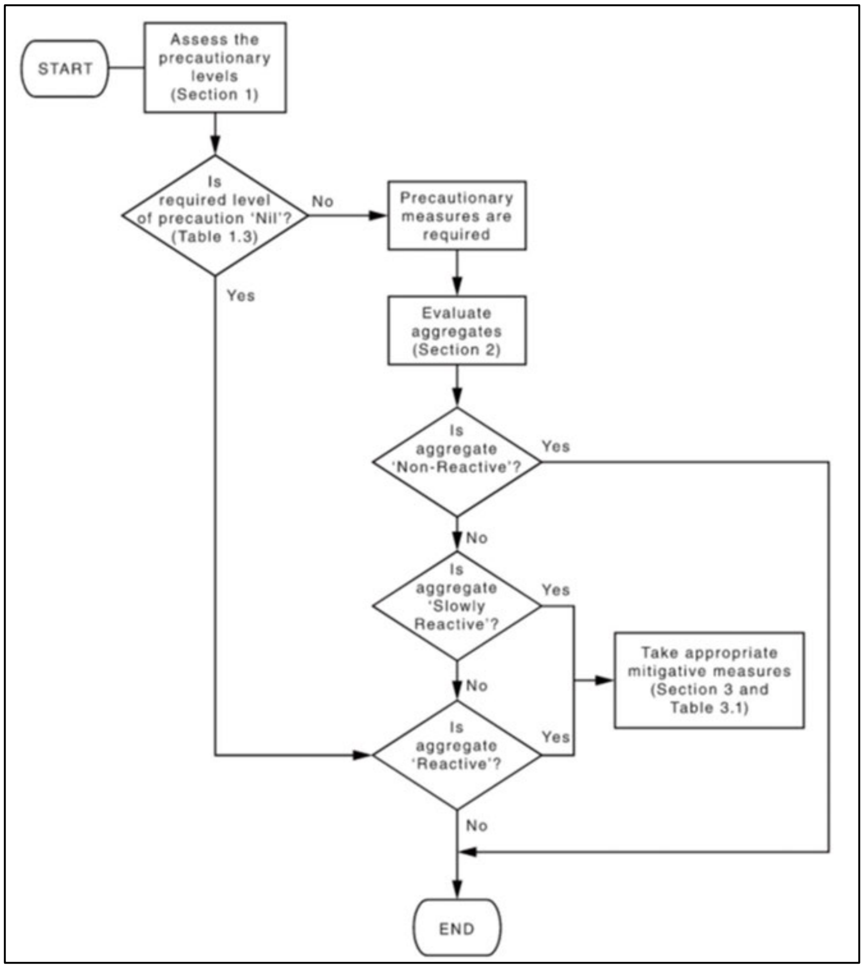


Figure 2.4 Flow chart for the review of aggregates and mitigating ASR in concrete (SA HB 79:2015 p5)

TABLE 3.1

MITIGATIVE MEASURES FOR MINIMISING RISK OF CONCRETE DAMAGE DUE TO ASR IN PROPOSED STRUCTURES USING POTENTIALLY REACTIVE AGGREGATES (SEE SECTION 2)

Item	Precautionary categories (refer to Table 1.3)					
	Low		Standard		Extraordinary[a]	
Aggregate's potential for ASR (see Section 2)	Slowly reactive	Reactive	Slowly reactive	Reactive	Slowly reactive	Reactive
Strategy for minimisation of ASR	Accept—no mitigative measures required	Limit alkali level in concrete (Clause 3.3) *or* Use a cement with sufficient blended SCMs to control ASR (Clause 3.4)		Use a cement with sufficient blended SCMs to control ASR *and* Either limit alkali levels or restrict moisture access		Use alternative aggregate or make assessment of proposed mixes using a cement with sufficient blended SCMs to control ASR (Clause 3.6)

Figure 2.5 Table 3.1 referred to in Figure 2.4 regarding the use of SCMs (Supplementary Cementitious Materials) (SA HB:79 p41)

With the introduction of AS3582.4 – 2022 it is hoped that ready mixed concrete producers will have accessibility to the use of the abundant stored CCP if research can prove its viability.

2.3 Use of Harvested Ash in concrete, HA vs Powder Fly Ash

Stored CCP, as previously mentioned, is made up of both BA and FA. FA has long been extracted and used in concrete and masonry products, as early in Australia as the 1960's (ADAA 2009). In reviewing the literature, we can compare the known use of FA with research into the potential use of HA.

2.3.1 Use of Classified Fly Ash as Supplementary Cementitious Material (SCM)

Fly Ash used in concrete is typically Grade 1 as per AS 3582.1 – 2016 *Supplementary cementitious materials Part 1 : Fly Ash.* It is a fine powder, limits show that greater than 75% must be finer than 45 microns, delivered to concrete plants via tankers and blown into silos by air pressure. The small particle size increases available surface area and in turn increases efficiency of pozzolanic reaction. One of the consistent arguments to the failing of HA as coarse substitute is the limited surface area and reduced capacity for reaction.

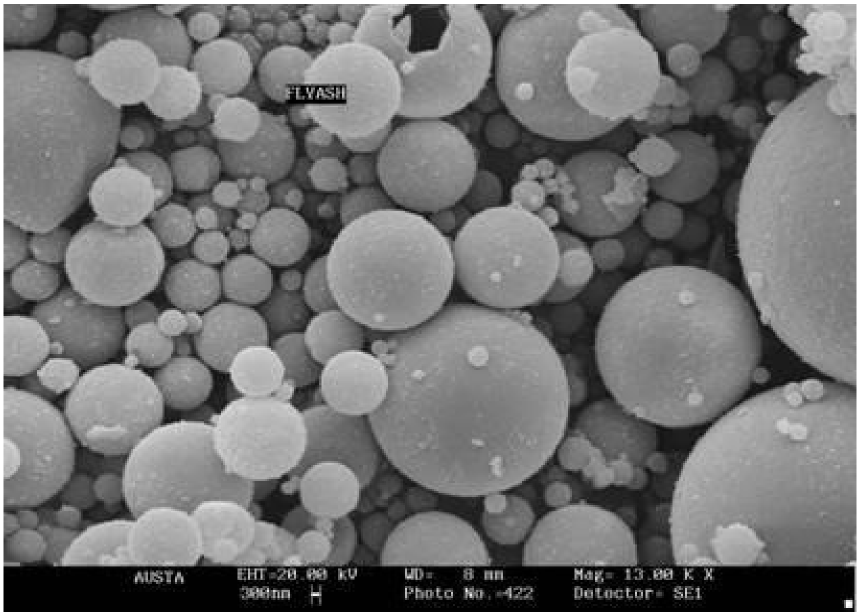


*Figure 2.6 Electron microscope image of FA particle (*Fly Ash Australia, <*https://flyashaustralia.com.au/WhatIsFlyash.htmllia*>*,*2023)

This introduces the idea of treating as a sand and applying limits of typical fine aggregates to that of HA, while this may work for such things as the Particle Size Distribution (PSD), however the reality of the material is that the HA is a conglomerate of very fine particles that have settled and dried together in comparison to a hardened material that has been broken down into fine grains. When the HA is introduced to the mixing action of concrete mixing it is expected that the HA will be pulverised and break down into the finer particles that make up the conglomerate, contributing to the paste volume of the concrete matrix. When fine aggregates are added they do not break down due to their strength and there is no difference to the expected water demand, based on their testing, other than that pre-determined when designing concrete mixes. (Alexander & Mindess 2005 p176-220)

Haldive & Kambekar (2013) compared both the use of FA and HA, referenced as Pond Ash (PA) in this paper, with Ordinary Portland Cement (OPC) concrete and combined both types of Ash. The finding of this study showed that for the chosen source of Ash the 20% HA replacement of sand resulted in higher compressive strength than 10% replacement of OPC with Fine grade FA, the ultimate best performance was achieved with 20% FA replacing OPC and 10% replacement of river sand with HA. As this study was targeting durability through testing with Rapid Chloride Penetration Test results and water permeability the recorded improved performance related to these values. The most relevant part of their study was that at 90 days the compressive strength of any of the HA mixes was considerably higher than the OPC mixes showing the pozzolanic secondary reaction of the calcium hydroxide produced when the OPC hydrates and the HA reacts from 3-5 days onwards.

2.3.2 USE AS FINE AGGREGATE

Internationally there has been several research projects carried out using both BA and HA as a substitute in both concrete and mortar research. There does not appear to be a great deal of research available within Australia. Several of these projects were reviewed to determine the necessary attributes to be tested of the HA in replacing the fine aggregate.
Andrade et al 2009 completed a study utilising bottom ash as fine aggregate replacement in concrete and testing the influence on plastic properties. Their focus was on the chemical composition of the BA relative to the Cement used and the PSD of the BA relative to the sand it was to replace.

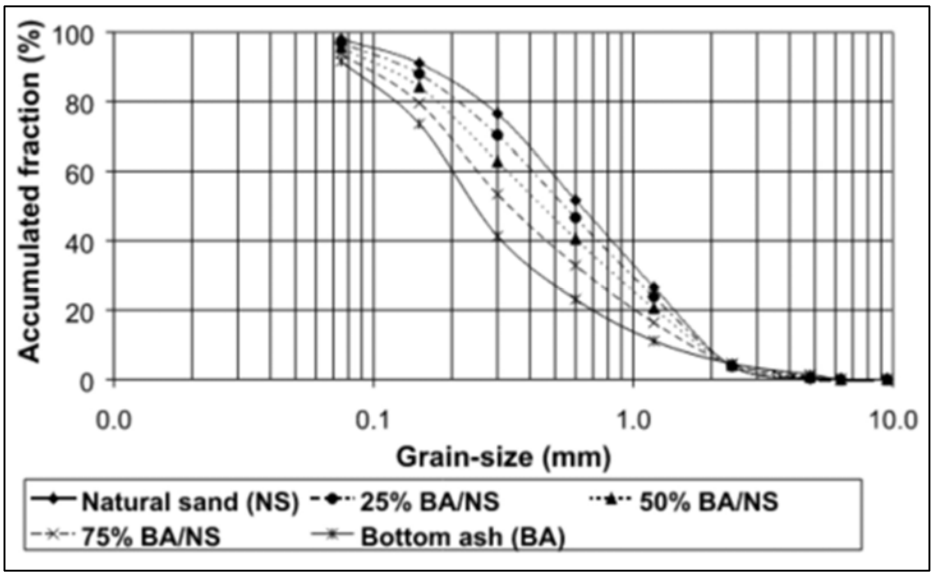
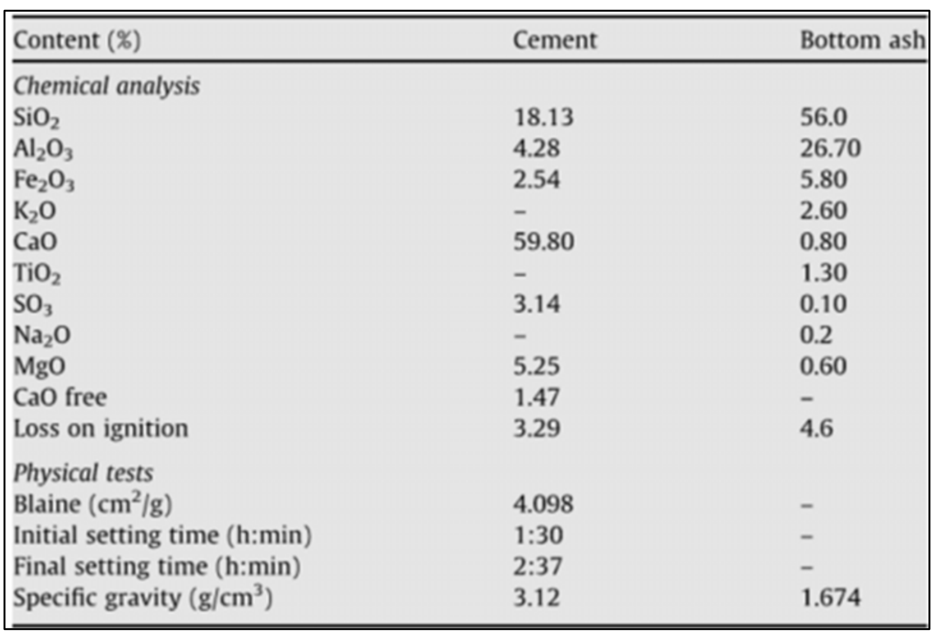


Figure 2.7 PSD f fine materials (Andrade et al 2009)



Content (%)	Cement	Bottom ash
Chemical analysis		
SiO_2	18.13	56.0
Al_2O_3	4.28	26.70
Fe_2O_3	2.54	5.80
K_2O	–	2.60
CaO	59.80	0.80
TiO_2	–	1.30
SO_3	3.14	0.10
Na_2O	–	0.2
MgO	5.25	0.60
CaO free	1.47	–
Loss on ignition	3.29	4.6
Physical tests		
Blaine (cm^2/g)	4.098	–
Initial setting time (h:min)	1:30	–
Final setting time (h:min)	2:37	–
Specific gravity (g/cm^3)	3.12	1.674

Figure 2.8 Comparative Analysis of Ash to Cement (Andrade et al 2009)

Another study of BA as a pozzolanic material reviewed the PSD of the BA, but with the focus of determining three things, the PSD, the median particle size, and the Specific Gravity of the Ash. (Abdulmatin et al 2018)

Physical properties of materials.

Materials	Retained on a No. 325 Sieve (% by weight)	Specific Gravity	Median Particle Size, d_{50} (μm)
OPC	16.8	3.14	14.7
5BA	3.7	2.88	4.3
15BA	14.5	2.85	15.4
25BA	24.0	2.83	24.2
35BA	35.3	2.76	39.8
45BA	43.7	2.72	72.3
OBA	96.3	2.33	400

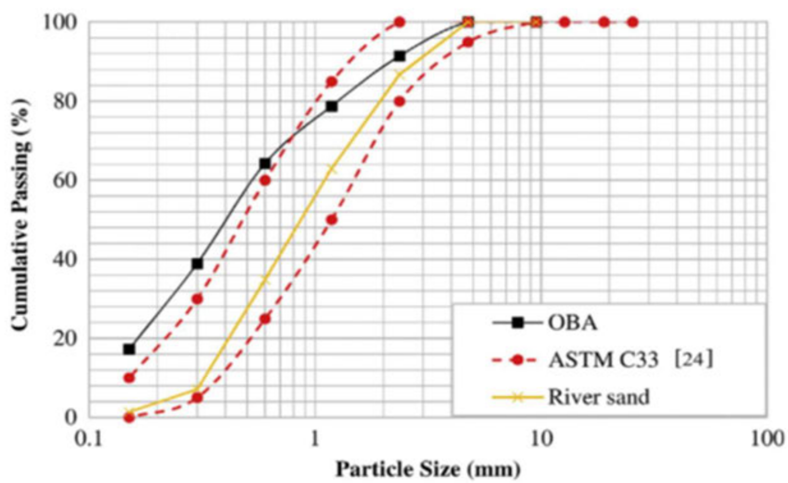


Figure 2.9 Material properties assessed of Bottom Ash used in research (Abdulmatin et al 2018)

2.3.3 Particle size distribution

The typical approach in the research has been to assess the PSD relative to the material that the HA or BA is substituting to determine the physical comparison in grain size and percentage the sand it is to replace. Figures 2.10 to 2.13 show the BA to be considerably coarser than FA. FA is majority passing the 75 micron sieve and none remaining above the 150 micron, whereas the bottom ash has a particle size ranging up to greater than 4.75 mm.

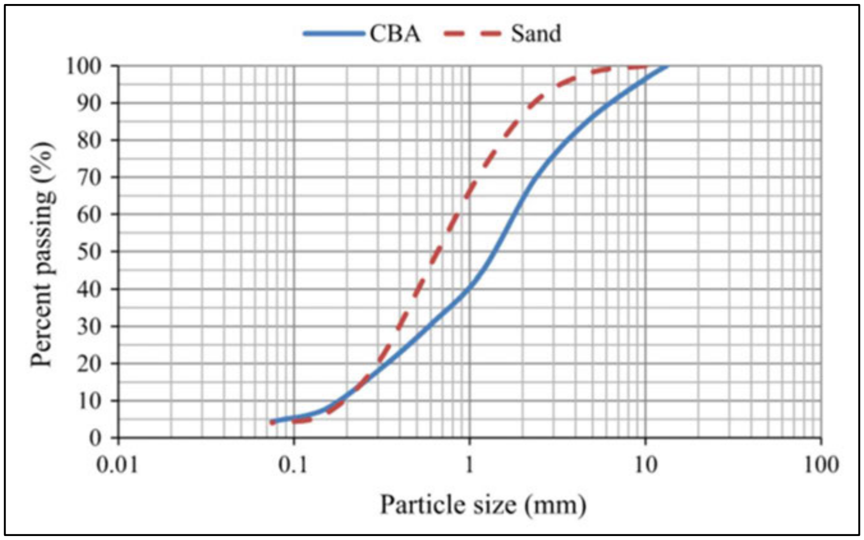


Figure 2.10 PSD (Rafieizonooz et al 2016)

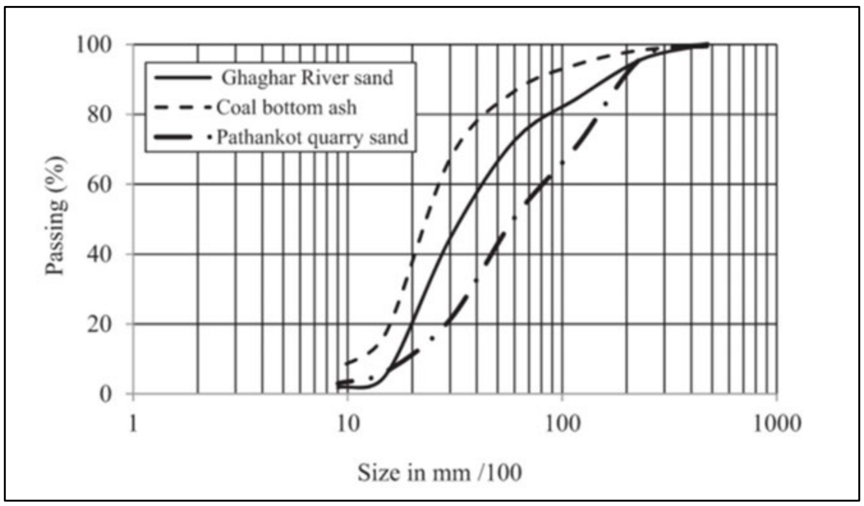


Figure 2.11 PSD (Singh & Siddique 2016)

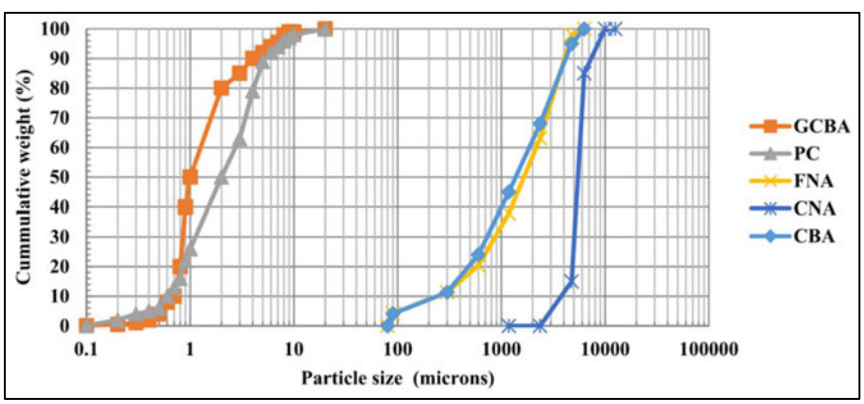


Figure 2.12 PSD of different Ash sources used n research (Ankur & Singh 2021)

Lal et al 2019 assessed the available Ash particle size in comparison to the Cement particle through electron microscopy as detailed in Figure 2.13 below.

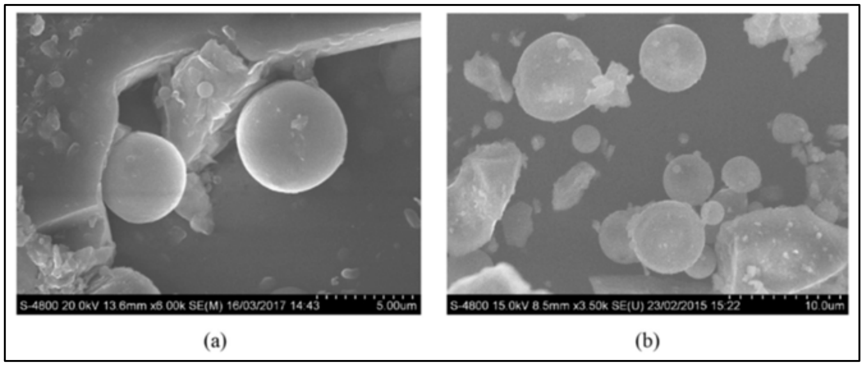


Figure 2.13 Comparison of and a) Ash Particle and b) Cement Particle for size and shape under electron microscope (Lal et al 2019)

Figure 2.14 below details the relationship established between the portion of material retained on the 0.325mm sieve and the compressive strength of concrete using BA as replacement of fine sand. This is an interesting assessment of the particle size distribution and presents the relationship between the fineness of material and the increase in pozzolanic reaction. As the material is finer it increases the surface area for reaction. (ADAA 2014) states that typically a FA is smaller than 75 µm. This study chose a much larger aperture to develop the relationship. (Abdulmatin et al 2018)

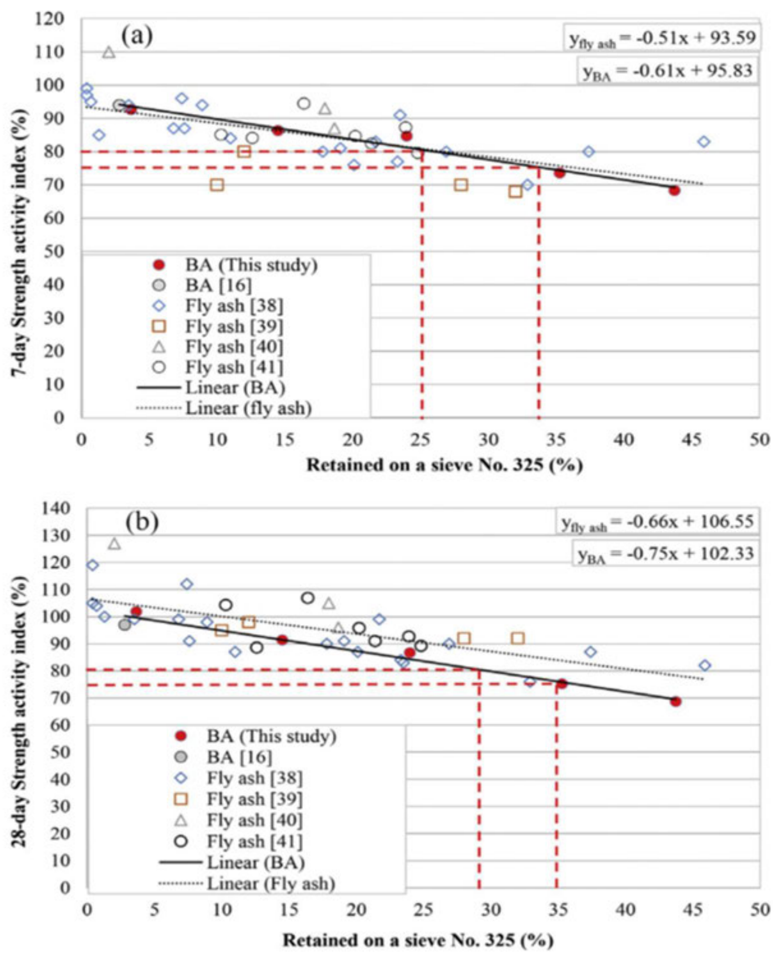


Figure 2.14 Relationship between compressive strength and portion of material retained on 0.325 sieve (Abdulmatin et al 2018)

2.4 PROPERTIES OF HARVESTED ASH-BASED CONCRETE.

Various research has been carried out internationally in the use of both BA and PA, as it is referred to in papers, in this project referred to as HA. There is limited Australian research in the use and testing of Harvested HA in concrete and the impact on the concrete properties by its introduction and substitution.

2.4.1 WORKABILITY LOSS DUE TO INCREASED WATER DEMAND

The workability loss in concrete utilising Ash is reported in numerous research programs. Different Ash sources have differing levels of porosity and water absorption. These characteristics, along with particle shape are noted to be the most common issue causing reduced workability as the percentage of HA replacement increases.

Figure 2.15 below shows the recorded workability (slump) loss as the percentage of HA increases in a C-25 concrete mix of fixed water content. It is reportedly due to the material's water absorption. (Yimam et al 2021)

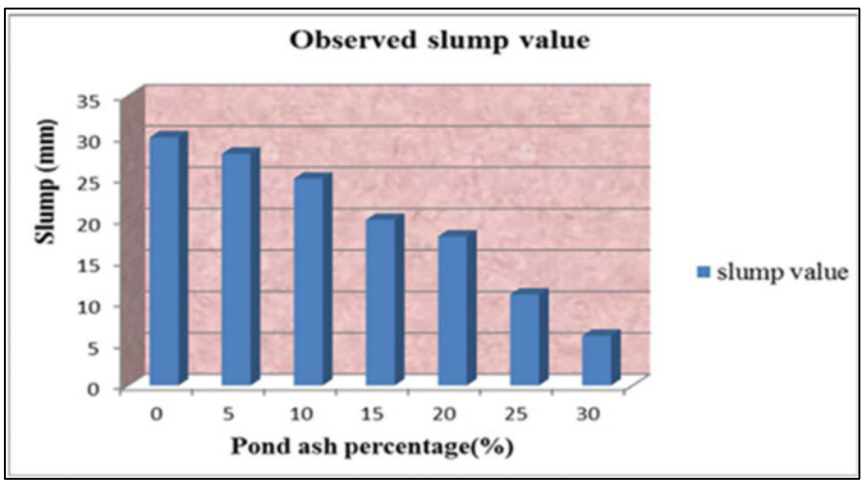


Figure 2.15 Workability loss recorded (Yimam et al 2021)

2.4.2 ADMIXTURE ADDITION

Shrikant M. Harle's research published in 2019 trialled various admixture types with use of PA in Concrete. The research found that using a Napthelene based High Range Water Reducer to increase the workability resulted in a lower compressive strength. The water in these mixes was not restricted and for this reason it appears that the strength decreased s both the admixture and water content were responsible for the increase in workability.

Dose (gm)	7 days compressive strength (N/mm^2)	Compressive strength in N/mm^2			Slump (mm)
		Average 7days Strength	14 days Strength	28 days Strength	
100	17.6	18.06	25.00	27.51	80
	18.52				
	18.06				
200	16.06	15.11	20.92	23.01	130
	14.168				
	15.10				
300	13.20	15.05	20.84	22.92	150
	16.89				
	15.06				

Figure 2.16 Compressive strength results using Naphthalene HWR to improve workability (Harle 2019)

2.4.2.1 DISPERSION DUE TO ADMIXTURE ADDITION

The formation of hydration products that coat the external surface of cement particles will quickly reduce workability in concrete and these hydration products are generated at the time that the cement is combined with the mixing water (Hewlitt &Liska, 2019). The function that is performed by admixtures is that they coat the cement particle for a period that delays the development of the hydration products, releasing the water from being locked in early for hydration and improving workability until the saturation of the admixture is worn off. Once the admixture has worn off, the water then coats the particle and begins hydration. As the water has been allowed access to greater surfacer area the hydration is more effective so the use of admixtures can produce higher compressive strength for the same w/c ratio (Neville, 2012)(Hewlitt & Liska, 2019).

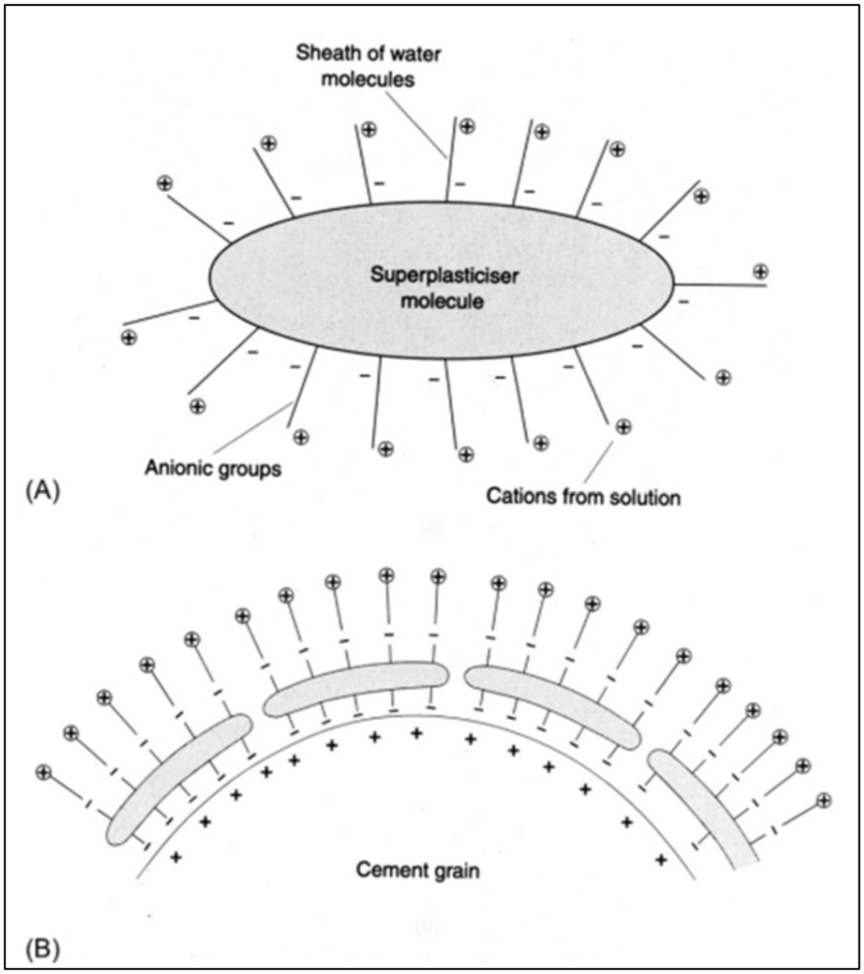


Figure 2.17 Suggested adsorption of polycarboxylate-ether admixtures resulting in particle dispersion (Hewlitt & Liska, 2019 p661)

2.4.3 Bleeding in plastic concrete

Bleeding of concrete is effectively the settling of the concrete in place prior to the concrete setting (Neville, 2012). As the water is the mix constituent with the lightest specific gravity of all the materials in the concrete mix, it rises to the surface as this occurs. This water is then known as the bleed water. As the total free water content increases, the likelihood for increased bleeding of plastic concrete occurs. The likelihood of the bleed percentage of total water added to increase in influenced by the amount of hydraulic binder in the concrete mix. (Neville 2012, p207-209) (Andrade et al 2009) found that as the BA percentage of replacement increased, the total water increased, and as a result the recorded bleed increased relative to the BA inclusion. Figure 2.19 below shows the relationship established in their study.

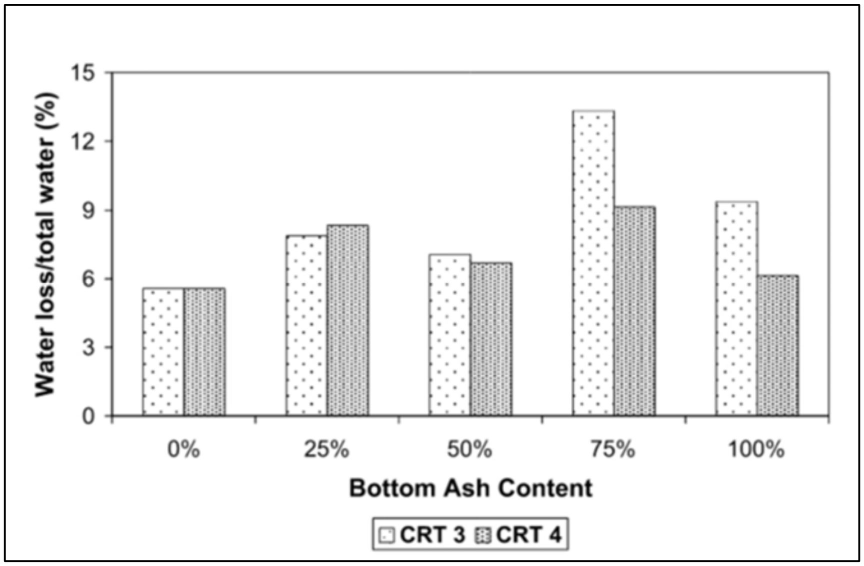


Figure 2.18 Plot of bleed water vs bottom ash percentage from (Andrade et al, 2009)

2.4.4 Compressive strength and the pozzolanic reaction

The compressive strength of concrete is developed due to the hydration of cement. In this project we are relying on the pozzolanic reaction of the HA to occur to improve the compressive strength of the concrete to counteract the additional water required to be in the concrete.

2.4.4.1 Compressive strength

(Andrade et al 2009) explored the use of BA in concrete and states the as the BA percentage increased there was significant loss in compressive strength due to the increased water content. This study allowed the total water to binder ratio to increase and varied the amount of cement, water and BA used. Figure 2.20 below shows the variability in cementitious, water and all other materials across the mixes. As well as this, the BA is considerably coarser and said to be less reactive due to limited surface area when compared with FA finer than 75 µm. (Neville, 2012).

Concrete	Mix proportion (kg/m^3)					Fresh density (kg/m^3)	BA moisture (%)[a]	Compressive strength (MPa)		
	Cement	Sand	BA	Gravel	Water			3 days	28 days	90 days
0% CRT	304	912	0	806	219	2238	-	15.9	28.4	32.0
25% CRT3	305	686	145	808	277	2177	50.0	12.5	23.2	25.7
50% CRT3	301	452	287	798	336	2090	50.0	9.9	18.0	23.0
75% CRT3	295	221	422	782	373	1964	52.0	6.3	11.5	14.9
100% CRT3	299	0	570	792	378	1869	57.0	4.2	8.6	12.5
25% CRT4	323	727	103	856	245	2220	50.0	19.5	27.2	32.1
50% CRT4	334	501	212	885	272	2138	50.0	17.0	28.5	35.9
75% CRT4	356	267	340	943	303	2109	50.0	16.1	26.1	32.7
100% CRT4	386	0	441	1023	323	2040	67.0	21.2	32.6	38.4

Figure 2.19 Mix details and compressive strength results for Andrade's study using bottom ash in 2019.

Yimam ‘s study in 2021 using pond ash in C25 concrete up to a replacement of 30 % found that the compressive strength increased at 5 and 10 % replacement but higher than this the strength was lower than the control, as is shown in Figure 2.21 below.

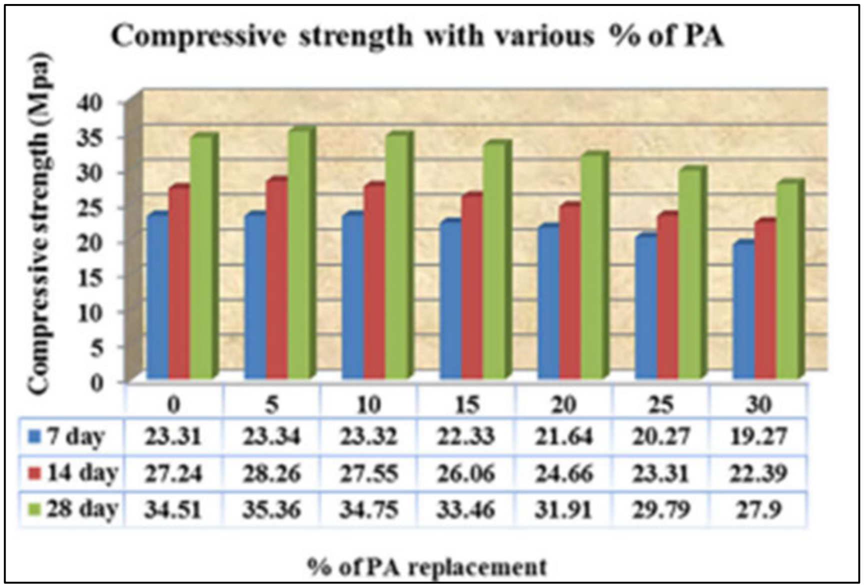


Figure 2.20 Compressive strength vs replacement percentage of Pond Ash from Yimam et al 2021

2.4.4.2 Pozzolanic reaction and quantification of efficiency

Key to this project is to determine if the harvested ash in its raw state can achieve a pozzolanic reaction and we are able to quantify this reaction. To understand how best to do this we need to be able to define the pozzolanic reaction and determine the method for quantification.

2.4.4.2.1 Pozzolanic reaction

Hewlitt & Liska 2019 define pozzolanic activity as any reaction taking place between the active constituents, being pozzolanic materials, lime and water. There are typically two methods to test for this reaction, to test the lime present before and after the reaction, chemical analysis, or to determine the increase in formation of alumina-silicate through the hydration process, determine the increase in compressive strength (Hewlett & Liska, 2019).

2.4.4.2.2 Quantification of efficiency

AS 3583.6-2018 Methods of test for supplementary cementitious materials; method 6: determination of relative water requirement and strength index, provides the framework for testing the efficiency of fly ash as a supplementary cementitious material. Control samples are cast using GP cement only and substitution of this cement is then made with fly ash to determine the comparative performance of the ash with the same content of GP cement.

2.4.5 Tensile strength

The tensile strength of concrete is proportionately very low relative to the compressive strength of concrete. This is partially due to the make-up of the matrix of concrete, there are larger and smaller particles of hard material held together with binder levels of varying thickness and varying strength individually relative to the particles bonded. Concrete also contains pores and voids, microcracking and weak particles being commonplace. This results in uneven stress distribution across a section when the concrete undergoes tension and the result of testing is reflective of the weakest point that has undergone concentrated stress (Neville 2009 p291)

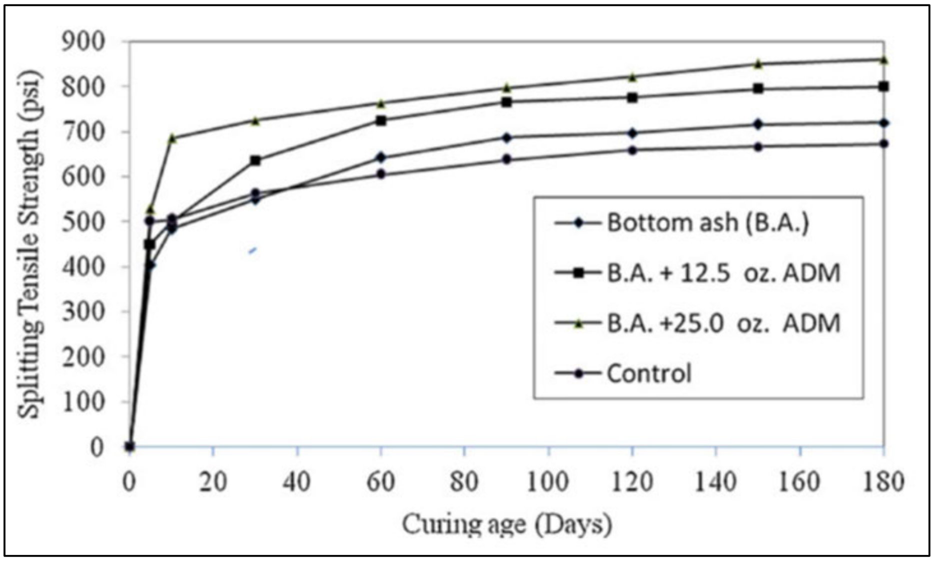


Figure 2.21 Splitting Tensile Strength results using Coal Bottom Ash as sand with and without admixture (Singh & Siddique 2021)

Singh & Siddique's research from 2013, shown in Figure 2.22 above, found that with only water the tensile strength dropped, however with the introduction of admixture and BA substitution the Tensile Splitting Strength improved.

2.4.6 Mass per unit volume, Dry density of hardened concrete

Density or Mass per Unit volume of concrete is the theoretical sum of all ingredients in the concrete. (Neville 2009 p 186) This does not include air voids and because of this the yield of a concrete mix is determined. AS it is a sum of materials, the more materials with lower specific gravity introduced to the mix, the more the dry density will reduce. As HA has a specific gravity between 1.9 and 2.1 (ADAA 2014), the higher percentage of addition is expected to see the lowest dry concrete density per cubic metre.

Yimam et al's findings were in line with this, as they increased the substitution of pond ash in their C25 concrete, they found that the dry density, or as they refer to it, unit weight in kg/m^3 decreased as shown in Figure 2.23 below.

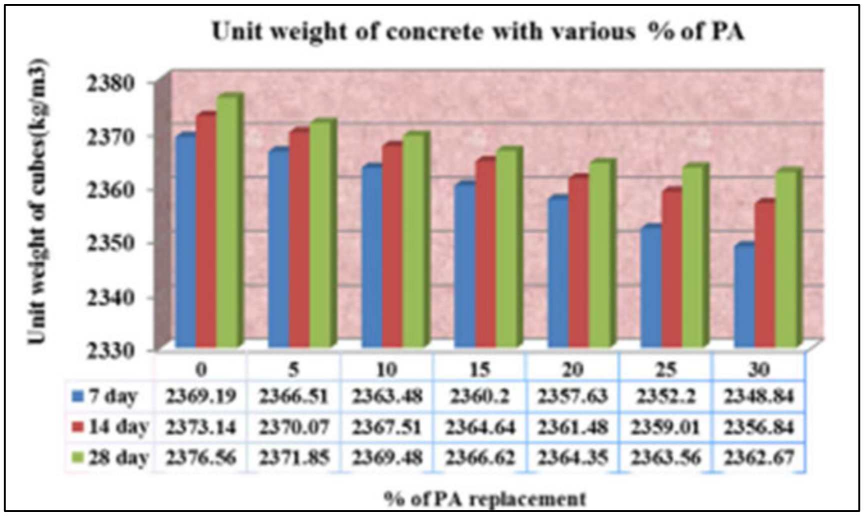


Figure 2.22 Density vs Pond Ash replacement in C25 Concrete (Yimam et al, 2021)

2.4.7 FLEXURAL STRENGTH

As the flexural strength is assumed to be proportionately relative to the compressive strength of concrete it is widely assumed that any factors impacting the compressive strength will have the same impact on the flexural strength. (Neville 2014 p286 – 289)

There are however several properties in concrete that can impact the flexural strength of concrete more so than the compressive strength, such as aggregate selection and minerology, aggregate bond to paste, external and internal factors, aggregate shape and interlock, mix design and a multitude of other parameters (C&CI 2009, p97 – 105)

Muthusamy's 2020 study found that the substitution of BA for fine aggregate resulted in lower flexural strengths than the control mix. This study maintained a fixed GP content and added the BA as replacement of fine aggregate while fixing the water content. This model is similar to the approach this study will take, by fixing the GP content and maintaining coarse aggregate content for each mix. The flexural testing results of Muthusamy's 2020 research are shown in Figure 2.24 below.

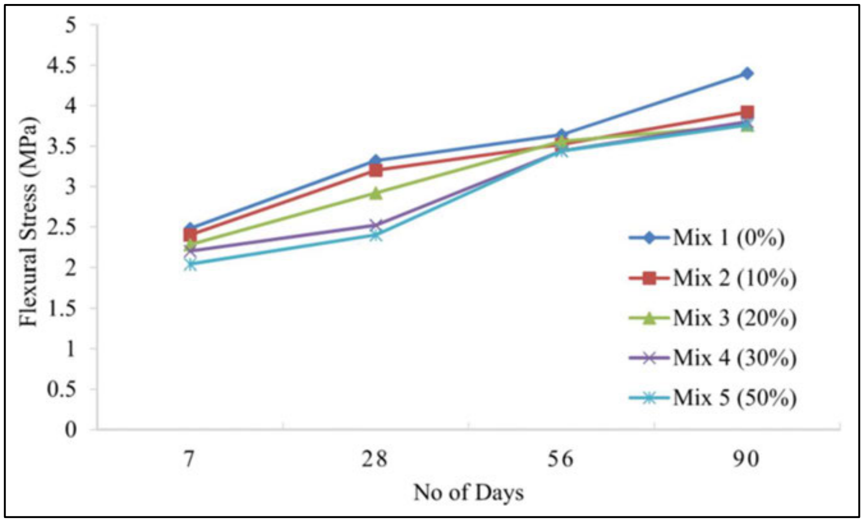


Figure 2.23 Muthusamy's 2020 Flexural testing results showing the reduction of strength based on BA substitution.

Ankur & Singh 2021 also found from their research into the use of Coal BA in Mortars that the increase in addition of Ash replacement results in a reduced performance in flexural strength. Figure 2.25 below shows the plot results of reinforced concrete beams cast with various percentages of BA as both fine and coarse aggregate substitution. The study found that the concrete using BA was comparable to the performance of the control concrete. (Nasrudin et al 2022)

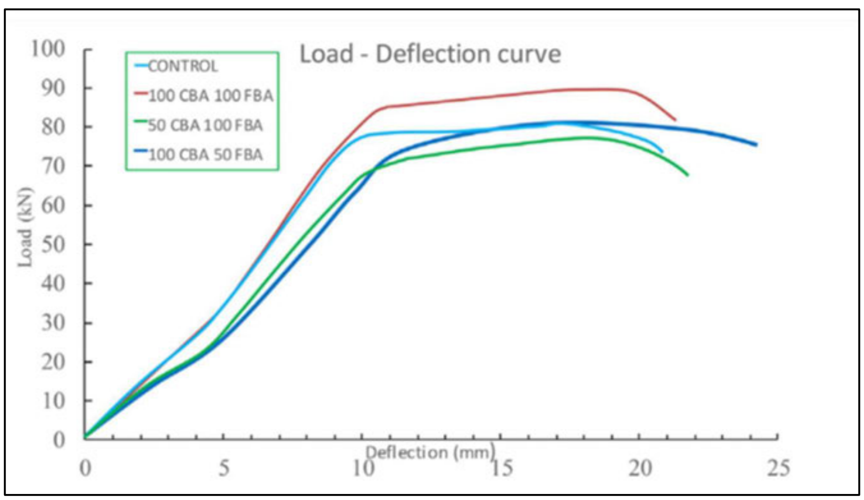


Figure 2.24 Plotted results of reinforced concrete beams placed into bending via a point bending test (Nasrudin et al 2022)

2.4.8 Drying Shrinkage

Shrinkage characteristics in concrete consists of reversible and irreversible types. Drying shrinkage is largely irreversible and is caused by the moisture loss of the concrete as it ages. (C&CI 2009, p132) Figure 2.26 below shows the impact of drying of concrete on the overall deformation as the concrete ages. The drying range is the measurement taken here to determine the deformation due to drying shrinkage.

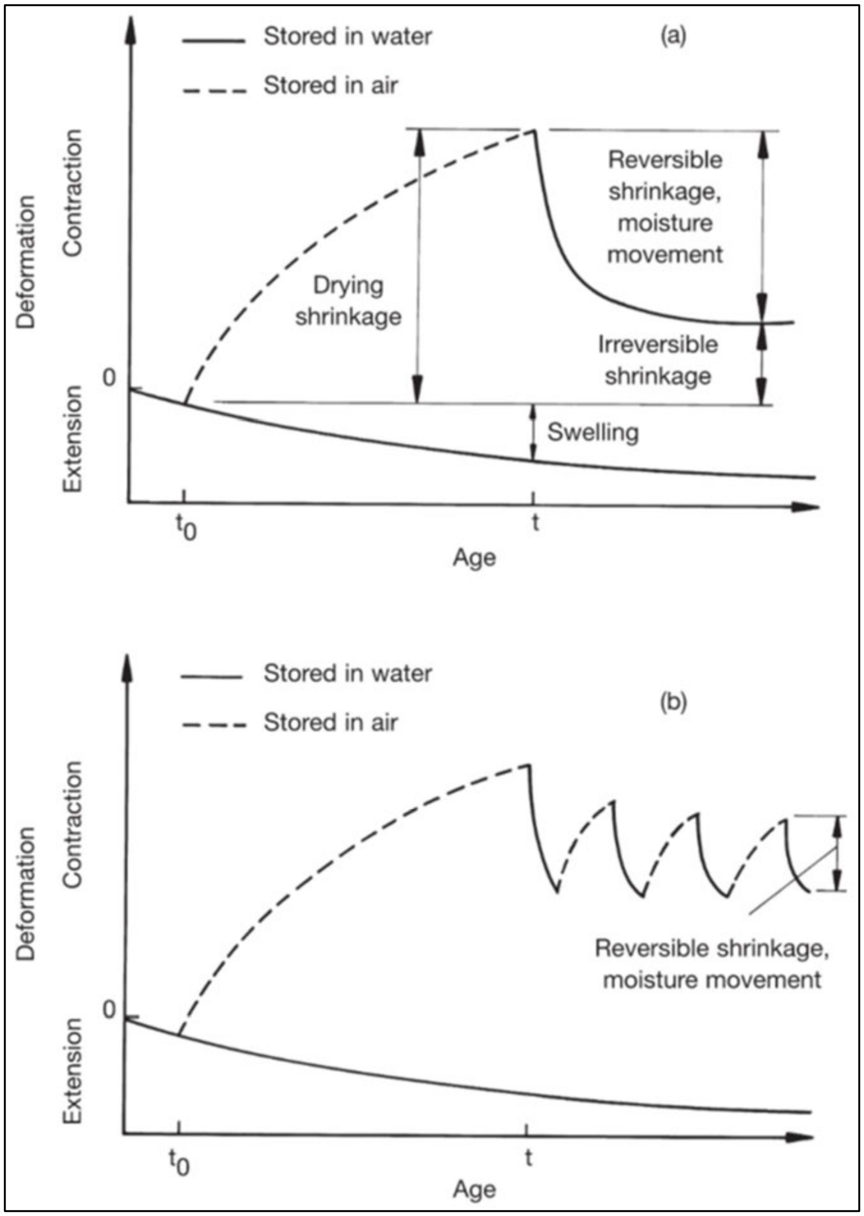


Figure 2.25 Shrinkage in concrete when considering reversible and irreversible drying (C&CI 2009)

Research using the substitution of BA for fine aggregate found that with the control of the Water / Cement ratio, varying substitution amounts of the BA yielded improvement in drying shrinkage, however with using the slump as control and not limiting the water, the drying shrinkage of the same substitution amounts increased the drying shrinkage relative to the control. (Muthusamy et al 2020)

2.5 Coarse aggregate selection

Commercial concrete supply uses crushed coarse aggregate that is typically sourced from the closest available hard rock quarry. The aggregates chosen must comply with the requirements outlined in *AS 2758.1 Aggregates and rock for engineering purposes – Concrete Aggregates*, so that the concrete manufacturer can comply with *AS 1379 -2007 Specification and Supply of Concrete.*
The aggregates chosen for this project will be a metagreywacke that is common to all major concrete suppliers in the greater Brisbane region. The effects of aggregate variability will be controlled by sampling all the aggregate at one time. This maintains the coarse aggregate as a constant as much a is feasible for the research.
The coarse aggregates used in previous research substituting the Harvested Ash as fine aggregates make use of locally sourced crushed aggregates or gravels. (Shrikanth et al 2020) (Haldive and Kambekar 2 2013) (Muthusamy et al 2020) (Abdulmatin et al 2018) (Nasrudin et al 2022)

2.6 Research gap

In completing the literature review it became clear that there was limited local published research in the reuse of HA in concrete. It is also apparent that research into HA reuse in general is limited at Australian level, that is public and available works for review. It is mentioned when speaking in industry that a number of commercial entities have looked at research but no publication of results has been carried out and no trace of this research is available for review.

CHAPTER 3: METHODOLOGY

3.1 Experimental model and Design Mix

The purpose of these trials is to determine that the HA undergoes a quantifiable pozzolanic reaction. To do this we must first establish a way to control other factors that could interfere with the results and develop our constant and controls.

3.1.1 Control Mix and Constants

The control mix has no HA addition, it does have admixture addition and shows us the expected maximum strength contribution due to the GP Content at 0.45 Water / Cement Ratio, which is 0.41 Effective Water/GP ratio.

The GP cement content is fixed at 400 kg per m^3 and the water /GP ratio shall remain higher than the control for all other mixes. This is deliberate so that the decrease in water cement ratio cannot be influencing any increase in strength.

As the Water / Cement ratio increases it is expected that the early age strength, which is contributed to only by the GP, will decrease and this will enable extrapolation of expected strength contribution from only the GP in the mix, this is explained in Figure 3.1 below.

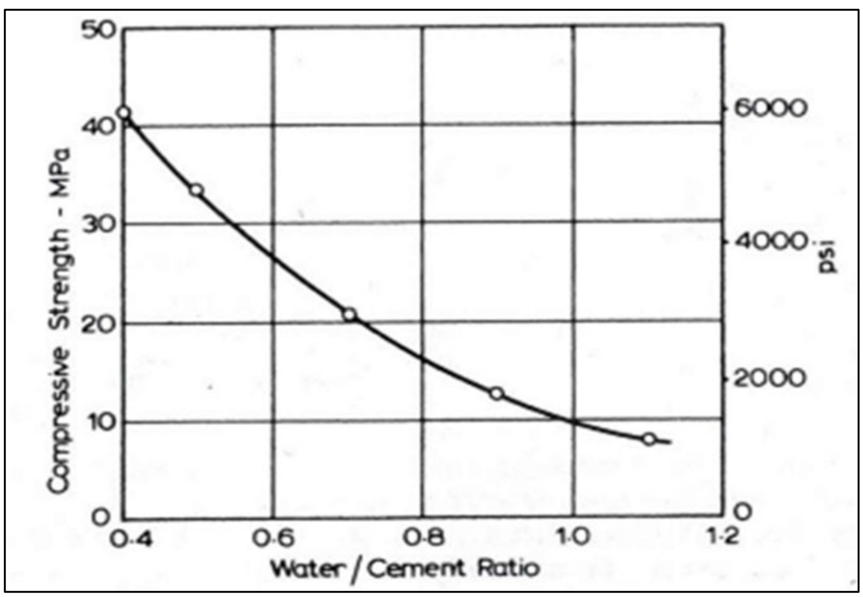


Figure 3.1 W/C ratio impact on strength (Neville,2012 p273)

The extrapolation will be based on the strength development of the control mix and determination of growth factors to understand the strength development in stages from 3 day to 7, 28 and 56 day compressive strength. Figure 3.2 below shows the strength development of GP only control mix to be used when calculating the developed strength of the GP portion of binder in mixes 2 through to 9 of trials.

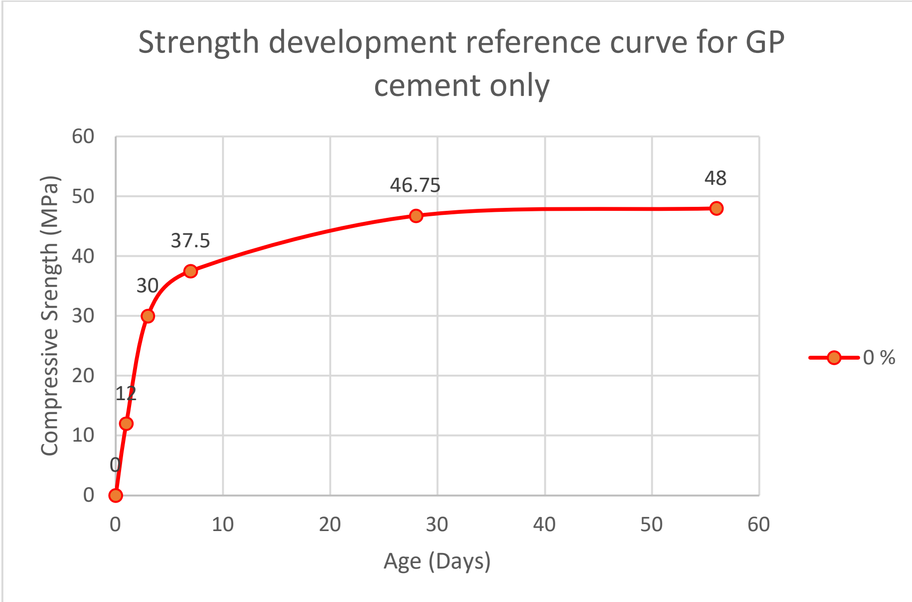


Figure 3.2 GP Cement reference curve for strength extrapolation

3.1.2 Coarse Aggregates

The aggregates chosen for this project will be a metagreywacke that is common to all major concrete suppliers in the greater Brisbane region. The aggregates will be prepared and sampled by construction sciences laboratory and conditioned as per AS1012.2-2014. The design mix will maintain a fixed coarse aggregate content for all mixes, and these will all be obtained and conditioned form one sample, this is intended to remove coarse aggregate influence as a variable.

3.2 Harvested Ash Testing for fine aggregate properties

Based on the literature the common testing carried out on the Ash consists of Particle size distribution, Particle density and water absorption. These tests will be completed on the HA to determine the adjustments required for each mix design step.

3.2.1 Particle Size Distribution/ sieve analysis

The Particle Size Distribution (PSD) is not related to the replacement of the fine aggregate, the fineness of the material will be quite different to the fine aggregate it will be replacing, however it is important to understand the amount passing the 75 µm sieve as this is defined as the Fly Ash portion of the HA, and the increased fines content will impact the water demand of the concrete mix, so this information will be utilised in determining the design mixes.

3.2.1.1 Test Method

The steps for completing the testing are as follows:

- Dry the material to be sieved until all moisture is removed.

- Stack all the sieves with the sieve having the largest aperture on the top to the smallest aperture on the bottom.
- Place known mass of dried material in top sieve.
- Shake manually or use vibrating table to shake material through sieves.
- Do not force the material.
- Remove sieve and weigh mass remaining on each sieve and the mass in the bottom pan, ie passing 75 µm.
- Report weights retained on each sieve.
- Repeat procedure to confirm.

3.2.2 Particle density and water absorption of fine aggregate

It is critical to know the particle density of the HA to be able to yield the mix correctly and be sure the designed quantity is being weighed. As well as the importance of the density is the water absorption of the material. This will impact the water demand of any concrete that is to be made using the material and whether the HA will retain the water or release it as bleed during plastic state. As well as this there are specified limits for water absorption for aggregate use, while there is no limits for Ash, or pozzolanic material, it will show risk if the water absorption is too high, above 2.5 % as an example.

3.2.2.1 Test Method

The test method is as follows:

- Weigh a portion of the fine aggregate, at least 500 g.
- Sieve through a 4.75 mm sieve if needs be.
- Soak the test sample in water for at least 24 h, be sure to tap the sample to get all bubbles out.
- Drain the water and lay the material out to dry
- Dry to saturated surface dry condition SSD, this is tested with a small cone, tamp into the cone and ensure the cone of material slumps, if it holds its shape it is too wet, if it completely collapses it is too dry.
- Once at SSD, weigh the sample.
- Place sample into volumetric flask and fill to 500 ml
- Weigh the flask and contents. m_3
- Remove fine aggregate from flask and place in a dish.
- Dry the aggregate out completely and weigh the sample m_1
- Fill the flask with water and weigh m_4
- Perform below calculations.

$$\varrho_a = \frac{m_1 \times \varrho_w}{m_4 + m_1 - m_3} \quad \ldots 1$$

where

ϱ_a = the apparent particle density of the test portion, in tonnes per cubic metre

m_1 = the dry mass of the test portion, in grams

ϱ_w = the density of water at the test temperature, in grams per cubic centimetre (see Table 1)

m_4 = the mass of the flask filled with water, in grams

m_3 = the mass of the flask filled with water and the test portion, in grams

3.3 Fresh Concrete Testing:

Fresh concrete testing is the type of testing that is carried out on the concrete to evaluate comparative properties while it is still plastic. While concrete is used for its hardened properties, the quality of the concrete while in its plastic state is critical to determine whether it is feasible for use in construction. The two initial parameters that have been chosen are slump and the bleed.

3.3.1 Slump

The slump test originated before electronic batch systems now employed by ready mix suppliers. It was designed to measure the consistency of loads produced s the mix design being the same, it was assumed that a similar water content would be required to maintain the same slump from load to load of the same design mix. It is still used as a measure of consistency and typically quoted as a measure of workability. It is a relatively simple result that has a common level of understanding throughout the concrete and construction industry.

3.3.1.1 Test Method

To Carry out a slump test there will need to be a slump cone, slump tray / board and a tamping rod. Slump cone dimensions are provided in Figure 3.3 below.

The steps for casting a slump test are as follows:

- Place the slump cone on the board with the large diameter end down.
- Fill the cone in three layers of equal depth, rodding each layer 25 times without touching the board below.
- Once the top layer has been rodded, flatten the top of the concrete to the top of the cone.
- Lift the cone off the concrete in 3 +/- 1 seconds, being sure to move smoothly and not in a jerky fashion.
- Invert the cone and stand next to the concrete, place the rod across the top of the inverted cone to establish a level surface at the height of the cone.
- Measure with a rule from the bottom of the rod to the top of the concrete, measure in three heights and take the average.

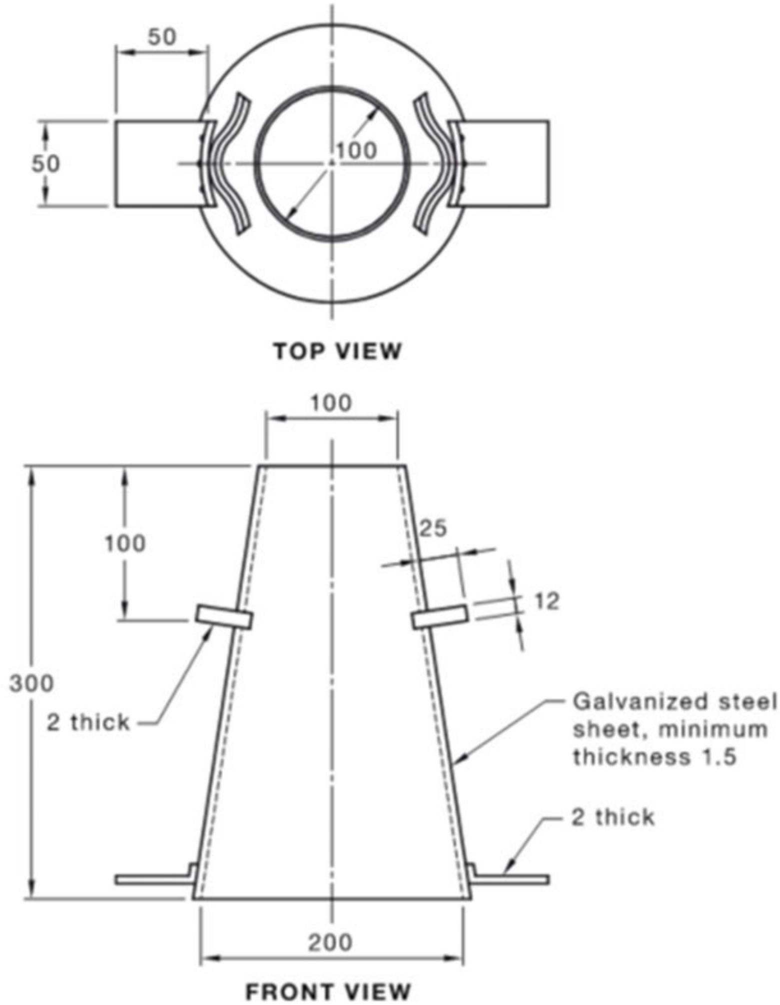


Figure 3.3 Slump cone dimensions as detailed in AS 1012.3.1 - 2014 p4.

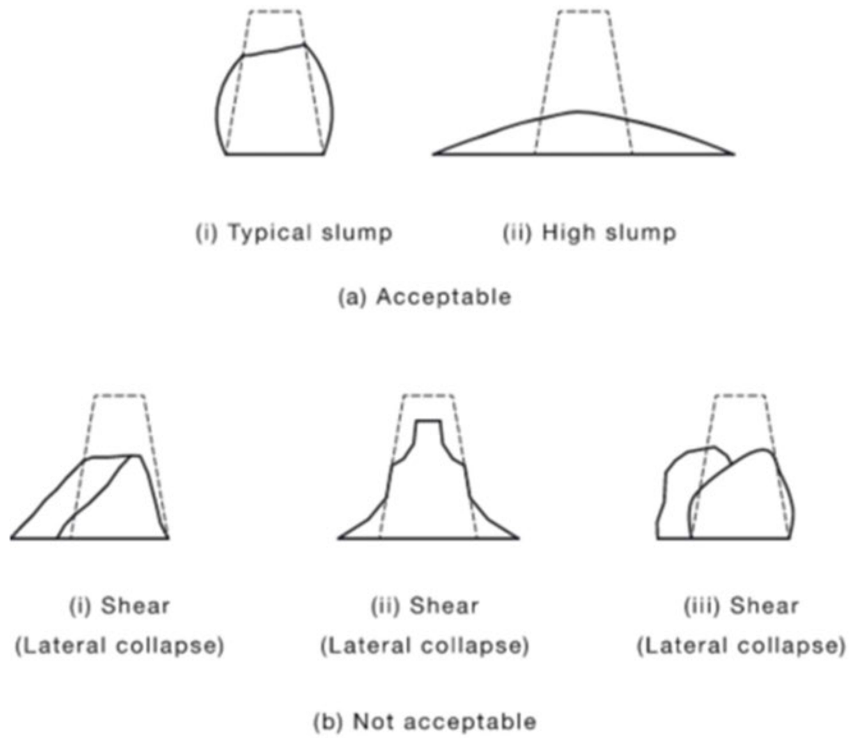


Figure 3.4 Types of slump failure, AS1012.3.1 - 2014 p6

3.3.2 Observed bleed

This test is a visual test only and is to establish if the concrete bleeds out an excessive amount of the free water after sitting for the first 60 minutes following completion of sampling all of the tests. If concrete bleeds excessively it can lead to surface issues and difficulty in the finishing of the placed concrete.

As some of the mixes will contain a large amount of water it needs to be determined if the concrete will contain and consume that water or will release and allow the water to bleed out of the surface.

3.4 Hardened Concrete Testing:

The stages involved in the testing of the concrete include the following:

- Mixing trial mix as per AS1012.2-2014
- Test the plastic properties of each mix as follows:
  - Slump AS1012.3.1 - 2014
  - Visible bleed
- Sample for the following hardened properties:
  - Compressive strength; AS1012.8.1-2014
  - Indirect tensile strength; AS1012.8.1-2014
  - Flexural strength; AS1012.8.2-2014
  - Drying shrinkage AS1012.13-2015

- The following day, demould specimens, labelled and place in curing tanks.

3.4.1 Compressive strength

The most common test carried out for compliance of concrete. Cylinders are cast from the fresh concrete in calibrated moulds which are checked for their diameter, height and square. They are to be 200 mm high and 100 mm diameter. Once they are hardened, after a minimum of 18 hours and no more than 24 hours, they are placed in lime saturated curing tanks that are kept at controlled temperature ranges depending on the region of Australia they are in. They are then taken from the tank when required to be crushed. The ends of cylinders are either ground or capped using rubber or sulphur so they are square to the platens and loaded at a controlled load rate until they fail under compression. This result is then transferred from kN of load to MPa based on standard calculations provided in AS 1012.9:2014.

3.4.1.1 Casting Specimens AS1012.8.1-2014

The steps for casting cylinders are as follows:

- Prepare cylinder moulds by cleaning, ensuring they are adequately labelled or tagged and oiled.
- When filling 100mm diameter moulds fill in two equal layers.
- If compacting by rod it is 25 strokes per layer, if compacting with vibrating table, then vibrate until no air is released from concrete.
- After compacting the top layer, trowel off the top surface flat with the top of the mould.
- Ensure caps are placed on cylinders and cylinders are placed in safe level position for overnight storage.

Figure 4.27, Figure 4.28 and Figure 4.29 are examples of this occurring in stages.

3.4.1.2 Testing Specimens AS1012.9 – 2014

The steps for testing the specimens at the correct age are as follows:

- Cylinders are capped or ground.
- Placed in the jig of the compression machine, his is to hold the cylinder in location while loading occurs. The cylinder should be in a standing position.
- Load the cylinder in compression at the load rate specified in AS 1012.9.
- Continue to load until the cylinder fails.
- Record the KN of load required, this will be converted to N/mm^2, or Pa and MPa.

3.4.2 Indirect tensile testing

Indirect tensile testing is carried out to determine the horizontal tensile capacity of the concrete when the concrete is vertically loaded in crushing. This loading causes the cylinder to split, hence the common name of ‘splitting test’. For this the standard compressive test cylinder is laid on its side in a specific testing jig to be loaded with the compression machine. See Figure 3.5 below for jig set up.

3.4.2.1 Casting Specimens AS1012.8.1-2014

The steps for casting cylinders are as follows:

- Prepare cylinder moulds by cleaning, ensuring they are adequately labelled or tagged and oiled.
- When filling 100mm diameter moulds fill in two equal layers.
- If compacting by rod it is 25 strokes per layer, if compacting with vibrating table, then vibrate until no air is released from concrete.
- After compacting the top layer, trowel off the top surface flat with the top of the mould.
- Ensure caps are placed on cylinders and cylinders are placed in safe level position for overnight storage.

3.4.2.2 Testing Specimens

- Cylinder is placed in the jig of the compression machine, see Figure 3.5 below, this is to hold the cylinder in location while loading occurs. The cylinder should be in a laying on its side position.
- Load the cylinder in compression at the load rate specified.
- Continue to load until the cylinder fails by splitting.
- Record the KN of load required, this will be converted to N/mm^2, or Pa and MPa.

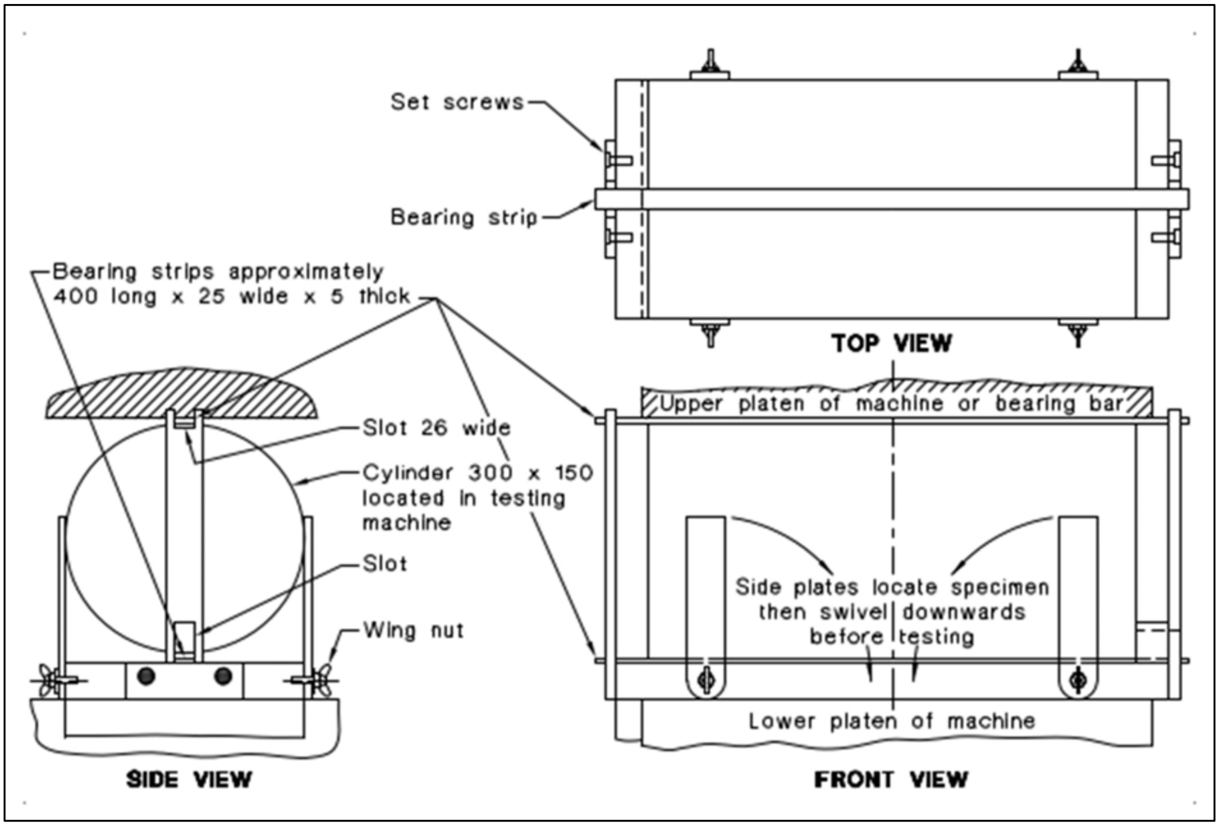


Figure 3.5 Indirect tensile or splitting strength testing jig set up.

3.4.3 Flexural strength testing

Flexural strength testing is used to determine the strength capacity of concrete in the tensile chord generated when the concrete is loaded in bending.

3.4.3.1 Casting Specimens

The steps for casting beams are as follows:

- Prepare beam moulds by cleaning, ensuring they are adequately labelled or tagged and oiled.
- When filling moulds fill in two equal layers.
- If compacting by rod it is 25 strokes per layer, if compacting with vibrating table, then vibrate until no air is released from concrete.
- After compacting the top layer, trowel off the top surface flat with the top of the mould.
- Ensure lids are placed on cylinders and cylinders are placed in safe level position for overnight storage.

3.4.3.2 Testing Specimens

The testing of the concrete beams for flexural strength is carried out by placing the beams in a jig that has four rollers, two top, and two bottom. These rollers are not in alignment, the top two are centrally placed and the bottom two are aligned to be outside of the top. The concrete beam is then loaded by applying force to the top rollers in controlled loading rates until the beam fails in tension due to bending.

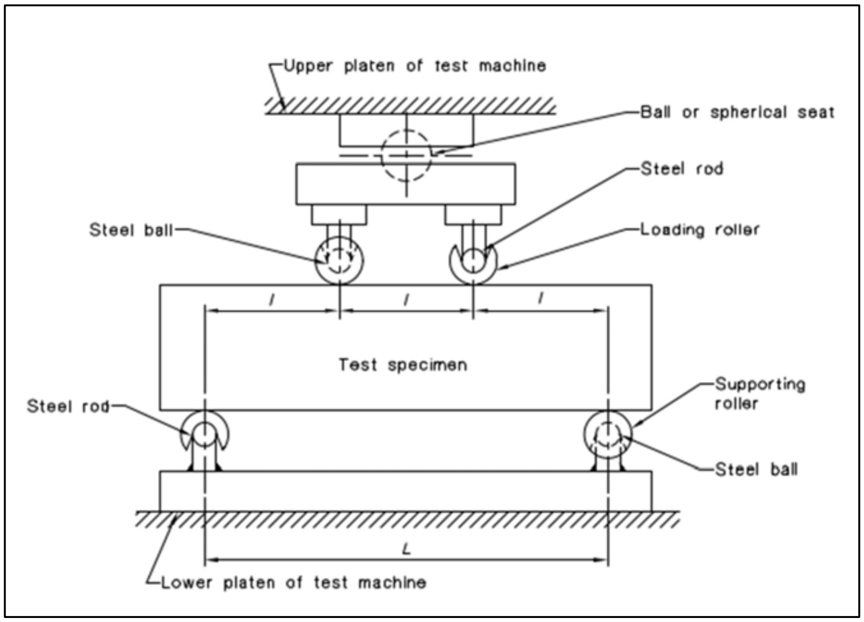


Figure 3.6 Testing set up for flexural testing of specimens, image taken from AS1012.11:2000.

3.4.4 Drying Shrinkage

For the measurement of drying shrinkage 3 prisms of equal proportion are cast. The moulds for shrinkage casting have three chambers, in the ends of them they have metal pins that will form the end points that are measured for their change in dimension. These measurements are then taken by a length comparator at given test ages.

3.4.4.1 Casting Specimens

The steps for casting cylinders are as follows:

- Prepare moulds by cleaning, ensuring they are adequately labelled or tagged and oiled.
- Ensure the pin assembly is correctly put together on ends of moulds.
- When filling moulds fill in two equal layers.
- If compacting by rod it is 25 strokes per layer, if compacting with vibrating table, then vibrate until no air is released from concrete.
- After compacting the top layer, trowel off the top surface flat with the top of the mould.
- Ensure moulds are placed in safe level position for overnight storage.

3.4.4.2 Testing Specimens

- Specimens are left overnight then demoulded and labelled.
- Specimens are then placed in shrinkage room.
- Initial measurement of the prisms are then taken with vernier callipers at 7 days.

- Further measurements are taken of the three prisms at 7, 14, 28 and 56 days from initial reading, so 63 days from casting.
- Each reading is an average of the three prisms.

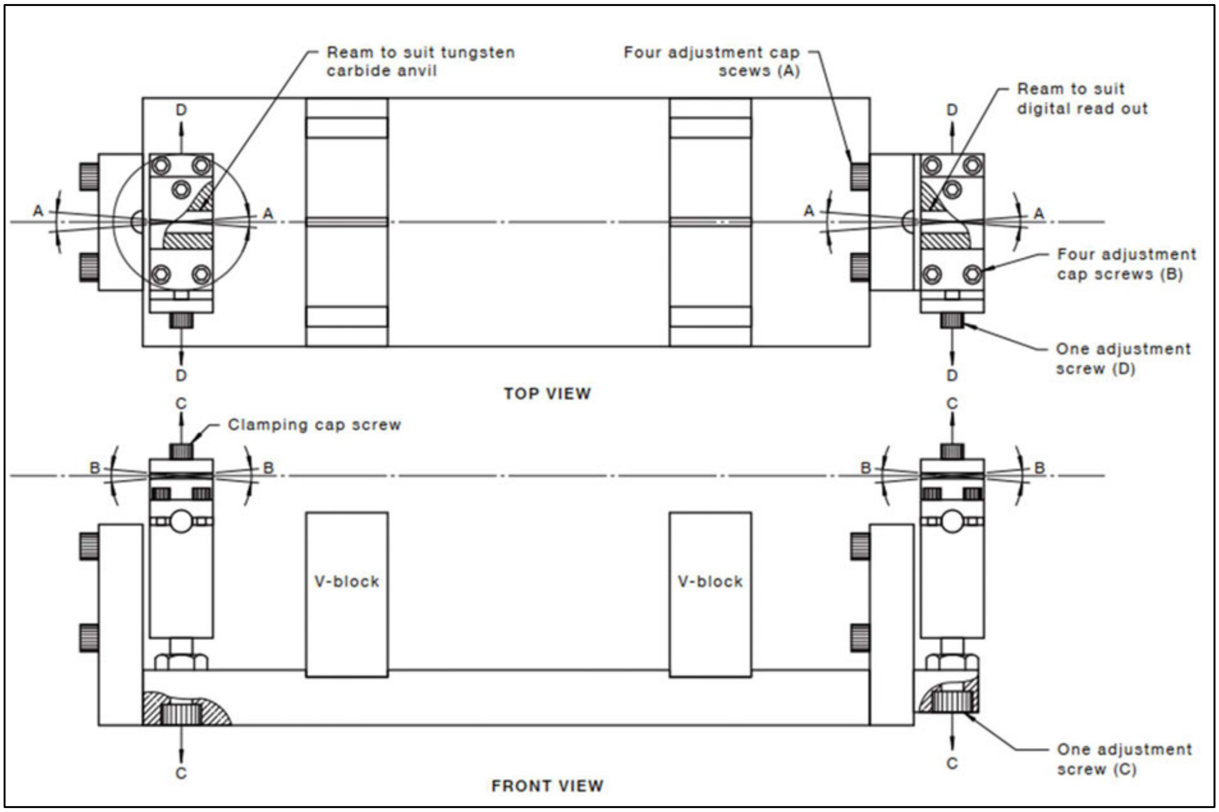


Figure 3.7 Shrinkage comparator set up taken from AS1012.13:2015.

CHAPTER 4: EXPERIMENTAL INVESTIGATION

In this chapter we discuss the materials collected and used, the mixing and testing methods used and the experimental procedure that was carried out compared with the programmed experiment.

4.1 Materials

The materials used for the concrete trials were sourced from company representatives in support of the research and the potential positive outcome it may provide for the concrete industry in the future. I am fortunate to have relationships and experience in the materials supply sector. These materials were supplied with approval of organisations that employ the representatives in support of the research.

4.1.1 Cement

The cement used was supplied by Sunstate Cement. The chosen Cement is General Purpose Cement which is milled with up to 7.5% lime addition as per AS 3972 *General purpose and blended cements*.

Figure 4.1 Cement used, Sunstate General Purpose Cement

4.1.2 Coarse aggregate

Commercial concrete supply uses crushed coarse aggregate that is typically sourced from the closest available hard rock quarry. The aggregates chosen must comply with the requirements outlined in *AS 2758.1 Aggregates and rock for engineering purposes – Concrete Aggregates*, so that the concrete manufacturer can comply with *AS 1379 -2007 Specification and Supply of Concrete.* The Coarse aggregates chosen for this project will be a metagreywacke that is common to all major concrete suppliers in the Brisbane district. The effects of aggregate variability will be controlled by sampling all the aggregate at one time. Then the aggregates will be prepared by construction sciences laboratory and conditioned as per AS1012.2-2014 *Preparing concrete mixes in the laboratory*

Figure 4.2 Coarse aggregate used, 20mm maximum.

Figure 4.3 Coarse aggregate used, 10mm maximum.

4.1.3 Fine aggregates

The fine aggregates used are again a combination of typical fine aggregates in commercial use locally. The fine aggregates are made up of fine sand and coarse sand. In this case the fine sand is a natural sand extracted from Moreton Bay by dredge. The coarse sand is a manufactured sand produced at the same hard rock quarry that produces the 20mm and 10mm coarse aggregate. The manufactured sand is a processed by product of the crushing process and is used by almost all concrete suppliers in Southeast Queensland region.

Figure 4.4 Coarse Sand used, Manufactured sand of the same source as the coarse aggregate.

Figure 4.5 Fine sand used; natural sand sourced from Moreton Bay.

4.1.4 Admixture and water

The admixture chosen was Sikaplast 3 in 1 mid-range water reducer. Water reducing admixtures work through dispersing the fine particles and achieving higher efficiency in hydration reaction by increasing the available surface area of the cement particles to water. (Neville 2011, p254-255) This admixture was chosen as it is a scalable from water reducer, 5 to 10% water reduction properties, to high range water reducer providing over 25% water reduction properties. As slump was a key control measure, with the unknown effect of the varied addition of the Harvested Ash on the slump, it was critical to have the ability to control excessive water addition and achieve the desired plastic properties.

The water used was potable tap water to remove level of impurities. In concrete production recycled plant water is commonly used which has specified limits for dissolved solids and other impurities set out in AS 1379.

As is typical for trial methodology the admixture is measured and added to the total batch water to disperse in the water and then the water is added to the batch as detailed in AS1012.2-2014.

Figure 4.6 Water and admixture being added to mixer.

4.1.5 Harvested ash

The Harvested Ash used was sampled directly from the Ash Dam at Tarong Power Station. This was assisted by the Stanwell Coal Combustion Products division in support of the research. Images of Harvested Ash provided below.

Figure 4.7 Harvested Ash

Figure 4.8 Harvested Ash

Figure 4.9 Harvested Ash in the mixer.

4.2 MIX DESIGN

This section details the development of the mix designs for the trial's particle size distribution (PSD or grading) of design mix and impact on water.

As the HA is being substituted for the fine aggregate fraction it is important to understand the implications on the combined grading of each mix and what that looks like as the substitution varies. As the ash is very fine it is expected that as the substitution increases and the amount of fine material increases each mix will require more water to achieve the design slump.(Neville, 2012) As slump is the key control measure throughout the mixing of each batch it is important to pre-determine how the changes in mix design are expected to impact the slump, so as to account for mix design adjustments at each stage of substitution.

4.2.1 STEPS FOLLOWED TO DEVELOP MIX

The steps followed to develop the mix are based on prior experience in determining a suitable 40 MPa concrete mix. Having worked with this material set designing mixes for a period of over 15 years, the base knowledge of the mix skeleton was already established. However, the steps taken to develop this mix follow the below outline:

- Determine strength required, from this Cementitious content and W/C ratio,
- Determine Coarse aggregate content,
- Establish the best ratio of fine to coarse sand to be used,

- Sum the volume of Cementitious, water and Coarse aggregate, taking that volume from 1000 L, the resulting volume becomes the volume of fine aggregate and air.
- Then to determine the additional variations, the fine to coarse sand ratio was kept constant and each iteration of substitution was made by percentage of volume.

4.2.2 MATERIAL PARTICLE SIZE DISTRIBUTIONS

Each aggregate material is assessed and tested for PSD as a measure of compliance with a specified limit of variance. This is to comply with Australian Standard 2758.1 and to ensure consistency in concrete produced by suppliers as the combined grading of all the materials has an impact on the plastic and hardened performance. AS 2758.1 has general limitations for the grading of each material but is more focused on the deviation from initial grading produced, hence is more focused on control of consistent material rather than specifying tight boundaries to produce aggregate. (Standards Australia 2014, p8).

Testing of the PSD was carried out for all the aggregates used in the mix to allow the combined grading of each proposed substitution to be determined.

The PSD of each material is detailed in Figures 4.10 to 4.14 below. Figure 4.15 provides a comparison of the three fine aggregates to be used in the mix designs, showing the difference in fine material percentage content of each of the three.

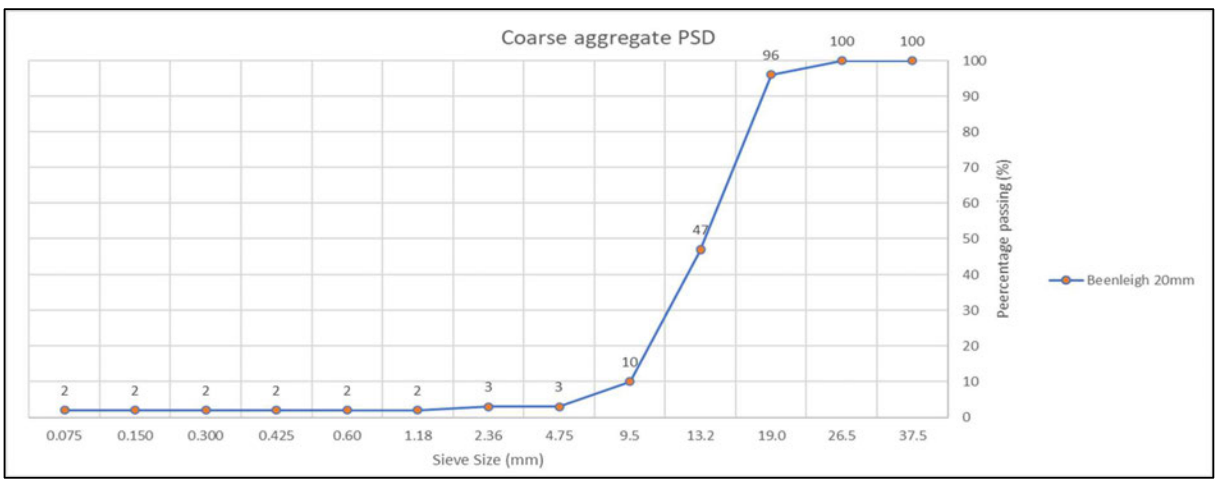


Figure 4.10 20mm Coarse aggregate PSD.

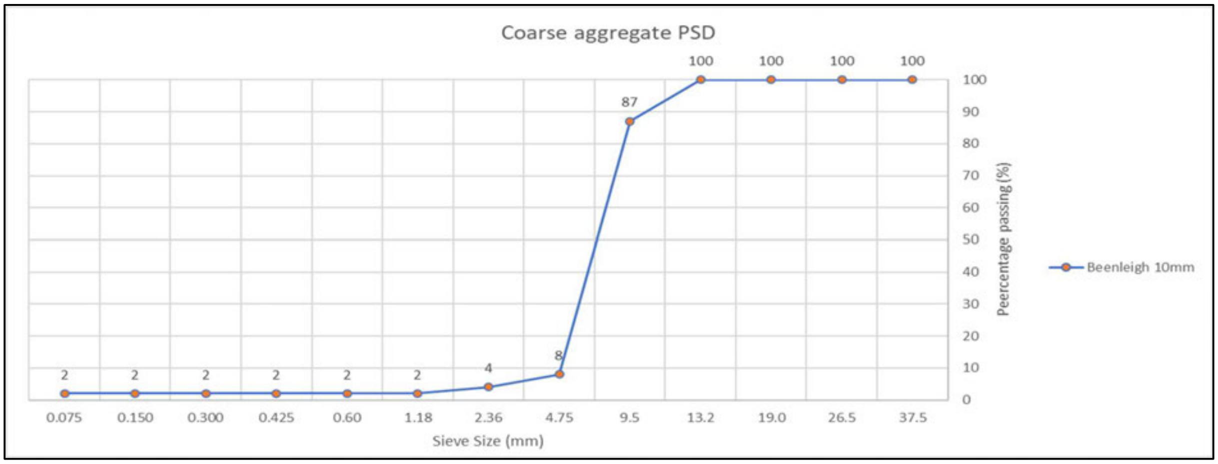


Figure 4.11 10mm Coarse aggregate PSD.

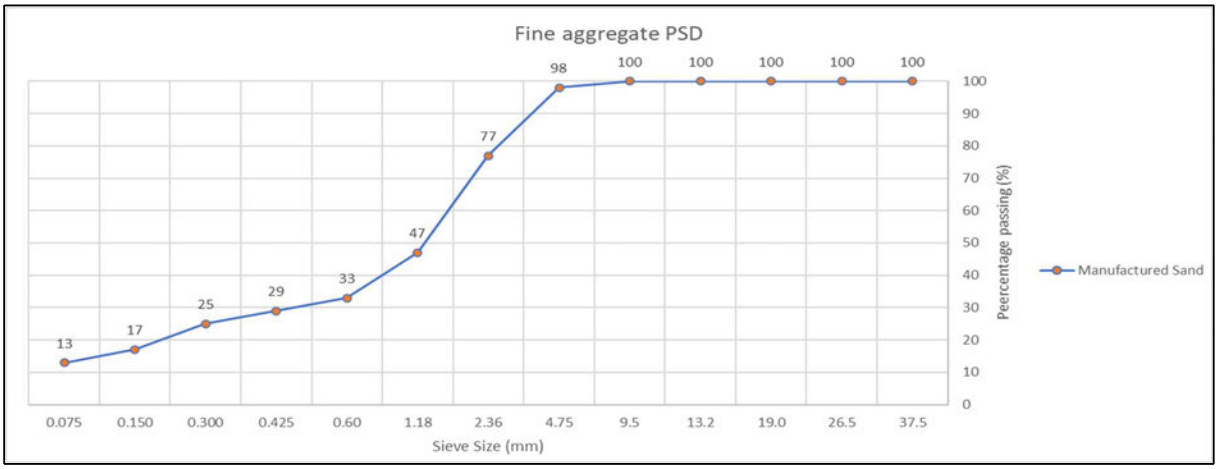


Figure 4.12 Manufactured sand PSD.

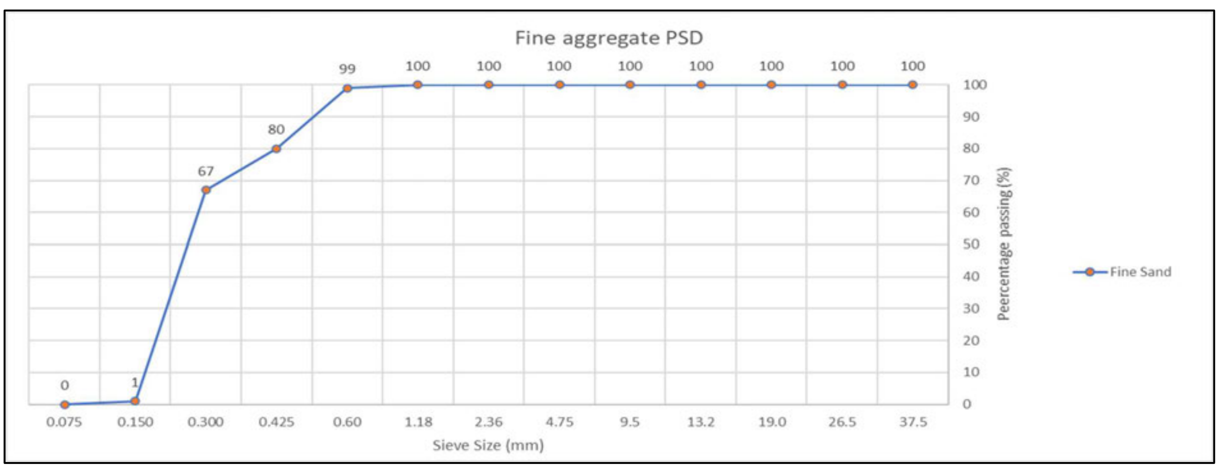


Figure 4.13 Fine sand PSD.

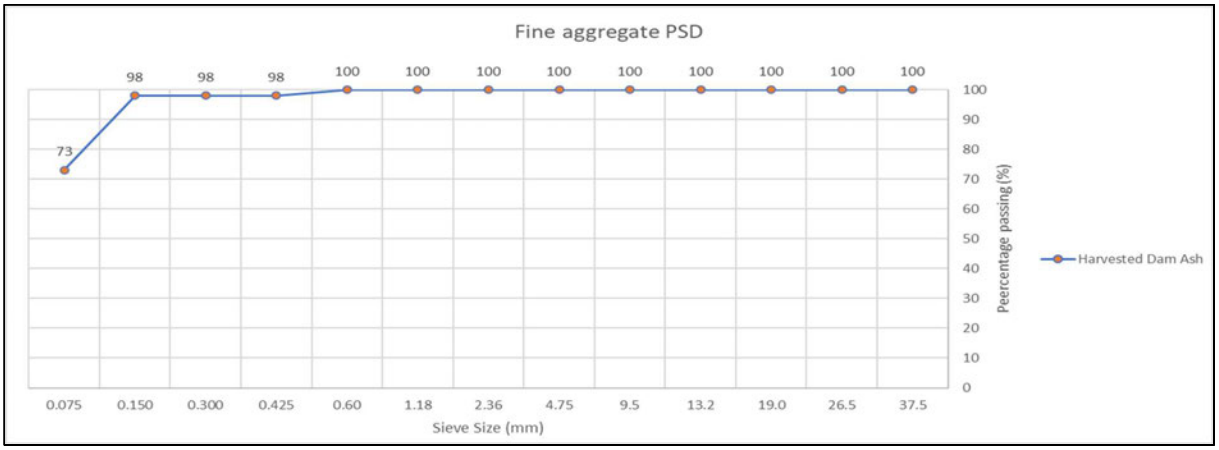


Figure 4.14 Harvested HA PSD.

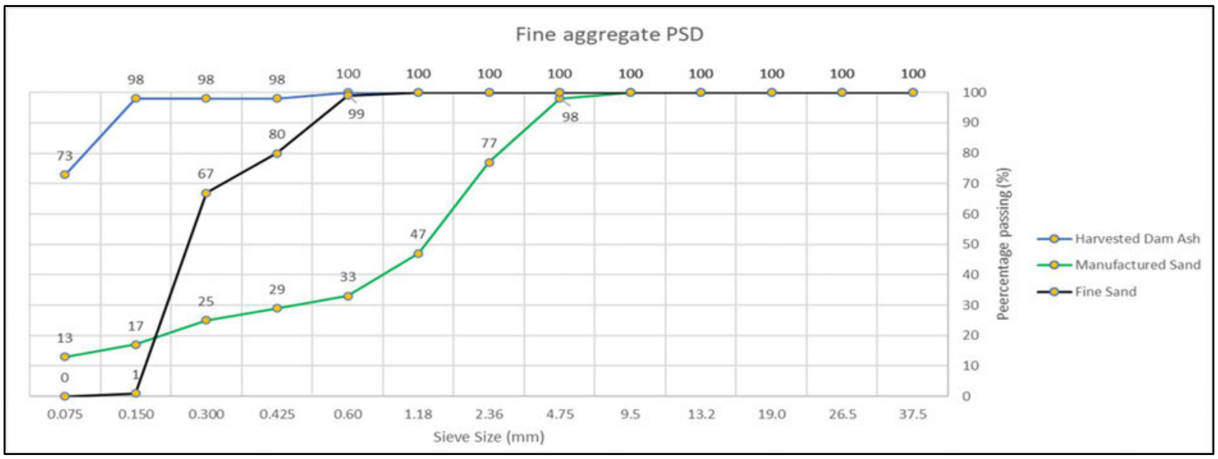


Figure 4.15 Comparison between the fine aggregates PSD.

4.2.3 COMBINED GRADING

The combined grading is assessed by determining the total volume of aggregate in the proposed mix, applying the PSD values tested to each aggregate as a portion of that total volume and then summing for each sieve size to determine the percentage passing for each sieve based on their combination.

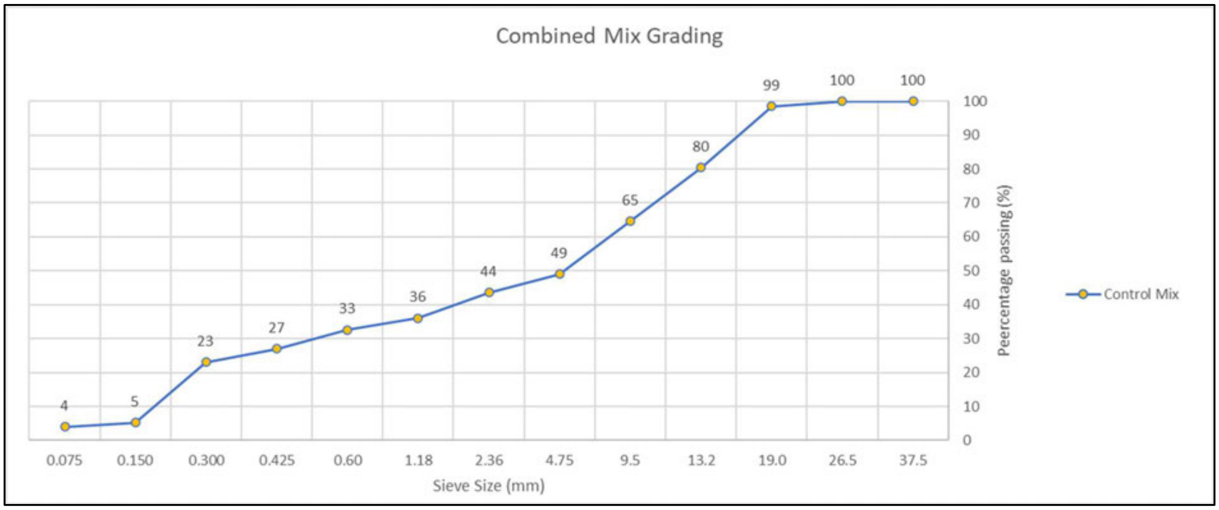


Figure 4.16 Combined grading of the control mix.

In some cases, the combined grading is used to determine the suitability of a mix for use (Heineman & Laska, 2019), however, in this case we are not determining the suitability, rather the expected impact on plastic properties as the percentage of fine material increases.

4.2.3.1 COMPARISON OF EACH SUBSTITUTION PERCENTAGE WITH REGARD TO COMBINED GRADING

When reviewing the combined grading for this experiment, the most critical point to note is the change in the amount of fine material and the 'shift' towards an excess of material passing the smaller sieve sizes, particularly the 600 µm and below as these are the indicators for increased water demand in the concrete mix.

Figure 4.17 below shows the combined gradings of the control vs the four different volumetric substitution levels used in the experiment. On review the percentage passing each sieve below the 600 µm has a higher percentage passing than the previous substation level. This is due to the fineness of the HA.

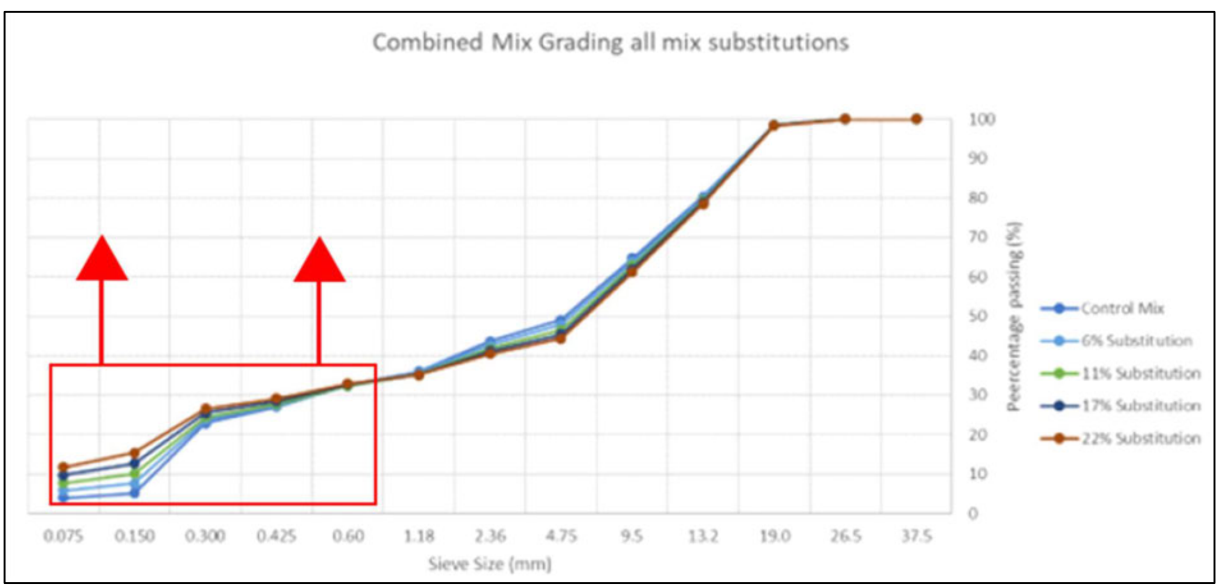


Figure 4.17 Comparison of all mix substitutions showing increase in fineness of combined grading.

4.2.4 WATER DEMAND AS FINE PERCENTAGE INCREASES

There is a relationship between fine aggregate content and water demand (Neville, 2012) as the portion of fine material increases, specifically the material finer than 0.15 mm the need for increasing the design water occurs due to the increase in particle surface area. This increase dictates the need for more paste volume to lubricate the concrete in its plastic state, to maintain the expected workability (Neville, 2012).

Table 4.1 PSD of all mixes using volumetric substitution of fine aggregates showing percentage passing.

	Particle Size Distribution of mixes established using volumetric substitution of fine aggregates (% passing)												
Mix Description	37.5	26.5	19.0	13.2	9.5	4.75	2.36	1.18	0.600	0.425	0.300	0.150	0.075
Control Mix	100	100	99	80	65	49	44	36	33	27	23	5	4
6% Substitution	100	100	98	80	64	48	43	36	32	27	24	8	6
11% Substitution	100	100	98	79	63	46	42	35	32	28	24	10	8
17% Substitution	100	100	98	79	62	45	41	35	33	29	26	13	10
22% Substitution	100	100	98	78	61	44	40	35	33	29	27	15	12

Table 4.2 PSD of all mixes using volumetric substitution of fine aggregates showing weights passing.

	Particle Size Distribution of mixes established using volumetric substitution of fine aggregates (assumed weights for each sieve passing kg)												
Mix Description	37.5	26.5	19.0	13.2	9.5	4.75	2.36	1.18	0.600	0.425	0.300	0.150	0.075
Control Mix	28	343	298	201	94	104	145	66	102	75	330	22	77
6% Substitution	28	343	298	200	94	95	132	59	91	67	291	29	100
11% Substitution	28	343	298	199	94	85	118	52	80	58	252	36	123
17% Substitution	28	343	298	198	94	76	105	46	71	51	221	44	145
22% Substitution	28	343	298	197	94	67	92	39	62	43	189	51	167

4.3 FINAL MIX DESIGNS.

The mix design details for the trial mixes are detailed below in Table 4.3 below.

Table 4.3 Mix design summary, design details are yielded to 1 cubic metre and cell values refer to Saturated Surface Dry (SSD) condition in kg/m3.

Material	Mix 1 Control	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
GP	400 kg	400 kg	400 kg	400 kg	400 kg	400 kg	400 kg	400 kg	400 kg
20mm Agg	700 kg	700 kg	700 kg	700 kg	700 kg	700 kg	700 kg	700 kg	700 kg
10mm Agg	300 kg	300 kg	300 kg	300 kg	300 kg	300 kg	300 kg	300 kg	300 kg
Man Sand	442 kg	398 kg	352 kg	308 kg	264 kg	398 kg	352 kg	308 kg	264 kg
Fine Sand	447 kg	394 kg	340 kg	298 kg	255 kg	394 kg	340 kg	298 kg	255 kg
HA	0	39 kg	78 kg	117 kg	155 kg	39 kg	78 kg	117 kg	155 kg
Admix	-	-	-	-	-	1.2 L	1.2 L	1.2 L	1.2 L
Water	180 L	210 L	240 L	260 L	280 L	210 L	240 L	260 L	280 L

4.4 Material preparation and conditioning

All materials were prepared, conditioned, tested for moisture content and weighed in batch lots by Construction Sciences in line with their procedures and AS1012.2 – 2014 *Methods of testing concrete – Preparing concrete mixes in the laboratory* requirements.

4.5 Testing of Concrete

The experiment will involve two types of testing of the concrete, fresh concrete or plastic testing and hardened concrete testing. These tests are typically used in evaluating the performance and compliance of concrete in both the laboratory and field and provide us with the ability to evaluate the influence of HA on the concrete's performance in entirety.

4.5.1 Fresh concrete testing

The two fresh concrete tests completed were the slump, which is critical as it is the control measure of consistency of the concrete.

4.5.1.1 Slump

The visual determination of the slump is the difficult part of this experiment, and it is quite easy to go over the desired slump if water addition or admixture addition is not allowed to effectively mix through and 'wet out' concrete completely before further addition. The characteristics of mixes with different cementitious make-up can be quite different to 'read' also. For example, mixes using only GP cement are not typically used in practise in Southeast Queensland, the paste of this type of mix is more cohesive than a mix using fly ash in addition as the fly ash particle is spherical and provides a ball-bearing effect, having a smoother paste. These small differences and tendencies for different behaviour in each mix composition provide challenges in achieving the same slump each time.

It is for this reason AS 1379-2007 specifies the slump with a tolerance range, in the case of this experiment the target slump is 120 mm +/- 30 mm.

TABLE 5.1

PERMISSIBLE TOLERANCE ON SLUMP

Specified slump, mm	Tolerance, mm
<60	±10
≥60 ≤80	±15
>80 ≤110	±20
>110 ≤150	±30
>150	±40

Figure 4.18 Table 5.1 (extracted form AS 1379 -2007 p29) permissible slump tolerances.

At the beginning of the trial set the decision was made to have the control mix at or below a slump of 120 mm but within the range specified, this allows the least water to be added to achieve the desired slump, in the effort to have conservative estimates of the harvested ash performance relevant to the control mix of GP only.

Figure 4.19 Example of slump being measured.

Figure 4.20 Mixer showing viewing opening with dry constituents mixed.

Figure 4.21 View of the concrete mixing to try and determine the slump.

4.5.1.2 Concrete Bleed

Due to resourcing of the lab and limited time available for the trial room, the bleed test for each mix was not able to be completed as per AS 1012.6-2014. The bleed of the concrete was determined to be non-critical to the scope of the project and therefor the visual comparison of bleed was adopted rather than delaying the trails to a period when the bleed could be tested in full.

In the absence of the full bleed test being carried out the concrete was placed into containers and observed for 2 hours after casting to determine the rank of highest to lowest visible bleed and the mixes were then ranked for the most to the least visible bleed. Figures 4.22 to 4.24 show the difference in visible bleed of the concrete observed.

Figure 4.22 Concrete with minimal to no visible bleed

Figure 4.23 Concrete with some visible bleed, sheen across the top surface

Figure 4.24 Concrete with higher amount of bleed, pooling in corners and indentations.

4.5.2 Hardened Concrete Testing

For the hardened concrete testing, the author directed control of batching the mixes but due to workplace safety rules was not able to be involved in any further part of the process and the reports were provided to the author on completion of the testing at the specified ages.

Figure 4.25 Specimens cast from trial day 1.

Each of the filled moulds of the various types pictured in Figure 4.25 above has an individual mould number. On the trial sheet there are the required number of samples and when preparing for the testing the mould numbers are allocated to the trial number so that when each specimen is removed from the mould the following day, the concrete is then labelled with the mould number and the date to be tested for whichever test is required.

Figure 4.26 Specimens from day 1 after being stripped and placed in curing until crushing / loading to be carried out at correct age in days.

As can be seen in Figure 4.26 above, all the specimens are labelled with their corresponding number and date to be tested.

4.5.2.1 Compressive strength testing

For each of the nine batches, seven cylinders were cast for compressive strength. These were to be crushed at 1 day, 3 days, 7 days, 28 days, and 56 days. The 28 days and 56 days were 2 cylinders for each age to provide an average result.

4.5.2.2 Casting cylinders

As the cylinders were cast, they are required to be filled in two layers with each layer being vibrated. In the trial laboratory there is a large vibrating table that can fit and secure 9 cylinders at a time. The cylinders are placed on the vibrating plate and a securing jig is placed over them to hold them down to the plate while vibrating. The vibrating table is then switched on for the required amount of time until the visible air that is scaping the concrete is seen to stop. This does not expel entrained air as it is micro-air and not visible to the naked eye but expels entrapped air and ensures adequate compaction which will then reflect the highest potential compressive strength of the concrete.

Figure 4.27 Cylinders in hold down jig filled in first layer before vibration.

Figure 4.28 Cylinders full and completely vibrated.

Figure 4.29 Cylinders trowelled off.

The cylinders were filled in two layers, each layer was vibrated to achieve adequate compaction, and in the case of the second layer to achieve a homogenous mass in the mould. Once the second layer was vibrated, they were then struck off and trowelled for an even flat top surface.

4.5.2.3 Testing for compressive strength

To prepare the cylinder for testing, the bottom end has been cast by a calibrated mould so it will be square, the top however has been trowelled off, so it will not be flat and true square for the platens on the compression machine. For this reason, each cylinder is ground flat on the trowelled end to be suitable for complaint testing on the compression machine. Figure 4.30 shows the cylinder grinding machine loaded and operating. As Construction Sciences lab is a commercial facility, there are hundreds of cylinders to process per day, so they employ a large grinding machine that can grind 3 cylinders simultaneously.

Figure 4.30 Cylinders having their trowelled end ground to be flat.

After the cylinders are ground to the correct square they are then weighed and measured. There are multiple ways to complete this, but typically commercial labs will use the apparatus pictured in Figure 4.31 below. This weighs the cylinder and measures height and diameter using laser measurement devices at the same time, then records the data in the corresponding record identified by the number on the bottom of the cylinder which is entered by the lab technician. This data is used to determine the dry density which is calculated automatically in the system used to report the test data.

Figure 4.31 Cylinder being weighed and dimensioned.

The cylinders are then placed into the crushing machine that has pre-programmed load rates entered and will be crushed until the machine detects failure. The specimen ID number is entered into the control computer once the cylinder is placed on the platens.

After failure is detected the lab technician will assess the specimen to determine if there has been complete failure and if not restart the machine, or if complete, note the failure mode as being normal or abnormal.

Once the machine detects failure it will record the kN applied at the time of failure electronically in the record relating to the specimen ID number entered. This information will then be used to automatically calculate the compressive strength using the previously measured dimensions and populate the NATA certified test report for review by the signatories of the lab.

Figure 4.32 Cylinder being crushed.

4.5.2.4 INDIRECT TENSILE STRENGTH

The cylinder used for indirect tensile strength testing are cast and prepared in the same way as those used for testing compressive strength.

4.5.2.5 TESTING INDIRECT TENSILE STRENGTH

After the cylinder has been ground and prepared it is placed in a jig to hold it steady and on it's side between the platens of the compression machine. It is the orientation that gets the common name splitting tensile as the cylinder splits horizontally in failure while being loaded vertically in compression.

Like the compression testing the lab technician enters the specimen number and the machine is programmed with required loading rates, and crushes until recording failure and load at time of failure. This is then automatically used to calculate the indirect tensile strength in MPa.

Figure 4.33 Cylinder in jig being crushed to determine the 'splitting tensile' or indirect tensile strength.

4.5.2.6 Flexural strength

Each of the nine mixes were sampled for flexural testing. This consisted of one 7 day sample and two 28 day samples. The flexural strength requires the use of larger moulds that are crushed in a point bending jig.

4.5.2.7 Casting for flexural strength

The moulds are filled using the same methodology as the cylinders, half fill and vibrate, then fill to the top and vibrate, typically they will be slightly over-filled and struck back to the top of the mould. The main difference here is that there is no jig to hold the moulds during vibration, so they need to be carefully vibrated in limited numbers at a time to ensure safe handling.

Figure 4.34 Half-filled flex beams.

Figure 4.35 Vibrated after half filling.

Figure 4.36 Filled and vibrated before being trowelled off.

4.5.2.8 Testing specimens for flexural strength

Like the cylinders, the specimens are weighed and dimensioned in preparation, then they are loaded into the jig pictured in Figure 4.37 below. The lab technician needs to measure the placement of the beam in the jig to ensure correct positioning. As with the other tests the machine is pre-programmed for load rates and the specimen is loaded until failure which is then recorded and calculated automatically as a flexural strength result in MPa.

Figure 4.37 Flex beam in jig to be crushed in four points bending to determine flexural tensile strength.

4.5.2.9 Drying shrinkage

Each of the nine mixes were sampled and tested for drying shrinkage to 56 days, which takes 63 days as the initial measurement is taken at 7 days. For each mix there was three prisms cast and the change in length of the prism is measured at specified time intervals. These specimens are kept in a drying chamber that has controlled air circulation, temperature, and relative humidity as per AS 1012.13-2015. The measurements are taken at 7 days, 14 days, 21 days, 28 days and 56 days after the initial measure taken at 7 days from casting.

4.5.2.10 Casting specimens for determining drying shrinkage

Like all other specimens cast, they prisms are filled in two separate layers that are then vibrated and vibrated together respectively. Figures 4.38 to 4.41 below show the filling and vibration of the shrinkage specimens. It is very important when filling and handling these moulds that the end pins are not damaged or dislodged as they are the pints used for measuring on the comparator.

Figure 4.38 Shrinkage mould half filled.

Figure 4.39 Shrinkage mould topping up second layer.

Figure 4.40 Shrinkage vibrated after filling.

Figure 4.41 Shrinkage sample trowelled off.

4.5.2.10.1 Testing specimens to determine drying shrinkage

The specimens are placed in the comparator, pictured in Figure 4.42 below, and at least 5 readings are taken to ensure the readings are correct. These are then averaged and recorded for each three prisms for each age in days for each mix.

Figure 4.42 Shrinkage prism being measured.

CHAPTER 5: PRE-EXPERIMANTAL ANALYSIS AND EXPECTED RESULTS

As there are specific differences between each mix design, this chapter will discuss the expected performance changes as the design changes.

5.1 INCREASED WATER DEMAND AS THE SUBSTITUTION INCREASES

It is important to consider the different types of water involved in the concrete matrix and where that water will be utilised. In large the water initially acts as a lubricant for the concrete mix and not all the water used will be available for hydration (Neville, 2012). All materials are tested for their water absorption, this value is used to determine the percentage by weight of material that will absorb water. These results are detailed in Table 5.1 below. After removal of these values, the remainder is known as the effective water (Neville, 2012)

Table 5.1 Water absorption values of coarse and fine aggregates.

Material	Water absorption (%)
Beenleigh Coarse 20mm	0.4
Beenleigh Coarse 10mm	0.4
Beenleigh Manufactured Sand	2.4
Lytton Fine Sand	0.4
HA	20.8

Example of this calculation is detailed in Table 5.2 below:

Table 5.2 Calculation of effective water in control mix

Material	Weight (kg)	Absorption Value (%)	Absorbed Water (kg)
20 mm Coarse Agg	700.0	0.4	2.8
10 mm Coarse Agg	300.0	0.4	1.2
Manufactured Sand	442.0	2.4	10.6
Fine Sand	447.0	0.4	1.8
Design Water	180.0	Total absorbed:	16.4
Effective Water	163.6		

5.2 DECREASING DENSITY AS SUBSTITUTION INCREASES

As the dry density is essentially a summation of the material that has gone into the mix by weight for 1 cubic metre of concrete (Neville, 2012), using a material with a lower specific gravity is expected to decrease the final dry density of the concrete. Each material volume must be accurately accounted for to allow these calculations to succeed. The mass per unit volume will be corrected back to exactly 1 m^3, so if there are any inaccuracies in estimated volume of the design mix and the air content of the plastic and hardened concrete this will change the results.

It is expected in line with what was found in available literature that the density will decrease as the substitution increases and Table 5.3 below summarises the expected density change as the substitution increases. The accuracy of these estimations is based on the yield being correct, and the expected air content also being correct.

Unfortunately, the air content will not be able to be tested during the trials as the testing equipment is all out for use elsewhere by the laboratory, so analysis of air entrainment with the substitution increase will form part of the future research recommendations provided by this project.

Table 5.3 Estimated Mass per unit volume of substitution mixes.

Mix Description	Estimated dry density kg/m^3
Control Mix	2469
6% Substitution	2441
11% Substitution	2410
17% Substitution	2383
22% Substitution	2354

The set of substitution mixes is carried out twice with admixture and no admixture, in concrete supply the additional water demand is controlled by use of water reducing admixtures. In most instances, due to the admixture being a dispersant, there is improved compressive strength due to increased effective surface area being hydrated or reacted in pozzolanic activity (Neville, 2012) Table 5.4 below shows the full list of mixes.

Through experience with concrete mix design, it is noted these densities appear quite high, it is expected to see a reduction in all of them to be corrected from control through to mix 9 as detailed in Table 5.4 below.

Table 5.4 Estimated mass per unit volume based on desktop summation.

Mix Description	Estimated dry density kg/m^3
Mix 1 Control Mix	2469
Mix 2 6% Substitution No admixture	2441
Mix 3 11% Substitution No admixture	2410
Mix 4 17% Substitution No admixture	2383
Mix 5 22% Substitution No admixture	2354
Mix 6 6% Substitution Admixture used	2441
Mix 7 11% Substitution Admixture used	2410
Mix 8 17% Substitution Admixture used	2383
Mix 9 22% Substitution Admixture used	2354

5.3 DECREASING STRENGTH AS WATER/CEMENT INCREASES

It is well known that as the water content increases, if the cementitious portion of the mix does not increase accordingly, the Water / Cement or Water / Binder ratio will increase, and this increase will bring about a reduction in strength of the concrete produced.

It is this relationship that this project relies on to explain and quantify the pozzolanic contribution to strength of the HA.

To determine the expected reduction in strength Figure 5.1 below shows the relationship between W/C ratio and compressive strength.

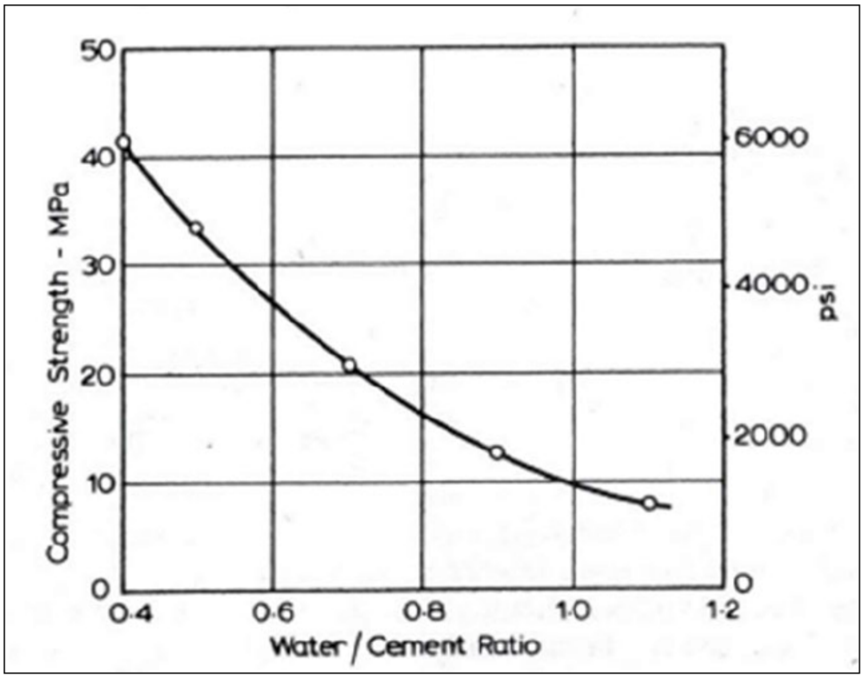


Figure 5.1 W/C ratio impact on strength (Neville,2012 p273)

Given that we know the Cement content is to remain at 400 kg / m^3 for all mixes and the design water and hence effective water will increase, we can estimate the decrease in compressive strength of each mix based on Figure 65 and the known W/C ratios of each 9 mixes.

5.3.1 COMPRESSIVE STRENGTH ESTIMATION

By completing the same calculation as carried out in section 5.1's example, we can determine the below details for each of the 9 mixes as shown in Table 5.5 below.

Table 5.5 Calculated Effective W/C ratios and Effective W/B ratios.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
GP	400 kg	400 kg	400 kg	400 kg	400 kg	400 kg	400 kg	400 kg	400 kg
HA	0	39 kg	78 kg	117 kg	155 kg	39 kg	78 kg	117 kg	155 kg
Total Binder	400 kg	439 kg	478 kg	517 kg	555 kg	439 kg	478 kg	517 kg	555 kg

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
Design Water	180	210	240	260	280	210	240	260	280
Effective water	163.6	186.8	210.0	223.1	236.4	186.8	210.0	223.1	236.4
Total W/C	0.45	0.53	0.60	0.65	0.70	0.53	0.60	0.65	0.70
Effective W/C	0.41	0.47	0.53	0.56	0.59	0.47	0.53	0.56	0.59
Total W/B	0.45	0.48	0.50	0.50	0.50	0.48	0.50	0.50	0.50
Effective W/B	0.41	0.43	0.44	0.43	0.43	0.43	0.44	0.43	0.43

By now plotting the values from Neville 2012 plot, shown in Figure 5.1, we can establish the relationship to calculate the estimated 7 Day compressive strength for each mix.

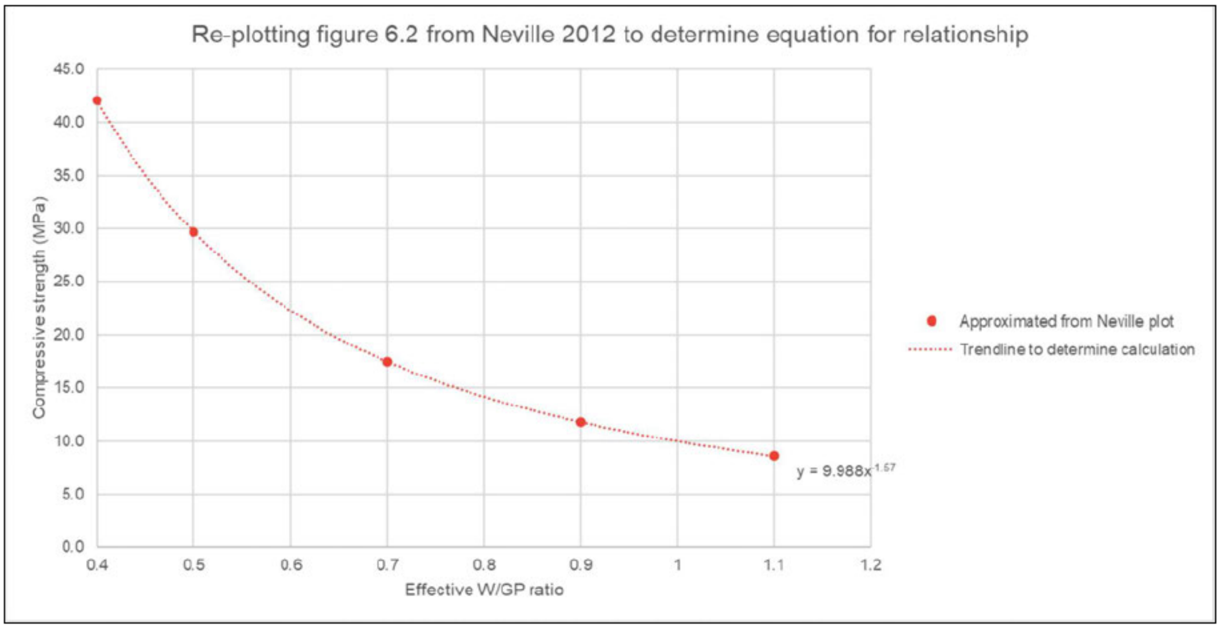


Figure 5.2 Plot of figure 6.2 taken from Neville 2012

Now having established the equation of the trendline we can calculate the estimated 7 day compressive strengths based on the Effective W/C ratio of the 9 mixes.

Table 5.6 Estimated 7 day Compressive strength for all mixes based on W/C ratio.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
W/C	0.41	0.47	0.53	0.56	0.59	0.47	0.53	0.56	0.59
7 Day compressive strength (MPa)	40.7	33.0	27.5	25.0	22.8	33.0	27.5	25.0	22.8

As we are aware that the final strength to be determined is not the 7 day compressive strength, but typically we would focus on the 28 day compressive strength, we must extrapolate these values to determine their estimated 28 day strength.

Figure 5.3 below shows the relationship that we will now use to extrapolate the 7 Day compressive strength estimates out to 28 day estimates.

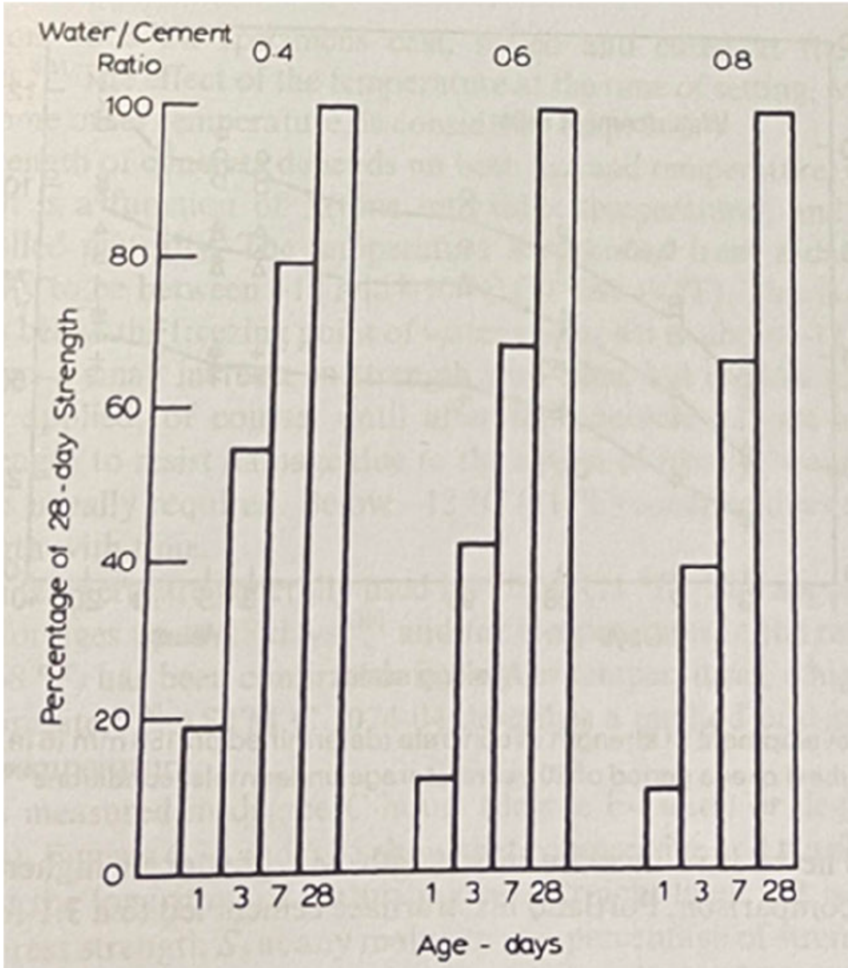


Figure 5.3 shows the relationship between W/C ratio and percentage of 28 day strength at typical tested ages (Neville,2012 p305).

This results in the below set of estimations in Table 5.7 for 28 Day Compressive strength based only on the GP cement performing as a cementitious product and no pozzolanic reaction occurring from the harvested ash.

Table 5.7 Estimated Compressive strength based on GP and W/C ratio.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
W/C	0.41	0.47	0.53	0.56	0.59	0.47	0.53	0.56	0.59
7 Day compressive strength (MPa)	40.7	33.0	27.5	25.0	22.8	33.0	27.5	25.0	22.8
28 Day compressive strength (MPa)	50.8	43.4	37.1	34.7	32.6	43.4	37.1	34.7	32.6

5.3.2 Flexural Strength

AS 3600- 2018 section 3.1.1.3 provides the calculation of the characteristic flexural tensile strength, (*f'ct.f*) as a function of the characteristic compressive strength (*f'c*).

This is given as: $f'ct.f = 0.6\sqrt{f'c}$

Using this relationship we can calculate the expected flexural tensile strength, for these calculations we will not be factorising the strengths back to a characteristic strength, we will use the estimated strength as *f'c*. Results of these calculations are in Table 5.8 below.

Table 5.8 Estimated flexural strength based on GP cement only.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
28 Day compressive strength (MPa)	50.8	43.4	37.1	34.7	32.6	43.4	37.1	34.7	32.6
28 Day flexural strength (MPa)	4.3	4.0	3.7	3.5	3.4	4.0	3.7	3.5	3.4

Like compressive strength, if the tested values exceed the mathematically determined we will assume the remaining portion of strength is attributable to harvested ash pozzolanic reaction and contribution, account will be taken of the control results to determine if the calculated are accurate relative to the control mix actual test results.

5.3.3 Indirect tensile strength

AS 3600- 2018 section 3.1.1.3 provides the calculation of the characteristic flexural tensile strength, (*f'ct*) as a function of the characteristic compressive strength (*f'c*).

This is given as: $f'ct = 0.36\sqrt{f'c}$

Using this relationship we can calculate the expected tensile strength, for these calculations we will not be factorising the strengths back to a characteristic strength, we will use the estimated strength as *f'c*. Results of these calculations are in Table 5.9 below.

Table 5.9 Tensile strength derived from estimated compressive strength.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
28 Day compressive strength (MPa)	50.8	43.4	37.1	34.7	32.6	43.4	37.1	34.7	32.6
28 Day tensile strength (MPa)	2.6	2.4	2.2	2.1	2.1	2.4	2.2	2.1	2.1

Like compressive strength and flexural strength, if the tested values exceed the mathematically determined we will assume the remaining portion of strength is attributable to harvested ash pozzolanic reaction and contribution, account will be taken of the control results to determine if the calculated are accurate relative to the control mix actual test results.

5.3.4 Drying shrinkage estimation

AS 3600:2018 Section 3.1.7.2 provides the following calculations to estimate the basic drying shrinkage strain:

$$\varepsilon_{\text{csd}} = k_1 k_4 \varepsilon_{\text{csd.b}} \qquad \text{. . . 3.1.7.2(4)}$$

$$\varepsilon_{\text{csd.b}} = (0.9 - 0.005 f'_c) \times \varepsilon^*_{\text{csd.b}} \qquad \ldots 3.1.7.2(5)$$

where $\varepsilon^*_{\text{csd.b}} = 800 \times 10^{-6}$ or determined by testing.

Figure 5.4 Equations for determining expected drying shrinkage strain based on compressive strength.

k_1 = 1.2 from figure 3.1.7.2 in AS 3600:2018 p47

k_4 = 0.6 as we are in a temperate zone as per AS 3600:2018 p46.

By following these calculations, we can produce the results in Table 5.10 below for the expected drying shrinkage.

Table 5.10 Calculated design shrinkage.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
28 Day compressive strength (MPa)	50.8	43.4	37.1	34.7	32.6	43.4	37.1	34.7	32.6
56 day drying shrinkage strain calculated ($\times 10^{-6}$)	372	393	412	418	425	393	412	418	425

5.4 Pozzolanic Reaction Determination

If the compressive strength results for each of the mixes are close to those predicted in section 5.3.1 then it is easy to determine that there has been no pozzolanic reaction and there was no contribution to the compressive strength by the harvested ash.

Contrary to this is that if the compressive strength values exceed those estimated, by amount exceeding normal variability, the only other possible contribution to compressive strength is that of the pozzolanic reaction of the harvested ash. In this case we can then determine the additional strength contribution and attempt to analyse and quantify the efficiency of the harvested ash using *AS 3583.6 – 2018 Methods of test for supplementary cementitious materials; Method 6: Determination of relative water requirements and strength index.*

By using the control mix with only GP Cement, we can test the compressive strength at all the proposed ages determining the strength contribution of the GP cement. We are then able to use the relationships developed in section 5.3.1 to determine the portion of compressive strength attributable to GP cement and any remaining strength can be attributed to the pozzolanic reaction of the harvested ash.

The test results can then be compared in a fashion like that outlined in AS3583.6 to determine the efficiency of the harvested ash.

CHAPTER 6: RESULTS AND DISCUSSION

6.1 Trial procedure and limitations

The trial batches were cast out over two days in the Construction Sciences Laboratory trial mix room with the assistance of Jardine Medland of Construction Sciences. Great thanks go to Jardine for his help and support. Due to the author not being an employee of the organisation there were limitations applied to the number of tasks the author was able to complete based on safety and workplace training rules. All rules and regulations were observed as part of the ethical and safe conduct required of a Professional Engineer. Some of the testing that was intended for the program had to be abandoned due to time constraints, resource constraints or inability to access the required testing equipment. As the organisation was assisting the author at no cost the non-critical tests were abandoned and will be recommended for inclusion in further research.
This study only carried out testing using one set of raw materials for concrete and a single source of HA. Due to the variability of the raw materials, it is highly recommended that this research be extended to multiple sources of cement and HA to confirm each source's viability.

6.2 Results

The results are reported below and tabulated for each type of test with images provided to show experiment being completed. Commentary regarding the experiment being carried out and any difficulties encountered are reported in these sections.

6.2.1 Slump results

Table 6.1 below shows the measured result for the slump of each of the 9 mixes. As previously mentioned, the concrete mix will have visual cues and characteristics that can be picked up on when mixing, the further through the trial mixes the characteristics were identified and repeatable slumps were obtained.

Table 6.1 Results of measured slump of each mix at completion of batching and prior to sampling for all test specimens.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
Measured slump at casting of test specimens (mm)	100	150	130	130	130	130	130	130	130

6.2.2 Observed Bleed

The mixes were ranked from highest to lowest in observed bleed with 1 being lowest and 9 being highest. Table 6.2 below summarises the results.

Table 6.2 Observed bleed ranking results.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
Observed bleed rank number	1	2	4	6	8	3	5	7	9

The bleed rank follows the expected trend that the highest water addition recorded the highest visible bleed, with the lowest water reporting the lowest visible bleed.

6.2.3 Hardened concrete test

The hardened concrete test results are presented by test method below.

6.2.3.1 28-day dry density results

The dry density results determined from the 28-day cylinders are summarised in Table 6.3 below.

Table 6.3 28-day dry density results.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
28 Day dry density (kg / m^3)	2340	2360	2340	2310	2290	2360	2320	2310	2270

6.2.3.2 Compressive strength results

The results of the compressive testing by age and mix are summarised in Table 6.4 below.

Table 6.4 Compressive strength results by mix and age of test in days.

Mix number	1 Day Result (MPa)	3 Day Result (MPa)	7 Day Result (MPa)	1st 28 Day Result (MPa)	2nd 28 Day Result (MPa)	1st 56 Day Result (MPa)	2nd 56 Day Result (MPa)
Mix 1	12.0	30.0	37.5	46.0	47.5	44.5	48.0
Mix 2	13.0	29.0	37.0	48.5	52.0	53.5	53.5
Mix 3	10.5	25.0	34.5	46.5	47.5	52.5	53.0
Mix 4	9.2	24.0	32.5	48.5	47.0	52.0	51.0
Mix 5	9.1	20.0	30.5	44.5	43.0	47.0	50.0
Mix 6	11.0	27.0	34.5	43.5	44.5	48.0	45.5
Mix 7	10.0	25.0	32.0	46.0	46.0	50.5	50.5

Mix number	1 Day Result (MPa)	3 Day Result (MPa)	7 Day Result (MPa)	1st 28 Day Result (MPa)	2nd 28 Day Result (MPa)	1st 56 Day Result (MPa)	2nd 56 Day Result (MPa)
Mix 8	8.8	23.0	31.0	45.0	45.0	48.0	49.0
Mix 9	7.8	21.0	28.5	45.0	44.5	47.5	45.0

6.2.3.3 Indirect tensile test results

The indirect tensile strength was tested with one 28-day specimen from each mix and the results are summarised in Table 6.5 below.

Table 6.5 Indirect tensile strength results.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
28 Day indirect tensile strength (MPa)	5.0	5.0	4.7	4.9	3.9	4.5	4.2	4.6	4.1

6.2.3.3.1 Flexural strength results

The flexural strength results are reported in Table 6.6 below.

Table 6.6 Flexural strength results by mix and age in days.

Mix number	7 Day Result (MPa)	1st 28 Day Result (MPa)	2nd 28 Day Result (MPa)
Mix 1	4.1	5.3	6.0
Mix 2	4.7	5.9	6.6
Mix 3	4.0	5.3	5.2
Mix 4	4.2	5.7	6.0
Mix 5	4.1	5.0	5.0
Mix 6	4.0	5.4	5.8
Mix 7	4.3	6.4	6.5
Mix 8	3.7	6.4	6.1
Mix 9	3.8	6.0	5.7

6.2.3.3.2 Drying shrinkage results

Mix	7 day (µStrain)	14 day (µStrain)	21 day (µStrain)	28 day (µStrain)	56 day (µStrain)
Mix 1 readings	370	520	590	660	800
	350	500	560	620	760
	350	500	580	640	770
Reported	360	510	580	640	780
Mix 2 readings	360	550	630	720	870
	330	500	570	660	780
	340	510	580	640	830
Reported	340	520	580	650	850
Mix 3 readings	360	520	600	680	840
	320	510	610	690	880
	290	450	540	630	790
Reported	320	510	610	690	840
Mix 4 readings	290	400	490	580	710
	320	440	520	610	750
	310	420	500	590	730
Reported	310	420	500	590	730
Mix 5 readings	300	410	500	600	740
	320	400	490	580	700
	310	410	500	580	730
Reported	310	410	490	590	730
Mix 6 readings	350	480	580	670	810
	340	460	550	640	790
	360	500	590	680	820
Reported	350	480	570	670	810
Mix 7 readings	330	430	530	640	790
	350	450	560	660	850
	360	460	540	630	780
Reported	350	450	540	640	780
Mix 8 readings	350	480	570	680	820
	360	460	550	660	780
	370	480	580	700	850
Reported	360	470	570	680	810
Mix 9 readings	400	520	620	730	890
	400	530	630	750	870
	350	470	570	680	820
Reported	400	530	630	740	880

6.3 Discussion and analysis of results

To be able to understand the success of the project we must interpret and analyse the results achieved through the experimentation.

The goal of this project is to prove that harvested ash sourced from Tarong Power station storage dam is suitable for use as a sand substitute and can produce a pozzolanic reaction which is identifiable through its contribution to compressive strength and can be measured for its efficiency against the GP cement used in combination and as the control mix.

6.3.1 Fresh concrete testing

Before reviewing the strength performance of the concrete in the hardened state we need to review whether we achieved the expected results in the plastic state.

6.3.1.1 Slump and water demand

To achieve the target slump range of 120 mm +/- 30 mm, a design water content of the concrete mixes was established. For confirmation that the design water was approximated accurately we need to compare estimated design water content with that utilised in experimentation to achieve the target slump.

Table 6.7 Comparison of design water and admixture vs actual batched water and admixture

	Mix 1 (L / m^3)	Mix 2 (L / m^3)	Mix 3 (L / m^3)	Mix 4 (L / m^3)	Mix 5 (L / m^3)	Mix 6 (L / m^3)	Mix 7 (L / m^3)	Mix 8 (L / m^3)	Mix 9 (L / m^3)
Proposed total design water	180	210	240	260	280	210	240	260	280
Effective proposed design water	163.6	186.8	210.0	223.1	236.4	186.8	210.0	223.1	236.4
Admixture design	1.8	1.8	1.8	1.8	1.8	-	-	-	-
Total Batch required	180	210	238	259	279	230	246	271	292
Effective Batch required	163.6	186.8	208	222.0	236.0	206.8	216.6	233	248

	Mix 1 (L / m^3)	Mix 2 (L / m^3)	Mix 3 (L / m^3)	Mix 4 (L / m^3)	Mix 5 (L / m^3)	Mix 6 (L / m^3)	Mix 7 (L / m^3)	Mix 8 (L / m^3)	Mix 9 (L / m^3)
Admixture required	1.8	1.8	0.6	0.8	0.81	-	-	-	-

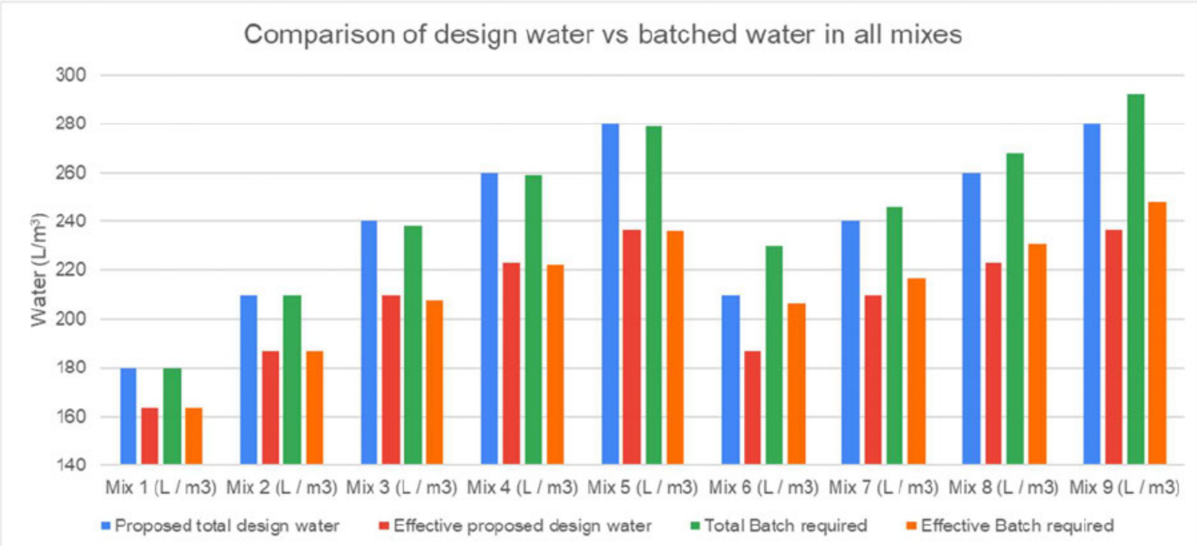


Figure 6.1 Comparison of the designed water vs that used for batching.

From the comparison of results, shown in Table 6.7 and Figure 6.1, the calculated water demand was accurate, and the mix required the additional water to achieve the targeted slump.

The mixes that employed the use of admixture allowed accurate control of the water within very close range of design, which is the reasoning behind their use in concrete production.

Without the use of admixture, mixes 6 through to 9 inclusive, the water demand was higher than expected due to the additional fines of the HA.

Through comparison of the mixes using admixture and no admixture we can determine the percentage of water reduction applied by the admixture, allowing us to determine the estimated water that would be required for the control mix, and from this determine the water requirement of the harvested ash.

Example calculation steps required:

- Determine water required without admixture (Mix 7 / 246) L
- Determine water with admixture (Mix 3 / 238) L
- Calculate additional water required with no admixture (246 – 238 = 8); this is the water reduced through admixture use.
- Calculate reduction as percentage of total water (8 / 246 = 3.25 %
- Now divide this percentage by the litres of admixture to calculate percentage reduction per litre (3.25 / 0.6 = 5.42 %)

Now to apply the same calculation to all mixes with the same substitution of harvested ash, Table 6.8 below shows the results of these calculations.

Table 6.8 Calculation of admixture efficiency and water reduction per L

Mix number	Mixes 2 & 6	Mixes 3 & 7	Mixes 4 &8	Mixes 5 & 9
Mix number	6	7	8	9
Recorded Slump (mm)	130	130	130	130
Water required	230	246	271	292
Mix number	2	3	4	5
Recorded Slump (mm)	150	130	130	130
Water required (L)	210	238	259	279
Water reduced through admixture (L)	20	8	12	13
Percentage of total water reduced (%)	8.70%	3.25%	4.43%	4.45%
Litres of admixture for reduction (L)	1.8	0.6	0.8	0.81
Percentage of reduction per litre (%)	4.83%	5.42%	5.54%	5.50%

Typically, when reviewing concrete results we would accept in slump range, however in this case we will treat the 150 slump as an outlier and average the other three mixes taking 5.48 % as the admixture efficiency in this case.

Now applying this to the control mix we can determine the control water for calculation of water requirement by increasing the total water by 5.48 %.

This gives us a control water of 189.86 L / m^3 with no use of admixture.

Using the method outlined in AS 3583.6:2018 and adapting to our experiment, we can now calculate the water requirement.

(b) *Fly ash samples* The relative water requirement is calculated as follows:

$$\text{Relative water requirement} = \frac{m_t}{m_c} \times 0.95 \times 100 \text{ (see Note)} \quad \ldots 9.1(2)$$

where

m_t = mass of water used in test mortar, in grams

m_c = mass of water used in control mortar, in grams

NOTE: The factor 0.95 is needed because the quantities of Type GP cement, fly ash, and water for fly ash test mortar are increased to account for the partial sand replacement. See Note 2 to Table 1.

Figure 6.2 Water requirement calculation taken from AS 3583.6:2018 p5.

These calculations are then completed for the range of substitutions, mixes 6 through to 9 as they are the varying water content with no admixture control.

Through analysis we can determine that there is a linear relationship between the percentage of harvested ash replacement and the water requirement vs control, as can be seen in Figure 6.3 below.

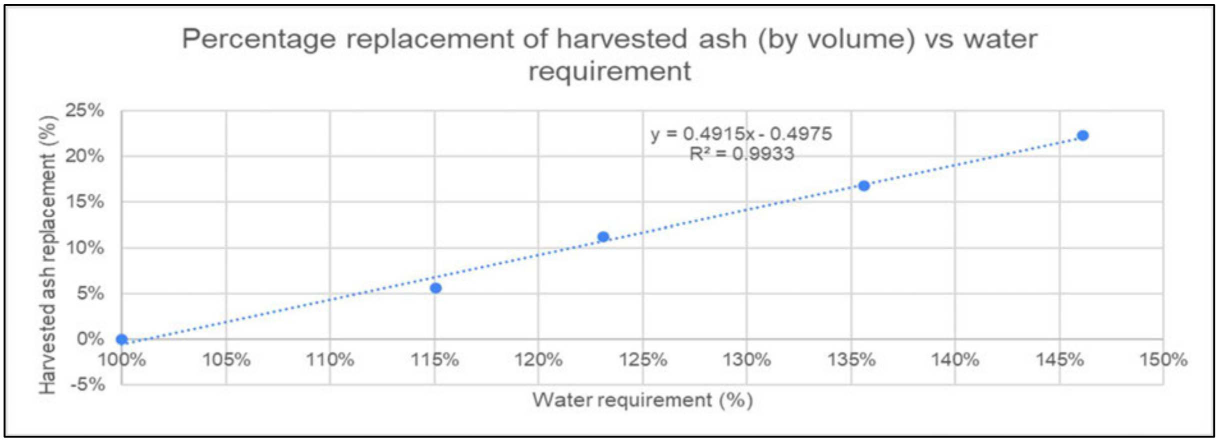


Figure 6.3 Water requirement vs volumetric replacement of fine aggregates with harvested ash.

6.3.1.2 Observed Bleed

As concrete bleed is typically a function of the amount of total water added (Neville, 2012), the recorded ranking of bleed observed is in line with what was expected. This being the mix with the lowest added water had the lowest observed bleed and the mix with the highest added water had the highest observed bleed and the remaining mixes were ranked equally with water addition and observed bleed respectively. Figure 6.4 below shows the relationship between bleed ranking and eater added.

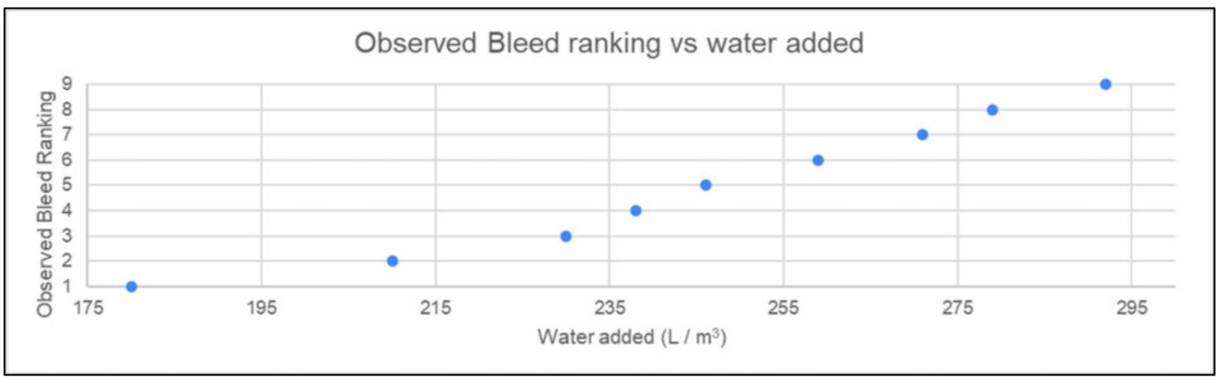


Figure 6.4 Plot of bleed rank vs water added.

6.3.2 Hardened concrete testing

The goal of this analysis is to determine whether there is any contribution to strength using the harvested ash. This will be analysed comparing expected strength due to GP content and effective W/C ratio detailed in Chapter 5 compared with the results shown in Section 6.2 of this chapter.

6.3.2.1 Compressive Strength

A typical set of compliance cylinders as per AS 1379-2007 consists of one 7 day cylinder and two 28 day cylinders. This is to allow prediction of how the compressive strength is trending at 7 days and then to determine compliance at 28 days of the compressive strength performance.

In the case of this project, we needed to determine the strength growth trend vs time, so it was important to understand the stage at which the concrete mix developed it's strength as the pozzolanic reaction is a much slower strength development when compared with the strength development of hydrating GP cement. (Neville,2012)

This analysis will focus primarily on the comparison of compressive strength but will compare all results with expected values across all testing carried out.

6.3.2.1.1 Comparison of actual compressive strength with estimated compressive strength

In chapter 5 we established the estimated compressive strength based on the GP cement content and W/C ratio. Table 6.9 below and Figure 6.5 show the comparison of the estimated results with the actual test results. This clearly indicates a higher than calculated compressive strength, which assumed that only GP cement would contribute to the strength.

As this is clearly not the case it can be determined that there is a pozzolanic reaction present and there is a portion of the compressive strength attributable to the harvested ash acting as a pozzolan.

Table 6.9 Comparison of estimated 28-day strength vs tested.

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
Harvested ash substitution	Control	6%	11%	17%	22%	6%	11%	17%	22%
Predicted 28 Day compressive strength (MPa)	50.8	43.4	37.1	34.7	32.6	43.4	37.1	34.7	32.6
Tested 28 Day compressive strength (MPa)	46.8	50.3	47.0	47.8	43.8	44.0	46.0	45.0	44.8

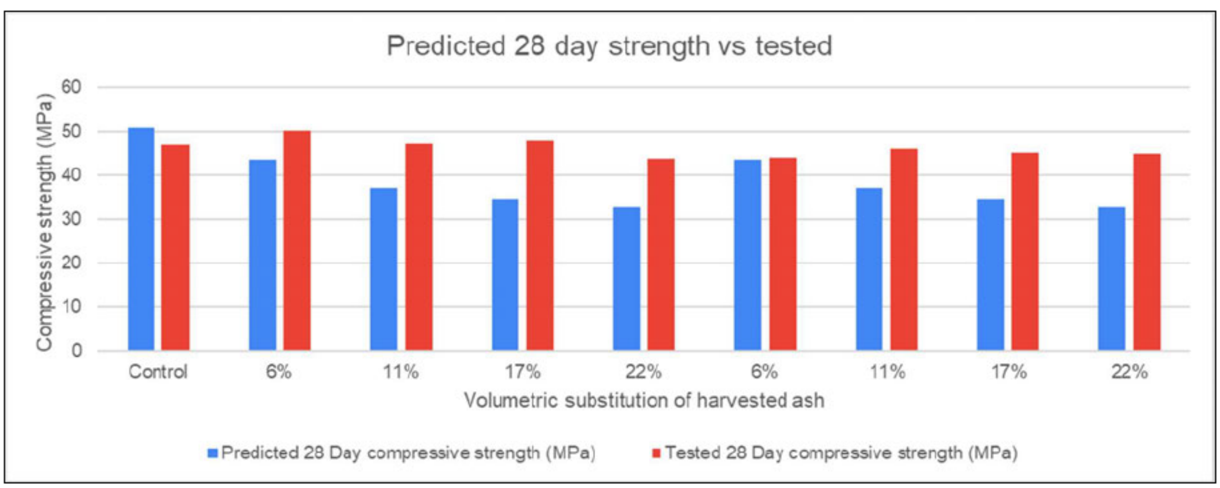
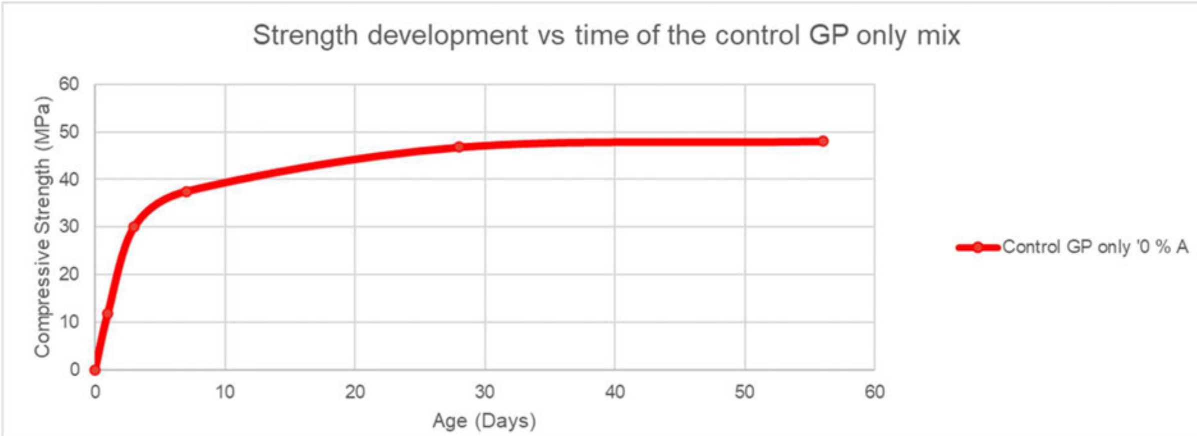


Figure 6.5 Comparison of estimated 28 day strength with tested 28 day strength plot.

6.3.2.1.2 Strength development vs time

From the control mix we can establish the rate of strength development of the GP only concrete.



Neville discusses the difference in strength development vs time of Fly Ash concretes, using 25% replacement of cementitious by weight, compared with Portland Cement concretes and the comparison is summarised in Table 6.10 below. To see the difference in relationship between strength development and time more clearly the results were plotted and can be seen in Figure 6.6. below.

Table 6.10 Fly ash concrete vs GP concrete (Neville, 2012 p661)

Table 13.1 Typical Compressive Strength of Fly Ash Concretes[13,14]

Cementitious material	*Compressive strength, MPa (psi) at age (days):*						
	1	*3*	*7*	*14*	*28*	*91*	*365*
Portland cement	12.1 (1750)	21.2 (3070)	28.6 (4150)	33.9 (4910)	40.1 (5810)	46.0 (6670)	51.2 (7420)
Class F fly ash* (25%)	7.1 (1030)	13.9 (2010)	19.4 (2820)	24.3 (3520)	30.3 (4400)	39.8 (5770)	47.3 (6860)
Class C fly ash** (25%)	8.9 (1290)	19.0 (2760)	24.1 (3490)	28.5 (4140)	29.4 (4260)	40.5 (5880)	45.6 (6620)

*BS Class V
**BSEN Class W

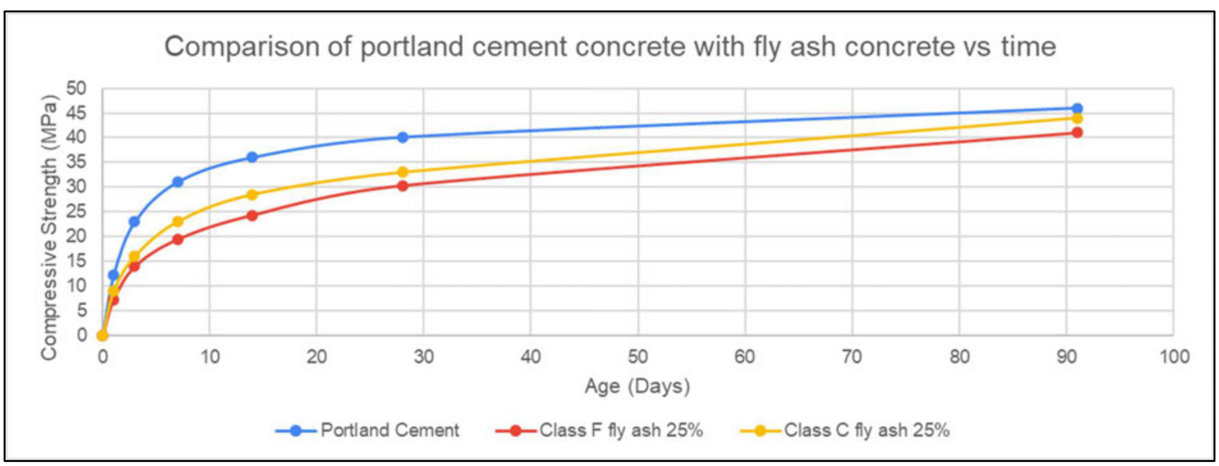


Figure 6.6 Plot of Neville's Table of results of difference in Portland cement concrete vs fly ash concrete

This relationship becomes critical to the analysis of the compressive strength and determination of the pozzolanic reaction.

The reduction in strength development of the fly ash concrete at an early age (less than 3 days) is due to the reduction in strength from hydration of cement, then as the time surpasses 3 days the growth of the compressive strength continues until a much later age.

By reviewing this in terms of percentage of the final strength achieved vs age, we can better understand the distinct difference in how the strength growth changes when relying on the pozzolanic reaction. Figure 6.7 below shows the increased percentage of early age strength achieved by the Portland cement concrete when compared with the fly ash concrete.

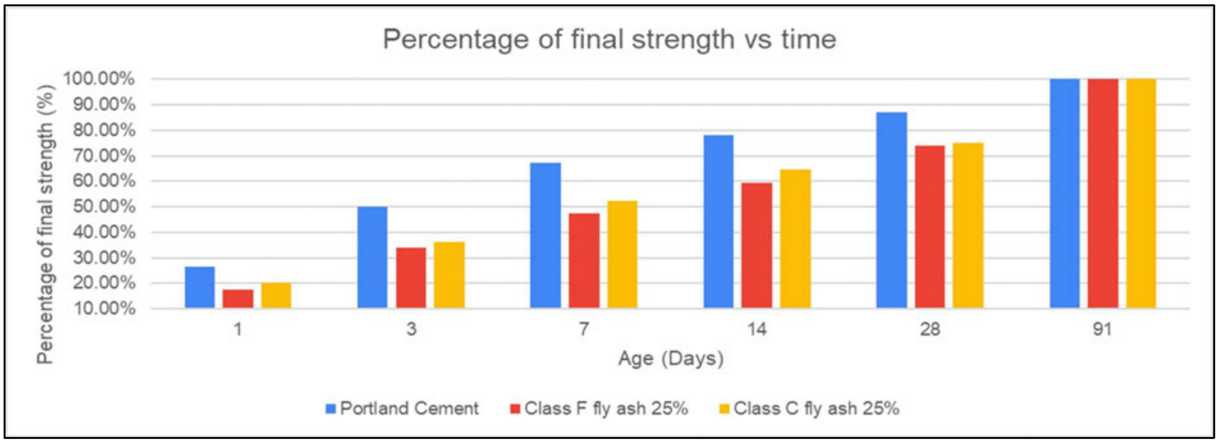


Figure 6.7 Plot of percentage of final strength vs age in days of Portland cement concrete and fly ash concrete from Neville 2012.

When comparing the results of this experiment for compressive strength vs time when the substituted mixes are compared with the control mix for their strength development vs time, they follow the same trend established in Neville's reference data, indicating the behaviour of the concrete to be in line with that of a fly ash blend concrete when it comes to compressive strength development.

Figure 6.8 shows the plot of actual results from this experiment and when compared to the trending visible in Figure 6.6, there is clear similarity in the development of strength of the trial concrete. This trend shows the concrete is behaving as a blended fly ash concrete.

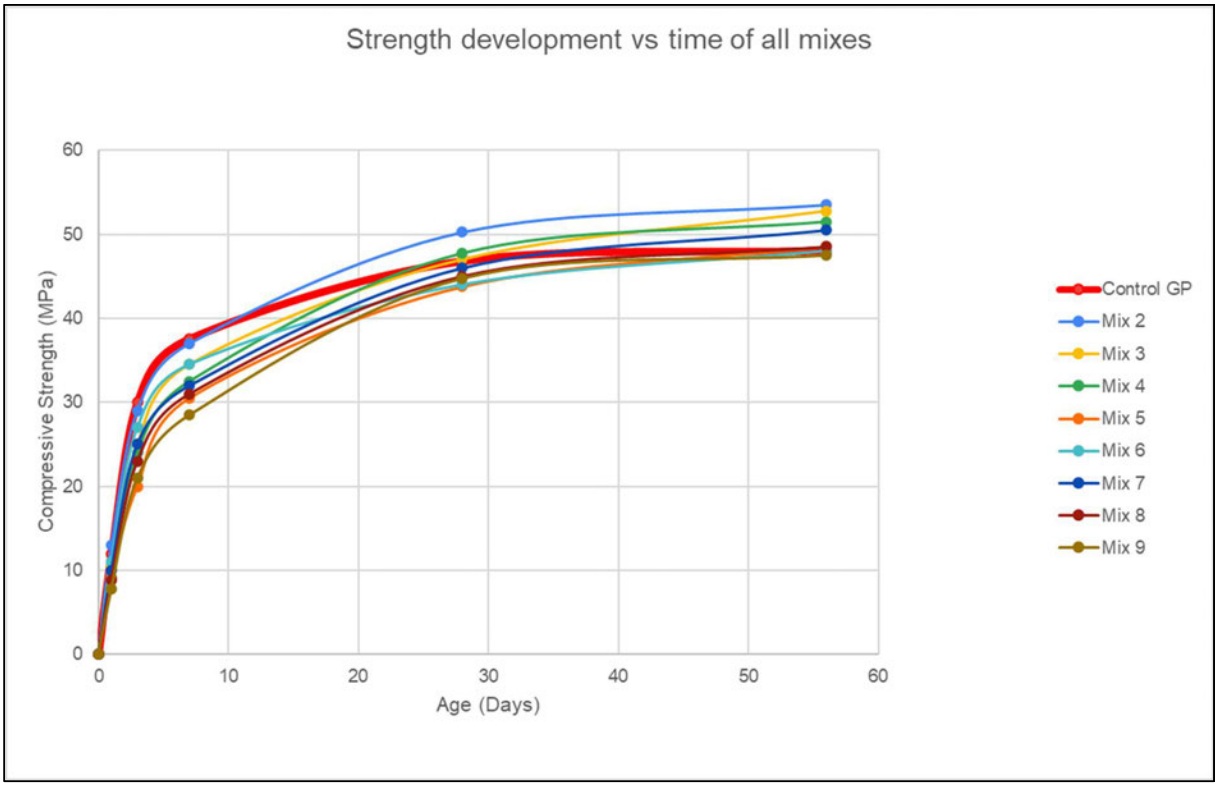


Figure 6.8 Comparison of cylinder strength vs time of all mixes.

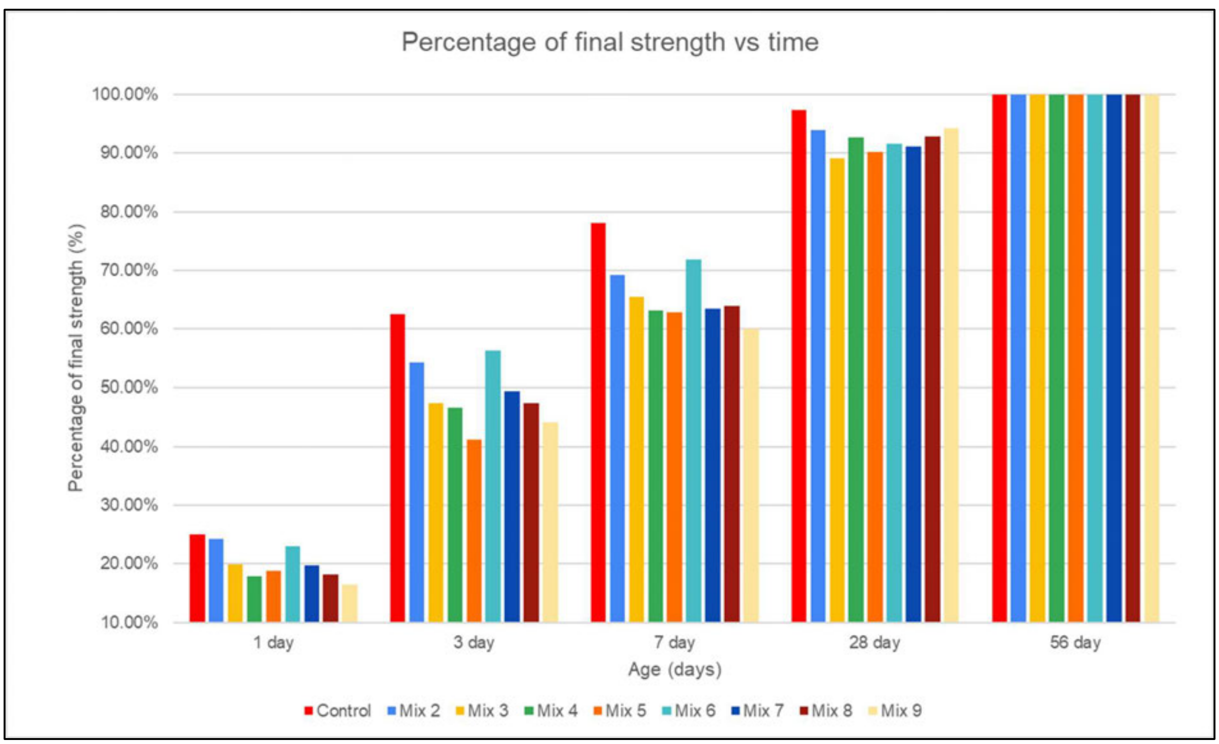


Figure 6.9 Plot of percentage of final strength vs time of actual results.

6.3.3 Pozzolanic reaction and Efficiency

When reviewing the compressive strength results, we can determine that the harvested ash has acted as a binder and contributed to compressive strength.

Based on the strength contribution by the GP and effective W/C ratio determined in section 5, we can now determine the portion of strength contributed by the harvested ash and the pozzolanic reaction.

Table 6.11 Determining the contribution to strength in MPa by the harvested ash.

Substitution volume (%)	Mix 1 Control	Mix 2 6%	Mix 3 11%	Mix 4 17%	Mix 5 22%	Mix 6 6%	Mix 7 11%	Mix 8 17%	Mix 9 22%
Predicted 28 Day compressive strength (MPa)	46.8	43.4	37.1	34.7	32.6	43.4	37.1	34.7	32.6
Tested 28 Day compressive strength (MPa)	46.8	50.3	47.0	47.8	43.8	44.0	46.0	45.0	44.8
28 Day Compressive strength contribution of harvested ash (MPa)	**0.0**	**6.9**	**9.9**	**13.1**	**11.2**	**0.6**	**8.9**	**10.3**	**12.2**
Predicted 56 Day GP strength (MPa)	48.0	44.5	38.1	35.6	33.4	44.5	38.1	35.6	33.4
Actual 56 Day strength tested (MPa)	48.0	53.5	52.5	52.0	47.0	48.0	50.5	48.0	47.5
56 Day Compressive strength contribution of harvested ash (MPa)	**0.0**	**9.0**	**14.4**	**16.4**	**13.6**	**3.5**	**12.4**	**12.4**	**14.1**

This can be more clearly understood visually as shown in Figures 6.10 and 6.11 below.

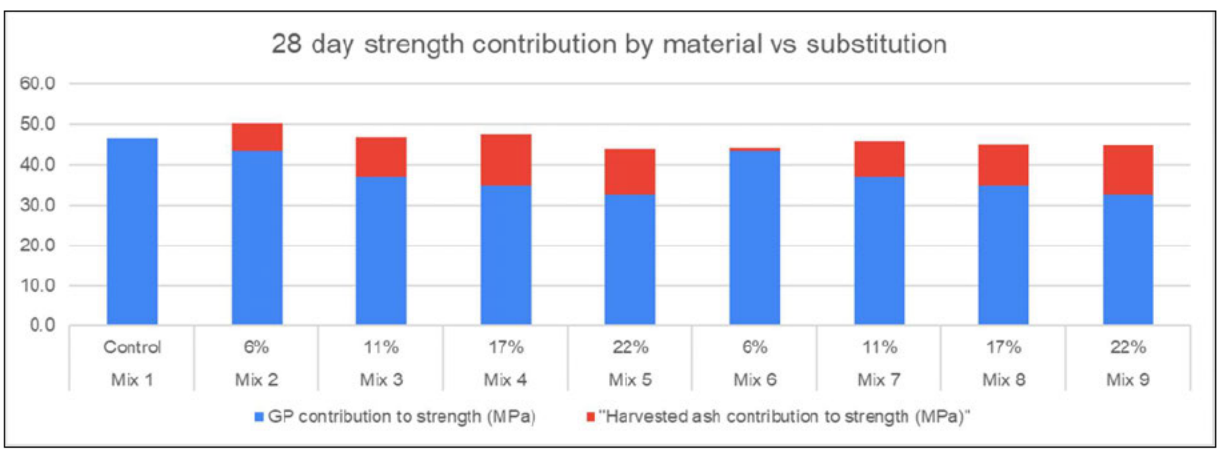


Figure 6.10 28-day contribution to strength by material plot.

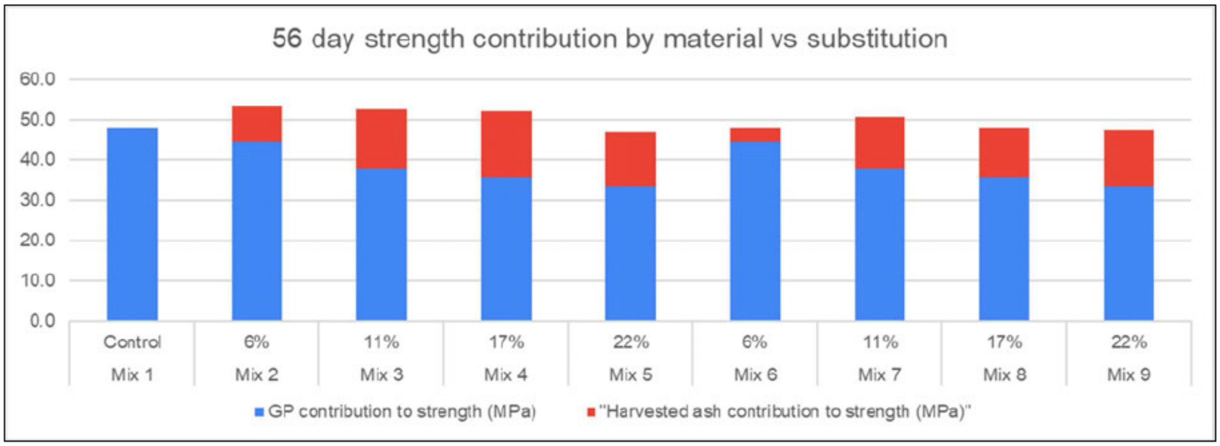


Figure 6.11 56 Day strength contribution by material plot.

Now that we have established the harvested ash is reacting as a binder, we are able to treat it as a binder and compare the resulting compressive strength with the control to determine the efficiency of the harvested ash.

To complete this we will adapt the method set out in AS 3583.6:2018 for the strength index at 28 days.

9.2 Strength index

The following calculations shall be made:

(a) *Standard cured test* The strength index at 28 days (R_{28}) is calculated as follows:

$$\text{Strength index}(R_{28}) = \frac{T_{28}}{C_{28}} \times 100 \qquad \ldots 9.2(1)$$

where

T_{28} = mean compressive strength of test mortar at 28 days, in MPa

C_{28} = mean compressive strength of control mortar at 28 days, in MPa

Figure 6.12 Calculation of 28-day strength index of Fly ash as binder.

In Appendix D the Fly Ash test certificate reports the strength index at 99% for Tarong Fly Ash supplied and tested by Cement Australia.

As we did not complete the testing as per AS 3583.6:2018 we will calculate in a similar method by using the test results for substituted binder values to form T_{28} and T_{56} and using the GP only control results as our C_{28} and C_{56}. This will allow us to determine R_{28} and R_{56} for our experimental results.

	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9	
Substitution volume (%)	6%	11%	17%	22%	6%	11%	17%	22%	Average
28 Day Strength index	104%	99%	104%	95%	93%	98%	96%	96%	98%
56 Day Strength index	111%	109%	108%	98%	100%	105%	100%	99%	104%

When comparing the average efficiency with that reported in the supplier test certificate it is close to the performance of the fine grade fly ash provided by Cement Australia at 28 days, and at 56 days shows better strength would be achieved using harvested ash as a replacement for GP.

6.3.4 Flexural strength

Interestingly the flexural strength did not decrease with the HA addition, rather improved with the addition of HA. Figure 6.13 below shows the flexural strength grew independently of the increase in W/B ratio and was not reduced by the introduction of HA.

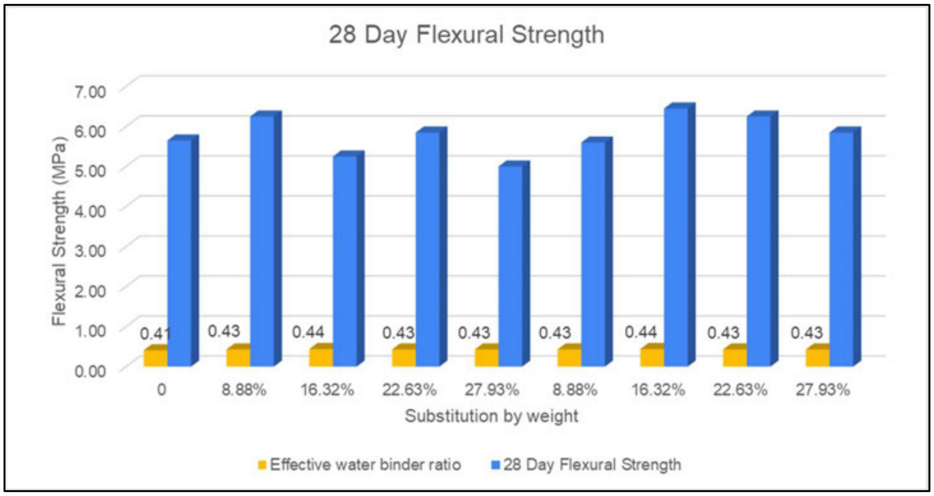


Figure 6.13 Visual comparison of Flexural Strength vs substitution % and effective W/B ratio

6.3.5 Indirect tensile strength

Indirect tensile strength gave some interesting insight to admixture impact on concrete. Figure 6.14 below shows that the introduction of admixture produced lower indirect tensile strength at all substitution percentages and effective W/B ratios.

The mixes using HA performed better than the control when considering the increase in effective W/B ratios, control being 0.41 and substitutions 0.43 and 0.44. To better understand this it would be necessary to repeat the control with no admixture to determine the impact of admixture addition.

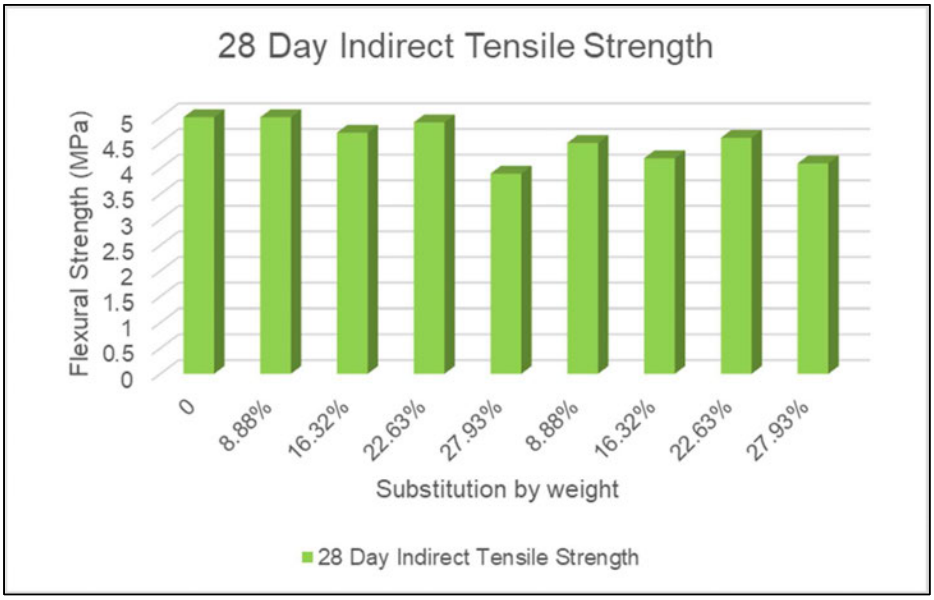
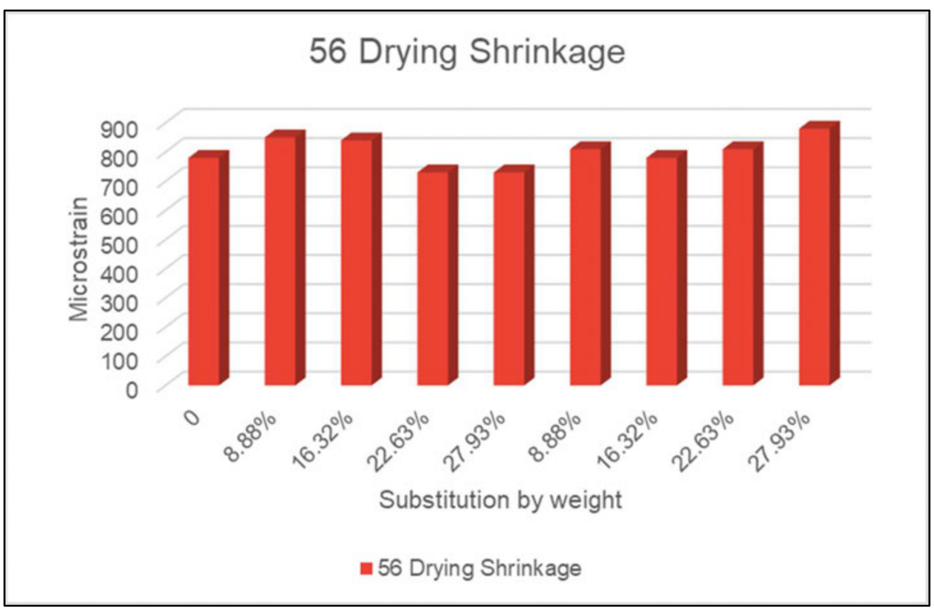


Figure 6.14 Indirect Tensile Strength vs substitution percentage

6.3.6 Drying shrinkage

As the drying shrinkage test is not a very repeatable result due to the way that the prism results for each reading age are averaged and outliers removed, it is difficult to draw definite conclusions from the results. However, broadly the mixes employing admixture have higher drying shrinkage than those without and the introduction of HA does not provide definitive increase or decrease in drying shrinkage as there is no visible trend for this.



CHAPTER 7: CONCLUSION

The goal of this project was to establish whether raw harvested ash from Tarong Power Station ash storage dam could be used as a substitution for fine aggregate and provide a quantifiable pozzolanic reaction in doing so.

7.1 Findings

The following has been successfully confirmed:

- The harvested ash could be used to produce concrete that performed similar in plastic properties to the control concrete.
- The harvested ash could be used to design concrete mixes in a typical fashion with predictable adjustments being made to mix design based on its use as substituted material.
- The harvested ash produced a pozzolanic reaction in the concrete.
- The pozzolanic reaction was quantifiable and cement efficiency could be calculated, which performed at a comparable rate to fine grade fly ash supplied form the same source.
- The water demand of the use of harvested ash was measurable and could be controlled by use of water reducing admixtures.

From these findings it is acceptable to conclude that there is potential for HA to be used in concrete. It is also recommended that further investigation into the use of HA in concrete be completed.

7.2 Future research

As this study was limited to a single sample taken from one ash dam it is recommended that the following be considered for future research:

- Multiple samples from the same source.
- Sampling that will consider the stratification of the storage dam.
- Sampling of other available ash dams across Australia.
- Combination of multiple ash sources with multiple aggregate sources.
- Combination of different GP cement sources to test effectiveness with different cementitious partnerships.
- Chemical analysis of harvested ash.

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APPENDIX A: PROJECT SPECIFICATION

ENG4111/4112 Research Project

Project Specification

For: James Moller

Title: Harvested Ash as Pozzolanic Sand substitute in concrete

Major: Civil

Supervisors: Weena Lokuge

Enrollment: ENG4111 – EXT S1, 2022

ENG4112 – EXT S2, 2022

Project Aim: Determine the validity of HA as sand replacement providing pozzolanic reaction in untreated raw substitution.

Program: Version 1, 16th March 2022

1. Conduct comprehensive literature review on the use of HA as substitute in concrete
2. Establish research significance.
3. Develop testing plan and mix trial program to best eliminate as many variables as possible. Establish mix design and percentage of sand replacement by HA for trials.
4. Source materials and prepare samples and complete testing.
5. Analyze data linking with available literature, draw conclusions, answer initial question, look for future opportunities.
6. Prepare thesis/ present findings at Project Conference

APPENDIX B: RISK MANAGEMENT

Table 7.1 Risk Matrix used for risk assessment.

	Consequence				
Likelihood	**Insignificant (1)** No injuries/ insignificant financial loss	**Minor (2)** First aid/ minimal financial loss	**Moderate (3)** Medical treatment/ Medium financial loss	**Major (4)** Hospitalisation/ large financial loss	**Catastrophic (5)** Death/massive financial loss
Almost Certain (5) Often occurs	Moderate (5)	High (10)	High (15)	Extreme(20)	Extreme (25)
Likely (4) Could easily happen	Moderate (4)	Moderate (8)	High (12)	Extreme (18)	Extreme (20)
Possible (3) Could happen	Low (3)	Moderate (6)	Moderate (9)	High (12)	High (15)
Unlikely (2) Known to have happened	Low (2)	Moderate (4)	Moderate (6)	Moderate (8)	High (10)
Rare (1) Possible but unlikely	Low (1)	Low (2)	Low (3)	Moderate (4)	Moderate (5)

Table 7.2 Risk assessment

Task / Activity	Risk / Hazard	Consequence	Risk score before control	Controls	Control hierarchy	Risk score after control
Travel to Site	Fatigue	Injury	High / Moderate	• Check vehicle travelling in is safe and operated by a competent driver. • Plan ahead allow sufficient travel time in the working day. • Do not travel if fatigued. • Do not travel at night. • Do not travel alone. • Always keep a First Aid Kit on person.	4. Administrate	Moderate / Low
Site Sampling	Uneven / unstable ground / slips, trips and falls	Injury	High	• Do not take short cuts through unsuitable areas.	4. Administrate 5. PPE	Moderate

Task / Activity	Risk / Hazard	Consequence	Risk score before control	Controls	Control hierarchy	Risk score after control
				• Apply caution whilst walking during site sampling. • Follow site escort. • Wear appropriate footwear.		
	Exposure to the sun	Sunburn, heatstroke, dehydration	Moderate	• Periodically reassess weather conditions and decide if safe to work. • Wear appropriate PPE including a sun hat and long-sleeved clothing, and use sunscreen as required. • Take, and drink plenty of water	4. Administrate 5. PPE	Low
	Wind	Dust may enter eye	Moderate	Cease work during extreme weather.	4. Administrate	Low
	Heavy Rain	Poor visibility, unsafe navigation, slips, trips and falls	Moderate	• Cease work during extreme weather. • Watch your step. Wear appropriate footwear.	4. Administrate 5. PPE	Low
	Cold	Hypothermia	Moderate	• Cease work during extreme weather Wear suitably warm clothes in cold conditions.	4. Administrate 5. PPE	Low
Laboratory trials	Entering industrial working environment	Injury / Serious Injury / Death	High	• Complete a site induction. • Be aware of your surroundings. • Maintain constant communication in the team via radio. • Stop in a safe location prior to	4. Administrate 5. PPE	Low

Task / Activity	Risk / Hazard	Consequence	Risk score before control	Controls	Control hierarchy	Risk score after control
				taking an image or completing testing. Wear high visibility vests.		
		Hearing damage	Moderate	Use hearing protection.	5. PPE	Low
	Cuts, abrasions	Injury	Moderate	• Do not put hand into mixer while mixing. Wear gloves.	4. Administrate 5. PPE	Low
	Lifting	Injury	Moderate	• Employ safe lifting techniques.	4. Administrate 5. PPE	Low
	Concrete splashing	Eye Injury	Moderate	• Wear safety glasses.	4. Administrate 5. PPE	Low
Report writing	Sitting for long periods	Injury	Moderate	• Take regular breaks. • Utilise sit/stand desk and change position regularly.	4. Administrate	Low
	Working long hours / late at night / early morning	Fatigue	Moderate	• Be aware of body condition. • Ensure minimum sleep obtained. • Maintain exercise. • Eat well. • Stay hydrated. • Maintain work/life balance.	4. Administrate	Low

APPENDIX C: CONSEQUENCES AND ETHICS

As an engineering professional, it is important to act in accordance with the Code of Ethics produced by Engineers Australia.

This code provides four key areas of discipline that shall be followed:

1. Demonstrate integrity,
    a. Act professionally and do the right thing.
    b. Be honest and trustworthy.
    c. Treat people well and respectfully
2. Practise competently,
    a. Act within your competency.
    b. Continuously learn.
3. Exercise leadership,
    a. Support those around you in a professional manner.
    b. Approach with open mind and avoid all prejudice.
4. Promote sustainability,
    a. Consider the future with your current actions.
    b. Practise in a manner that promotes health, safety and inclusion and protection of the community and environment.

APPENDIX D: FLY ASH TEST CERTIFICATE TARONG

STANDARD FLY ASH CERTIFICATE

FINAL

Prior Reports: None

CEMENT AUSTRALIA

Certificate Number: CERT140644

Issued: 18 August 2014

Cement Australia
PO Box 1034
Sumner Park, Qld, 4074
Australia
Telephone: +61 7 3335 3000
Fax: +61 7 3335 3227

Product being certified: Tarong Monthly Grab Fly Ash
Product sample date: 17-Jun-2014
Sample Identification: Sample Code: 14060382
Source Power Station Tarong Power Station
Testing Conditions: As received at Cement Australia Darra Laboratory, 12 Station Avenue, Darra Queensland 4076 Australia. Testing Commenced on 18-Jun-2014

Test Results

Test	Moisture %	Fineness @ 45 micron % Passed	Loss on Ignition %	Sulfuric Anhydride %	Available Alkali [1] %	Chloride Ion %
Result	< 0.1	84	0.6	< 0.1	0.1	< 0.001
Test Method	AS3583.2-1991	AS3583.1-1998	AS3583.3-1991	AS2350.2:2006	AS3583.12-1991	AS3583.13-1991
AS 3582.1:1998	1.0% Maximum	75%Minimum	4.0% Maximum	3.0% Maximum	-	-

Test	Relative Density	Relative Water Requirement %	Relative Str 28 Days %
Result	2.07	96	99
Test Method	AS3583.5-1991	AS3583.6-1995	AS3583.6-1995
AS 3582.1:1998	-	-	-

Reference Cement Details

Identification: 14060383
Source: Bulwer
Product Type: Type GP
Sample Date: 18-Jun-14

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	0.2	75.1	21.2	0.8	< 0.1	0.1	< 0.1
Test Method	AS2350.2:2006	AS2350.2:2006	AS2350.2:2006	AS2350.2:2006	AS2350.2:2006	AS2350.2:2006	AS2350.2:2006

Test	K_2O by XRF %	SrO by XRF %	TiO_2 by XRF %	P_2O_5 by XRF %	Mn_2O_3 by XRF %	Total Alkali (Na_2O Equiv) %
Result	0.43	<0.1	1.2	<0.1	< 0.1	0.28
Test Method	AS2350.2:2006	AS2350.2:2006	AS2350.2:2006	AS2350.2:2006	AS2350.2:2006	AS2350.2:2006

This sample grade conforms to the following requirements of AS 3582.1:1998

Special	Fine	Medium	Coarse
	X		

Approved Signatory

[redacted]

V Connell
Chemical Testing
Construction Materials Testing

Accredited for compliance with ISO/IEC 17025. The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards.

NATA

NATA Accredited Laboratory Numbers
187 188

Notes:

1 4 0 6 0 3 8 2

C E R T 1 4 0 6 4 4

DA-SF-019

APPENDIX E: PROJECT PLAN

James Moller [redacted]roject Timeline 2023			21-Feb	28-Feb	7-Mar	14-Mar	21-Mar	28-Mar	Break	Break	18-Apr	25-Apr	2-May	9-May	16-May	23-May	30-May	Exams	Exams	Break	Break	11-Jul	18-Jul	25-Jul	1-Aug	8-Aug	15-Aug	22-Aug	29-Aug	5-Sep	12-Sep	Break	Break	3-Oct	10-Oct	17-Oct
			Semester 1 weeks																			Semester 2weeks														
Task		Complete ?	1	2	3	4	5	6			7	8	9	10	11	12	13					1	2	3	4	5	6	7	8	9	10			11	12	13
1. Project Preperation																																				
1A	Project allocation	✓																																		
1B	Project specification and planning	✓																																		
1C	Literature review/ Establish research significance																																			
3. Develop Testing plan and mix trial program		✓																																		
4. Source Materials and prepare samples and test																																				
4A	Find Source of required materials	✓																																		
4B	Collect sampls of materials	✓																																		
4C	Carry out lab trials and cast test samples	✓																																		
4D	28 day data to mature	✓																																		
4E	56 Day Data to mature	✓																																		
5 Analyse Data																																				
5A	Analyse early age and 28 day results																																			
5B	Analayse 56 Day results																																			
6 Prepare Thesis																																				
6B	Present findings at conference																																			

APPENDIX F: MATERIAL TEST CERTFICIATES

Construction Sciences

Construction Sciences Pty Ltd
ABN: 74 128 806 735

Address:
134 Peachey Road,
Luscombe QLD 4207

Laboratory: Beenleigh Laboratory

Holcim

CONCRETE AGGREGATE QUALITY / DURABILITY REPORT

Client	Holcim (Australia)	Report Number:	1552/R/169503-2
Client Address:	[redacted]	Project Number:	1552/P/14
Project:	5117 - Holcim Beenleigh Quarry	Lot Number:	20D
Location:	Beenleigh	Internal Test Request:	1552/T/106175
Supplied To:	Beenleigh Quarry	Client Reference/s:	QBNL20 - 6 Monthly Compliance
Area Description:		Report Date / Page:	21/02/2023 Page 1 of 2

Sample Number	1552/S/674827	Production/Sales	Sales
Sampling Method	AS1141.3.1 Cl 9.4	Sampled From	Stockpile
Date Sampled	7/02/2023		
Specification Number	QBNL20-29/01/2018		
Material Source	Holcim Beenleigh Quarry (RQ: RQ147)	Material Type	Beenleigh 20mm Aggregate (QBNL20)

Test Method	Sieve Size / Test Result	Test Date	Specification Minimum	Result	Specification Maximum	Specification Target [Diff]
AS1141.11.1	Particle Size Distribution (% passing)	07/02/2023				
	26.5mm		100	**100**	100	100 [0]
	19.0mm		88	**96**	100	94 [2]
	13.2mm		35	**47**	51	44 [3]
	9.5mm		0	**10**	14	8 [2]
	6.7mm		0	**4**	6	3 [1]
	4.75mm		0	**3**	5	2 [1]
	2.36mm		0	**3**	4	2 [1]
	0.075mm		0	**2**	2	2 [0]
AS1141.24	Sodium Sulphate Soundness	17/02/2023				
	19.0mm - 13.2mm			**0.1**		
	13.2mm - 9.5mm			**0.1**		
	9.5mm - 4.75mm			**0.2**		
	Total Weighted Loss (%)			**0.1**		
AS1141.4	Bulk Density - Uncompacted (t/m^3)	18/02/2023		**1.49**		
	Bulk Density - Compacted (t/m^3)			**1.60**		
Q208B	Degradation Factor (%)	16/02/2023		**76**		
AS1141.15	Flakiness Index (%)	07/02/2023		**17**	25	20
AS1141.14	Misshapen Particles (%)	07/02/2023		**2**		
	Calliper Ratio			**3:1**		
	Flat Particles (%)			**1.4**		
	Elongated Particles (%)			**0.0**		
	Flat and Elongated Particles (%)			**0.0**		
AS1141.6.1	Apparent Particle Density (t/m^3)	18/02/2023		**2.72**		
	Particle Density (Dry) (t/m^3)			**2.69**		
	Particle Density (SSD) (t/m^3)			**2.70**		
	Water Absorption (%)			**0.4**		
AS1141.32	Weak Particles (%)	18/02/2023		**0.2**		

Remarks: Re-Issued Report Replaces Report No 1552/R/169503-1 (reason: Added results)., Sampling locations selected by client.

NATA

Accredited for compliance with ISO/IEC 17025 – Testing

Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

Approved Signatory: Anthony Dowden

Form ID: I01Rep Rev 1

Construction Sciences

Construction Sciences Pty Ltd
ABN: 74 128 806 735

Address:
134 Peachey Road,
Luscombe QLD 4207

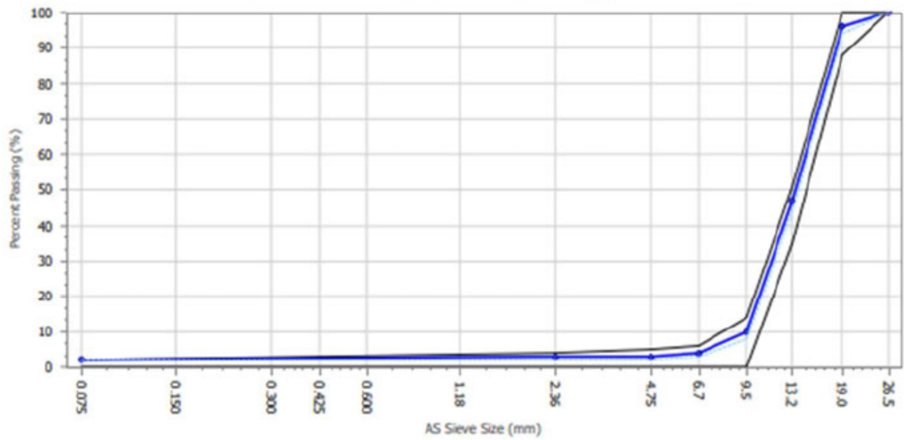
Laboratory: Beenleigh Laboratory

Holcim

CONCRETE AGGREGATE QUALITY / DURABILITY REPORT

Client:	Holcim (Australia)	Report Number:	1552/R/169503-2
Client Address:	[redacted]	Project Number:	1552/P/14
Project:	5117 - Holcim Beenleigh Quarry	Lot Number:	20D
Location:	Beenleigh	Internal Test Request:	1552/T/106175
Supplied To:	Beenleigh Quarry	Client Reference/s:	QBNL20 - 6 Monthly Compliance
Area Description:		Report Date / Page:	21/02/2023 Page 2 of 2

PARTICLE SIZE DISTRIBUTION GRAPH - 1552/S/674827



Method / Test	Test Details
AS1141.11.1 / Washed State:	Washed
AS1141.4 / Test Moisture Condition:	Dried
AS1141.4 / Nominal Size (mm):	20.0
Q208B / Wash Water State:	Not Clear
AS1141.15 / Drying Method:	Oven
AS1141.32 / Passing 2.36mm (%):	1

Remarks	Re-Issued Report Replaces Report No 1552/R/169503-1 (reason: Added results)., Sampling locations selected by client.

NATA

Accredited for compliance with ISO/IEC 17025 - Testing

Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

Approved Signatory: Anthony Dowden

Form ID: I01Rep Rev 1

Construction Sciences

Construction Sciences Pty Ltd
ABN: 74 128 806 735

Address:
134 Peachey Road,
Luscombe QLD 4207

Laboratory: Beenleigh Laboratory

Holcim

CONCRETE AGGREGATE QUALITY / DURABILITY REPORT

Client:	Holcim (Australia)	Report Number:	1552/R/169504-2
Client Address:	[redacted]	Project Number:	1552/P/14
Project:	5117 - Holcim Beenleigh Quarry	Lot Number:	10A
Location:	Beenleigh	Internal Test Request:	1552/T/106176
Supplied To:	Beenleigh Quarry	Client Reference/s:	QBNL10 - 6 Monthly Compliance
Area Description:		Report Date / Page:	17/02/2023 Page 1 of 2

Sample Number	1552/S/674828	Production/Sales	Sales
Sampling Method	AS1141.3.1 Cl 9.4	Sampled From	Stockpile
Date Sampled	7/02/2023		
Specification Number	QBNL10-29/01/2018		
Material Source	Holcim Beenleigh Quarry (RQ: RQ147)	Material Type	Beenleigh 10mm Aggregate (QBNL10)

Test Method	Sieve Size / Test Result	Test Date	Specification Minimum	Result	Specification Maximum	Specification Target [Diff]
AS1141.11.1	Particle Size Distribution (% passing)	07/02/2023				
	13.2mm		100	**100**	100	100 [0]
	9.5mm		78	**87**	94	84 [3]
	6.7mm		27	**37**	43	35 [2]
	4.75mm		0	**8**	12	8 [0]
	2.36mm		0	**4**	5	3 [1]
	0.075mm		0	**2**	2	1 [1]
AS1141.24	Sodium Sulphate Soundness	17/02/2023				
	13.2mm - 9.5mm			**0.2**		
	9.5mm - 4.75mm			**0.1**		
	Total Weighted Loss (%)			**0.1**		
AS1141.4	Bulk Density - Uncompacted (t/m³)	14/02/2023		**1.45**		
	Bulk Density - Compacted (t/m³)			**1.56**		
Q208B	Degradation Factor (%)	16/02/2023		**74**		
AS1141.15	Flakiness Index (%)	07/02/2023		**18**	25	20
AS1141.14	Misshapen Particles (%)	07/02/2023		**4**		
	Calliper Ratio			**3:1**		
	Flat Particles (%)			**3.8**		
	Elongated Particles (%)			**0.0**		
	Flat and Elongated Particles (%)			**0.0**		
AS1141.6.1	Apparent Particle Density (t/m³)	16/02/2023		**2.72**		
	Particle Density (Dry) (t/m³)			**2.68**		
	Particle Density (SSD) (t/m³)			**2.69**		
	Water Absorption (%)			**0.6**		
AS1141.32	Weak Particles (%)	16/02/2023		**0.0**		

Remarks: Re-issued Report Replaces Report No 1552/R/169504-1 (reason: Added results)., Sampling locations selected by client.

NATA

Accredited for compliance with ISO/IEC 17025 – Testing

Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

Approved Signatory: Anthony Dowden

Form ID: I01Rep Rev 1

Construction Sciences

Construction Sciences Pty Ltd
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134 Peachey Road,
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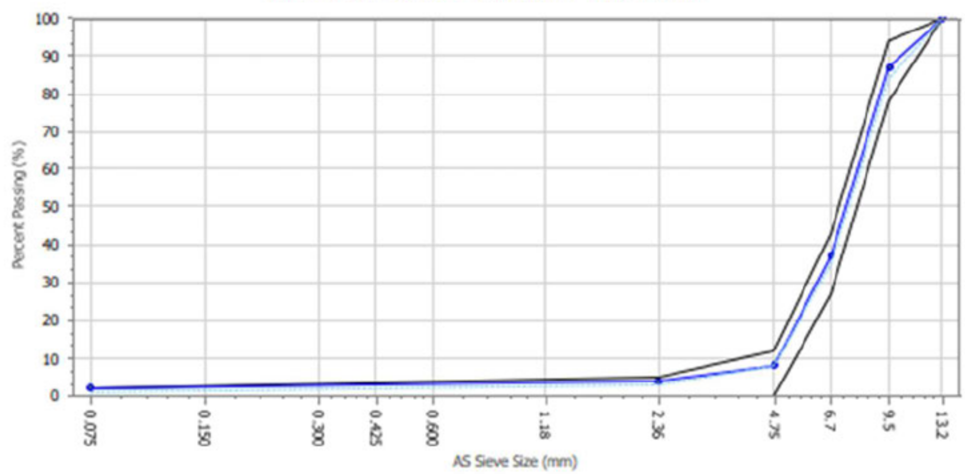
Laboratory: Beenleigh Laboratory

Holcim

CONCRETE AGGREGATE QUALITY / DURABILITY REPORT

Client:	Holcim (Australia)	Report Number:	1552/R/169504-2
Client Address:	[redacted]	Project Number:	1552/P/14
Project:	5117 - Holcim Beenleigh Quarry	Lot Number:	10A
Location:	Beenleigh	Internal Test Request:	1552/T/106176
Supplied To:	Beenleigh Quarry	Client Reference/s:	QBNL10 - 6 Monthly Compliance
Area Description:		Report Date / Page:	17/02/2023 Page 2 of 2

PARTICLE SIZE DISTRIBUTION GRAPH - 1552/S/674828



Method / Test	Test Details
AS1141.11.1 / Washed State:	Washed
AS1141.4 / Test Moisture Condition:	Dried
AS1141.4 / Nominal Size (mm):	10.0
Q208B / Wash Water State:	Not Clear
AS1141.15 / Drying Method:	Oven
AS1141.32 / Passing 2.36mm (%):	2

Remarks	Re-Issued Report Replaces Report No 1552/R/169504-1 (reason: Added results)., Sampling locations selected by client.

NATA

Accredited for compliance with ISO/IEC 17025 – Testing

Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

Approved Signatory: Anthony Dowden

Form ID: I01Rep Rev 1

Construction Sciences

Construction Sciences Pty Ltd
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Laboratory: Beenleigh Laboratory

Holcim

SAND REPORT

Client:	Holcim (Australia)	Report Number:	1552/R/169903-1
Client Address:	[redacted]	Project Number:	1552/P/14
Project:	5117 - Holcim Beenleigh Quarry	Lot Number:	2E
Location:	Beenleigh	Internal Test Request:	1552/T/106344
Supplied To:	Beenleigh Quarry	Client Reference/s:	QBNLMS - Lot 2E
Area Description:		Report Date / Page:	15/03/2023 Page 1 of 2

Sample Number	1552/S/675231	Production/Sales	Sales
Sampling Method	AS1141.3.1 Cl 9.4	Sampled From	Stockpile
Date Sampled	14/03/2023		
Specification Number	QBNLMS-06/01/2014		
Material Source	Holcim Beenleigh Quarry (RQ: RQ147)	Material Type	Beenleigh Manufactured Sand (QBNLMS)

Test Method	Sieve Size / Test Result	Test Date	Specification Minimum	Result	Specification Maximum	Specification Target [Diff]
AS1141.11.1	Particle Size Distribution (% passing)	15/03/2023				
	6.7mm		100	**100**	100	100 [0]
	4.75mm		95	**98**	100	98 [0]
	2.36mm		65	**77**	85	75 [2]
	1.18mm		40	**47**	60	50 [-3]
	0.600mm		30	**33**	42	36 [-3]
	0.425mm			**29**		
	0.300mm		19	**25**	29	24 [1]
	0.150mm		14	**17**	20	17 [0]
	0.075mm		9	**13**	15	12 [1]
AS1289.2.1.1	Moisture Content (%)	15/03/2023		**4.0**		

Remarks: Supplement to Simplified Report Number 230315A00956, Sampling locations selected by client.

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Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

Approved Signatory: Anthony Dowden
Form ID: I07Rep Rev 1

Construction Sciences

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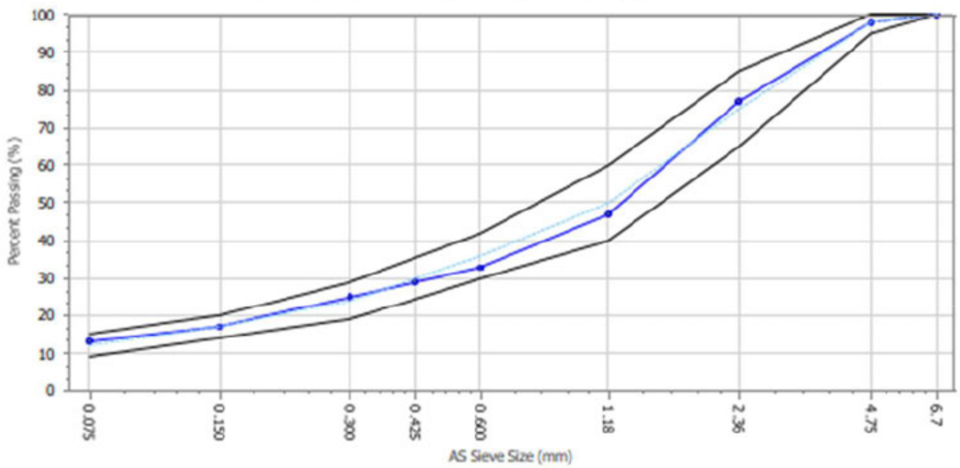
Laboratory: Beenleigh Laboratory

SAND REPORT

Client:	Holcim (Australia)	Report Number:	1552/R/169903-1
Client Address:	[redacted]	Project Number:	1552/P/14
Project:	5117 - Holcim Beenleigh Quarry	Lot Number:	2E
Location:	Beenleigh	Internal Test Request:	1552/T/106344
Supplied To:	Beenleigh Quarry	Client Reference/s:	QBNLMS - Lot 2E
Area Description:		Report Date / Page:	15/03/2023 Page 2 of 2

PARTICLE SIZE DISTRIBUTION GRAPH - 1552/S/675231



Method / Test	Test Details
AS1141.11.1 / Washed State:	Washed

Remarks	Supplement to Simplified Report Number 230315AD0956, Sampling locations selected by client.

NATA

Accredited for compliance with ISO/IEC 17025 – Testing

Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

Approved Signatory: Anthony Dowden
Form ID: I07Rep Rev 1

Construction Sciences

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Laboratory: Beenleigh Laboratory

Holcim

SAND REPORT

Client:	Holcim (Australia)	Report Number:	1552/R/170418-1
Client Address:	[redacted]	Project Number:	1552/P/14
Project:	5122 - Holcim Lytton Sands	Lot Number:	Sales
Location:	Beenleigh	Internal Test Request:	1552/T/106534
Supplied To:	Lytton Sand	Client Reference/s:	Lytton Sand Sales
Area Description:		Report Date / Page:	3/05/2023 Page 1 of 2

Sample Number	1552/S/675683	Production/Sales	Sales
Sampling Method	Tested As Received	Sampled From	Stockpile
Date Sampled	3/05/2023		
Specification Number	QLYTFS-07/10/2020		
Material Source	Holcim Lytton Sand Plant (RQ: RQ152)	Material Type	Fine Sand (QLYTFS)

Test Method	Sieve Size / Test Result	Test Date	Specification Minimum	Result	Specification Maximum	Specification Target [Diff]
AS1141.11.1	Particle Size Distribution (% passing)	03/05/2023				
	4.75mm		100	**100**	100	
	2.36mm		97	**100**	100	
	1.18mm		96	**100**	100	
	0.600mm		95	**99**	100	
	0.300mm		55	**67**	85	
	0.150mm		0	**1**	5	
	0.075mm		0	**0**	2	
AS1141.33	Clay and Fine Silt (%)	03/05/2023		**2**		
AS1289.2.1.1	Moisture Content (%)	03/05/2023		**4.0**		

Remarks: Supplement to Simplified Report Number 230503FG1320, Results apply to the sample/s as received.,

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Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

Approved Signatory: Fiona Miren Gonzales

Form ID: I07Rep Rev 1

Construction Sciences

Construction Sciences Pty Ltd
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Luscombe QLD 4207

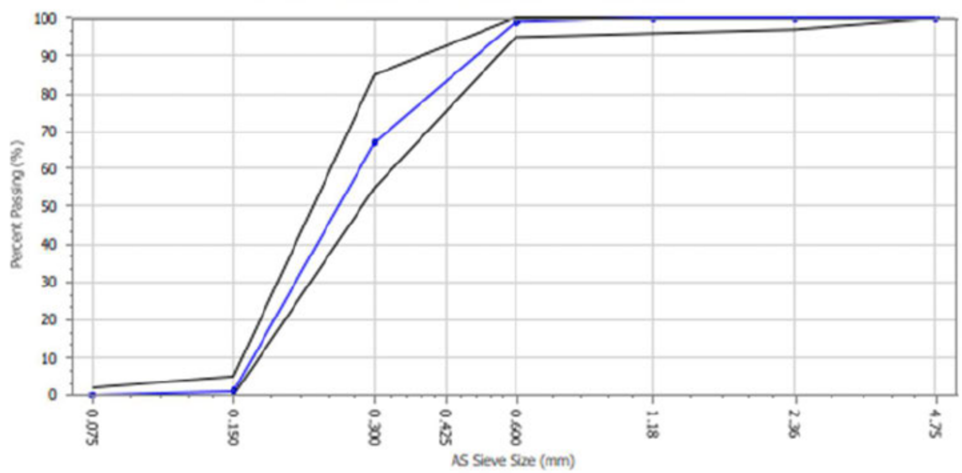
Laboratory: Beenleigh Laboratory

Holcim

SAND REPORT

Client:	Holcim (Australia)	Report Number:	1552/R/170418-1
Client Address:	[redacted]	Project Number:	1552/P/14
Project:	5122 - Holcim Lytton Sands	Lot Number:	Sales
Location:	Beenleigh	Internal Test Request:	1552/T/106534
Supplied To:	Lytton Sand	Client Reference/s:	Lytton Sand Sales
Area Description:		Report Date / Page:	3/05/2023 Page 2 of 2

PARTICLE SIZE DISTRIBUTION GRAPH - 1552/S/675683



Method / Test	Test Details
AS1141.11.1 / Washed State:	Washed
AS1141.33 / Test Methodology Used:	Standard

Remarks	Supplement to Simplified Report Number 230503FG1320, Results apply to the sample/s as received.,

NATA

Accredited for compliance with ISO/IEC 17025 - Testing

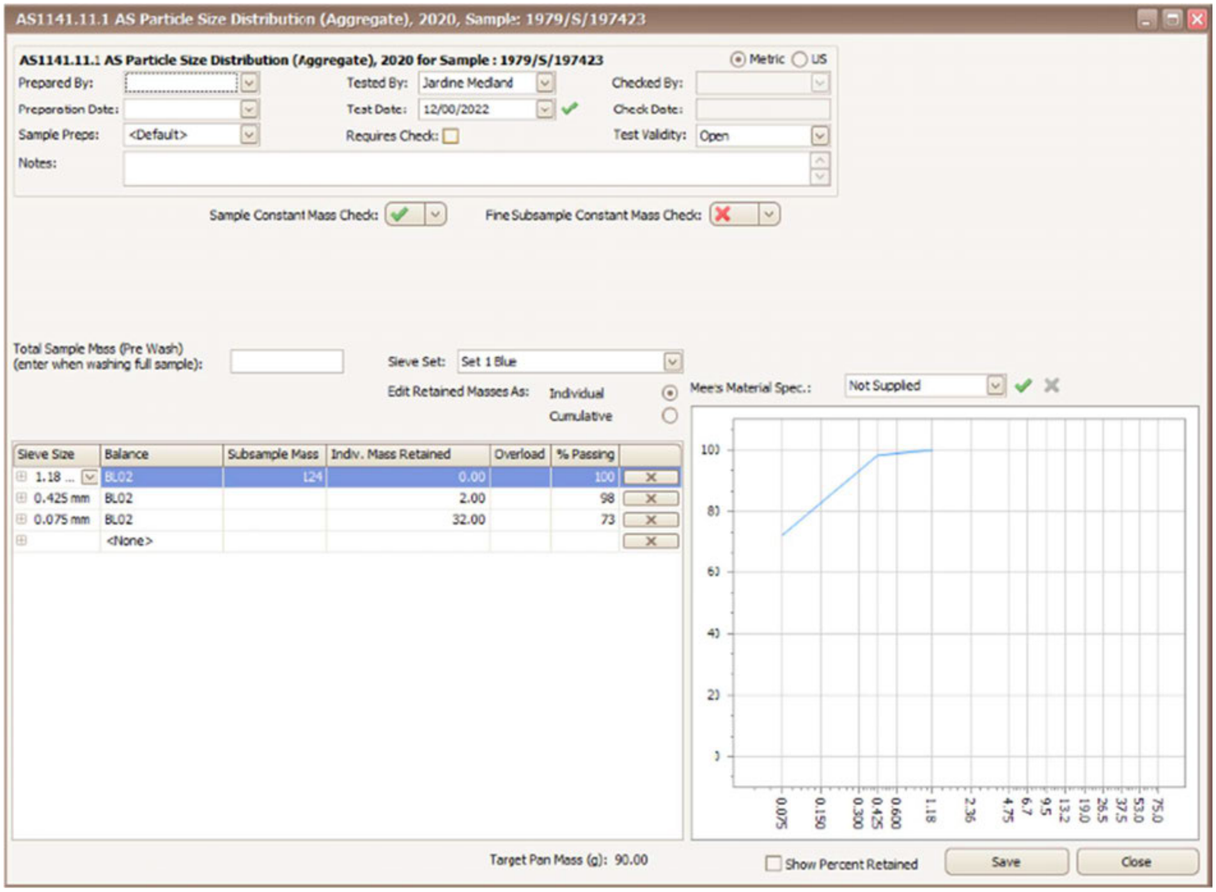
Accreditation Number: 1986

Corporate Site Number: 1552

[redacted]

Approved Signatory: Fiona Miren Gonzales

Form ID: I07Rep Rev 1



AS1141.11.1 AS Particle Size Distribution (Aggregate), 2020, Sample: 1979/S/197423

AS1141.11.1 AS Particle Size Distribution (Aggregate), 2020 for Sample : 1979/S/197423 ⦿ Metric ○ US

Prepared By:		Tested By:	Jardine Medland	Checked By:	
Preparation Date:		Test Date:	12/08/2022	Check Date:	
Sample Preps:	<Default>	Requires Check:	☐	Test Validity:	Open
Notes:					

Sample Constant Mass Check: ✔ Fine Subsample Constant Mass Check: ✘

Total Sample Mass (Pre Wash) (enter when washing full sample):

Sieve Set: Set 1 Blue

Edit Retained Masses As: Individual ⦿ Cumulative ○

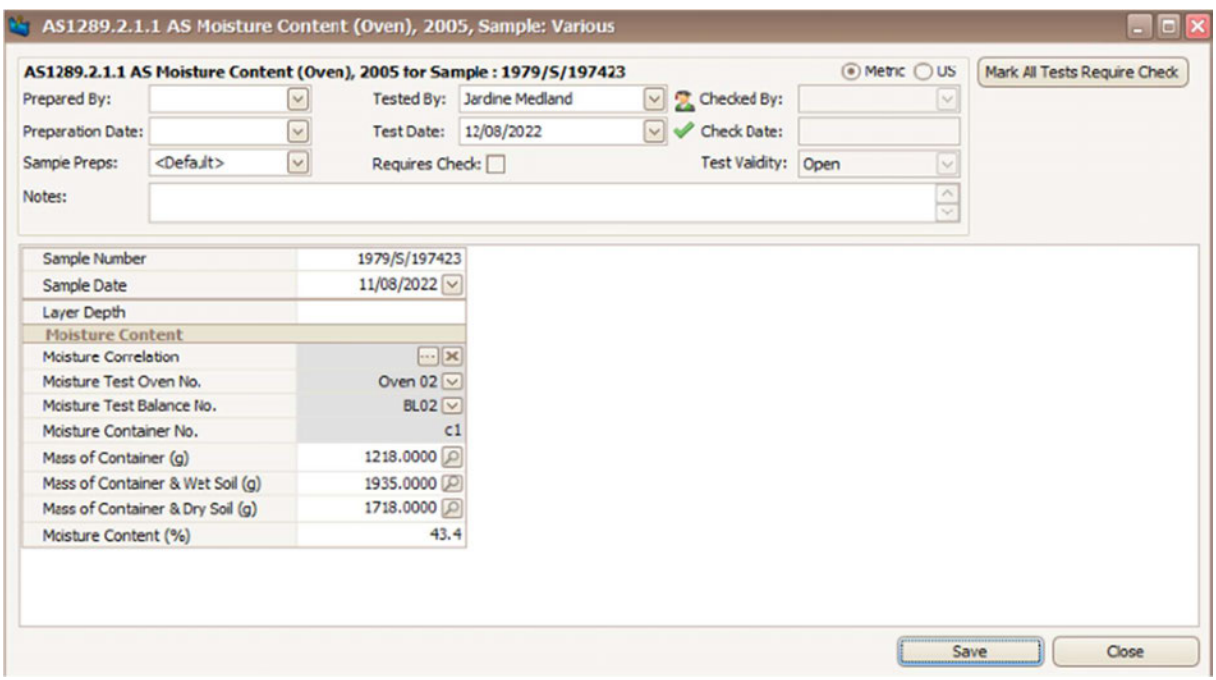
Meets Material Spec.: Not Supplied

Sieve Size	Balance	Subsample Mass	Indiv. Mass Retained	Overload	% Passing
1.18 ...	BL02	124	0.00		100
0.425 mm	BL02		2.00		98
0.075 mm	BL02		32.00		73
	<None>				

Target Pan Mass (g): 90.00

☐ Show Percent Retained

Save Close



AS1289.2.1.1 AS Moisture Content (Oven), 2005, Sample: Various

AS1289.2.1.1 AS Moisture Content (Oven), 2005 for Sample : 1979/S/197423 ⦿ Metric ○ US

Mark All Tests Require Check

Prepared By:		Tested By:	Jardine Medland	Checked By:	
Preparation Date:		Test Date:	12/08/2022	Check Date:	
Sample Preps:	<Default>	Requires Check:	☐	Test Validity:	Open
Notes:					

Sample Number	1979/S/197423
Sample Date	11/08/2022
Layer Depth	
Moisture Content	
Moisture Correlation	
Moisture Test Oven No.	Oven 02
Moisture Test Balance No.	BL02
Moisture Container No.	c1
Mass of Container (g)	1218.0000
Mass of Container & Wet Soil (g)	1935.0000
Mass of Container & Dry Soil (g)	1718.0000
Moisture Content (%)	43.4

Save Close

APPENDIX G: TEST CERTIFICATES FOR CONCRETE

Construction Sciences

Construction Sciences Pty Ltd
ABN: 74 128 806 735
Address:
57 Mudgee Street,
Kingston QLD 4114

Laboratory: Brisbane South Laboratory
Phone: 07 3865 3212 Fax: 07 3320 8599
Email: Brisbane@constructionsciences.net
Website: www.constructionsciences.net

CONCRETE COMPRESSIVE STRENGTH REPORT

Page 1 of 1

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	Control 1	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/75648-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/10/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38994
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-1	Weather:	Controlled Environment	Structure/s:	Mix-1		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.9, AS1012.12.1			Plant Code / Mix Code:	N/A / Control 1		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Specimen Dimensions (mm) Height	Mass per Unit Volume (kg/m³)	Compressive Strength (MPa)	Test Remarks
1979/C/196460	Mix-1	08:46	22	100	23	10/08/2022	23 hours	DRY	100.2	195	2320	**12.0**	
1979/C/196461	Mix-1	08:46	22	100	23	12/08/2022	3 days	45 hours - STD	100.0	196	2340	**30.0**	
1979/C/196462	Mix-1	08:46	22	100	23	16/08/2022	7 days	6 days - STD	100.2	199	2320	**37.5**	
1979/C/196463	Mix-1	08:46	22	100	23	6/09/2022	28 days	27 days - STD	99.5	198	2340	**46.0**	
1979/C/196464	Mix-1	08:46	22	100	23	6/09/2022	28 days	27 days - STD	100.1	199	2340	**47.5**	
1979/C/196465	Mix-1	08:46	22	100	23	4/10/2022	56 days	55 days - STD	99.9	198	2340	**44.5**	
1979/C/196466	Mix-1	08:46	22	100	23	4/10/2022	56 days	55 days - STD	100.0	197	2340	**48.0**	

Note 1: Temperature Zone - Standard Tropical Zone
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 3: Sampling from N/A
Note 4: Ground End used on specimens unless otherwise stated.
Note 5: All specimens are measured and weighed uncapped.
Note 6: This report is for concrete sampled and tested by this laboratory.

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 1979

[redacted]

Approved Signatory: Joseph Comiskey
Form ID: W84Rep Rev 1

Remarks

Construction Sciences

Construction Sciences Pty Ltd
ABN: 74 128 806 735
Address:
57 Mudgee Street,
Kingston QLD 4114

Laboratory: Brisbane South Laboratory
Phone: 07 3865 3212 **Fax:** 07 3320 8599
Email: Brisbane@constructionsciences.net
Website: www.constructionsciences.net

CONCRETE COMPRESSIVE STRENGTH REPORT

Client: 1552 - Construction Sciences Beenleigh
Client Address: [redacted]
Supplied To: n/a
Project: James Moller
Supplier: Laboratory Trial
Client Reference/s: Mix-2

Concrete Class: FW1
Specified Strength (MPa): 0.0
Lot Number:
Sampled By: Jardine Medland
Sampling Location: N/A
Weather: Controlled Environment

Date Sampled / Cast: 9/08/2022
Nom. Slump / Tol (mm): 120 / +/-30
Agg. Corr. Factor (%):
Air Cont. Comp Method:
Sampling Method:
Structure/s: Mix-2

Report Number: 1979/R/75649-1
Project Number: 1979/P/2295
Report Date: 6/10/2022
Test Request No: 1979/T/38995
Constr. Element: -

Test Procedures: AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.9, AS1012.12.1
Plant Code / Mix Code: N/A / FW1

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Specimen Dimensions (mm) Height	Mass per Unit Volume (kg/m³)	Compressive Strength (MPa)	Test Remarks
1979/C/196473	Mix-2	09:22	22	150	23	10/08/2022	24 hours	DRY	99.9	198	2340	**13.0**	
1979/C/196474	Mix-2	09:22	22	150	23	12/08/2022	3 days	45 hours - STD	99.9	198	2360	**29.0**	
1979/C/196475	Mix-2	09:22	22	150	23	16/08/2022	7 days	6 days - STD	100.0	199	2360	**37.0**	
1979/C/196476	Mix-2	09:22	22	150	23	6/09/2022	28 days	27 days - STD	100.0	199	2360	**48.5**	
1979/C/196477	Mix-2	09:22	22	150	23	6/09/2022	28 days	27 days - STD	99.9	198	2360	**52.0**	
1979/C/196478	Mix-2	09:22	22	150	23	4/10/2022	56 days	55 days - STD	100.0	199	2360	**53.5**	
1979/C/196479	Mix-2	09:22	22	150	23	4/10/2022	56 days	55 days - STD	99.7	199	2380	**53.5**	

Note 1: Temperature Zone - Standard Tropical Zone
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 3: Sampling from N/A
Note 4: Ground End used on specimens unless otherwise stated.
Note 5: All specimens are measured and weighed uncapped.
Note 6: This report is for concrete sampled and tested by this laboratory.

Accredited for compliance with ISO/IEC 17025 – Testing
Accreditation Number: 1986
Corporate Site Number: 1979

[redacted]
Approved Signatory: Joseph Comiskey
Form ID: W84Rep Rev 1

Remarks

Construction Sciences

Construction Sciences Pty Ltd
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Laboratory: Brisbane South Laboratory
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Email: Brisbane@constructionsciences.net
Website: www.constructionsciences.net

CONCRETE COMPRESSIVE STRENGTH REPORT

Client: 1552 - Construction Sciences Beenleigh
Client Address: [redacted]
Supplied To: n/a
Project: James Moller
Supplier: Laboratory Trial
Client Reference/s: Mix-3

Concrete Class: FW2
Specified Strength (MPa): 0.0
Lot Number:
Sampled By: Jardine Medland
Sampling Location: N/A
Weather: Controlled Environment

Date Sampled / Cast: 9/08/2022
Nom. Slump / Tol (mm): 120 / +/-30
Agg. Corr. Factor (%):
Air Cont. Comp Method:
Sampling Method:
Structure/s: Mix-3

Report Number: 1979/R/75650-1
Project Number: 1979/P/2295
Report Date: 6/10/2022
Test Request No: 1979/T/38996
Constr. Element: -

Test Procedures: AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.9, AS1012.12.1
Plant Code / Mix Code: N/A / FW2

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Specimen Dimensions (mm) Height	Mass per Unit Volume (kg/m³)	Compressive Strength (MPa)	Test Remarks
1979/C/196486	Mix-3	09:55	22	130	22	10/08/2022	24 hours	DRY	99.8	197	2320	**10.5**	
1979/C/196487	Mix-3	09:55	22	130	22	12/08/2022	3 days	45 hours - STD	99.9	196	2340	**25.0**	
1979/C/196488	Mix-3	09:55	22	130	22	16/08/2022	7 days	6 days - STD	99.9	198	2320	**34.5**	
1979/C/196489	Mix-3	09:55	22	130	22	6/09/2022	28 days	27 days - STD	99.9	197	2340	**46.5**	
1979/C/196490	Mix-3	09:55	22	130	22	6/09/2022	28 days	27 days - STD	100.1	197	2340	**47.5**	
1979/C/196491	Mix-3	09:55	22	130	22	4/10/2022	56 days	55 days - STD	99.9	198	2340	**52.5**	
1979/C/196492	Mix-3	09:55	22	130	22	4/10/2022	56 days	55 days - STD	100.1	196	2360	**53.0**	

Note 1: Temperature Zone - Standard Tropical Zone
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 3: Sampling from N/A
Note 4: Ground End used on specimens unless otherwise stated.
Note 5: All specimens are measured and weighed uncapped.
Note 6: This report is for concrete sampled and tested by this laboratory.

Accredited for compliance with ISO/IEC 17025 – Testing
Accreditation Number: 1986
Corporate Site Number: 1979

[redacted]
Approved Signatory: Joseph Comiskey
Form ID: W84Rep Rev 1

Remarks

Construction Sciences

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Website: www.constructionsciences.net

CONCRETE COMPRESSIVE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FW3	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/75652-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/10/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38997
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-4	Weather:	Controlled Environment	Structure/s:	Mix-4		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.9, AS1012.12.1			Plant Code / Mix Code:	N/A / FW3		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Height	Mass per Unit Volume (kg/m³)	Compressive Strength (MPa)	Test Remarks
1979/C/196499	Mix-4	10:46	22	130	21	10/08/2022	24 hours	DRY	99.8	196	2280	**9.2**	
1979/C/196500	Mix-4	10:46	22	130	21	12/08/2022	3 days	45 hours - STD	100.3	198	2300	**24.0**	
1979/C/196501	Mix-4	10:46	22	130	21	16/08/2022	7 days	6 days - STD	99.9	197	2300	**32.5**	
1979/C/196502	Mix-4	10:46	22	130	21	6/09/2022	28 days	27 days - STD	100.1	199	2300	**48.5**	
1979/C/196503	Mix-4	10:46	22	130	21	6/09/2022	28 days	27 days - STD	99.9	197	2320	**47.0**	
1979/C/196504	Mix-4	10:46	22	130	21	4/10/2022	56 days	55 days - STD	100.0	197	2300	**52.0**	
1979/C/196505	Mix-4	10:46	22	130	21	4/10/2022	56 days	55 days - STD	100.1	197	2300	**51.0**	

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: Ground End used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
Note 6: This report is for concrete sampled and tested by this laboratory.

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 1979

[redacted]

Approved Signatory: Joseph Comiskey
Form ID: W84Rep Rev 1

Remarks

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CONCRETE COMPRESSIVE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FW4	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/75653-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/10/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38998
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-5	Weather:	Controlled Environment	Structure/s:	Mix-5		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.9, AS1012.12.1			Plant Code / Mix Code:	N/A / FW4		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Height	Mass per Unit Volume (kg/m³)	Compressive Strength (MPa)	Test Remarks
1979/C/196512	Mix-5	11:24	22	130	22	10/08/2022	24 hours	DRY	100.2	197	2240	**9.1**	
1979/C/196513	Mix-5	11:24	22	130	22	12/08/2022	3 days	44 hours - STD	99.6	199	2280	**20.0**	
1979/C/196514	Mix-5	11:24	22	130	22	16/08/2022	7 days	6 days - STD	100.2	198	2260	**30.5**	
1979/C/196515	Mix-5	11:24	22	130	22	6/09/2022	28 days	27 days - STD	100.1	196	2300	**44.5**	
1979/C/196516	Mix-5	11:24	22	130	22	6/09/2022	28 days	27 days - STD	100.4	197	2280	**43.0**	
1979/C/196517	Mix-5	11:24	22	130	22	4/10/2022	56 days	55 days - STD	100.1	196	2300	**47.0**	
1979/C/196518	Mix-5	11:24	22	130	22	4/10/2022	56 days	55 days - STD	100.7	197	2240	**50.0**	

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: Ground End used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
Note 6: This report is for concrete sampled and tested by this laboratory.

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NATA

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Remarks

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CONCRETE COMPRESSIVE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA1	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/75654-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/10/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39102
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-6	Weather:	Controlled Environment	Structure/s:	Mix-6		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.9, AS1012.12.1			Plant Code / Mix Code:	N/A / FA1		

Sample No	Batch No	Time	Concrete	Slump	Initial	Date of Test	Test Age	Curing	Specimen Dimensions (mm)		Mass per Unit Volume	Compressive	Test Remarks
		Cast	Temp (°C)	(mm)	Curing (hrs)			Conditions	Avg Diameter	Height	(kg/m³)	Strength (MPa)	
1979/C/196940	Mix-6	09:31	22	130	22	11/08/2022	24 hours	DRY	100.2	197	2320	**11.0**	
1979/C/196941	Mix-6	09:31	22	130	22	13/08/2022	3 days	46 hours - STD	99.9	197	2360	**27.0**	
1979/C/196942	Mix-6	09:31	22	130	22	17/08/2022	7 days	6 days - STD	99.9	198	2360	**34.5**	
1979/C/196943	Mix-6	09:31	22	130	22	7/09/2022	28 days	27 days - STD	100.3	198	2360	**43.5**	
1979/C/196944	Mix-6	09:31	22	130	22	7/09/2022	28 days	27 days - STD	99.8	199	2360	**44.5**	
1979/C/196945	Mix-6	09:31	22	130	22	5/10/2022	56 days	55 days - STD	100.4	196	2360	**48.0**	
1979/C/196946	Mix-6	09:31	22	130	22	5/10/2022	56 days	55 days - STD	100.1	196	2360	**45.5**	

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: Ground End used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
Note 6: This report is for concrete sampled and tested by this laboratory.

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CONCRETE COMPRESSIVE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA2	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/75655-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/10/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39104
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-7	Weather:	Controlled Environment	Structure/s:	Mix-7		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.9, AS1012.12.1			Plant Code / Mix Code:	N/A / FA2		

Sample No	Batch No	Time	Concrete	Slump	Initial	Date of Test	Test Age	Curing	Specimen Dimensions (mm)		Mass per Unit Volume	Compressive	Test Remarks
		Cast	Temp (°C)	(mm)	Curing (hrs)			Conditions	Avg Diameter	Height	(kg/m³)	Strength (MPa)	
1979/C/196957	Mix-7	10:08	22	130	22	11/08/2022	24 hours	DRY	100.0	197	2320	**10.0**	
1979/C/196958	Mix-7	10:08	22	130	22	13/08/2022	3 days	46 hours - STD	100.2	196	2340	**25.0**	
1979/C/196959	Mix-7	10:08	22	130	22	17/08/2022	7 days	6 days - STD	99.9	198	2340	**32.0**	
1979/C/196960	Mix-7	10:08	22	130	22	7/09/2022	28 days	27 days - STD	100.3	199	2320	**46.0**	
1979/C/196961	Mix-7	10:08	22	130	22	7/09/2022	28 days	27 days - STD	100.3	199	2320	**46.0**	
1979/C/196962	Mix-7	10:08	22	130	22	5/10/2022	56 days	55 days - STD	100.1	198	2340	**50.5**	
1979/C/196963	Mix-7	10:08	22	130	22	5/10/2022	56 days	55 days - STD	99.7	198	2340	**50.5**	

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: Ground End used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
Note 6: This report is for concrete sampled and tested by this laboratory.

Accredited for compliance with ISO/IEC 17025 – Testing

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Remarks

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CONCRETE COMPRESSIVE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA3	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/75656-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/10/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39105
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-8	Weather:	Controlled Environment	Structure/s:	Mix-8		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.9, AS1012.12.1			Plant Code / Mix Code:	N/A / FA3		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Height	Mass per Unit Volume (kg/m³)	Compressive Strength (MPa)	Test Remarks
1979/C/196970	Mix-8	10:36	22	130	21	11/08/2022	24 hours	DRY	100.5	196	2280	**8.8**	
1979/C/196971	Mix-8	10:36	22	130	21	13/08/2022	3 days	46 hours - STD	100.1	199	2300	**23.0**	
1979/C/196972	Mix-8	10:36	22	130	21	17/08/2022	7 days	6 days - STD	99.9	199	2300	**31.0**	
1979/C/196973	Mix-8	10:36	22	130	21	7/09/2022	28 days	27 days - STD	99.9	198	2320	**45.0**	
1979/C/196974	Mix-8	10:36	22	130	21	7/09/2022	28 days	27 days - STD	99.8	198	2300	**45.0**	
1979/C/196975	Mix-8	10:36	22	130	21	5/10/2022	56 days	55 days - STD	99.9	197	2320	**48.0**	
1979/C/196976	Mix-8	10:36	22	130	21	5/10/2022	56 days	55 days - STD	99.7	198	2320	**49.0**	

Note 1: Temperature Zone - Standard Tropical Zone
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 3: Sampling from N/A
Note 4: Ground End used on specimens unless otherwise stated.
Note 5: All specimens are measured and weighed uncapped.
Note 6: This report is for concrete sampled and tested by this laboratory.

Accredited for compliance with ISO/IEC 17025 – Testing

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Form ID: W84Rep Rev 1

Remarks

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CONCRETE COMPRESSIVE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA4	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/75657-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/10/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39106
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-9	Weather:	Controlled Environment	Structure/s:	Mix-9		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.9, AS1012.12.1			Plant Code / Mix Code:	N/A / FA4		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Height	Mass per Unit Volume (kg/m³)	Compressive Strength (MPa)	Test Remarks
1979/C/196983	Mix-9	11:25	22	130	21	11/08/2022	24 hours	DRY	100.0	199	2240	**7.8**	
1979/C/196984	Mix-9	11:25	22	130	21	13/08/2022	3 days	47 hours - STD	100.0	197	2280	**21.0**	
1979/C/196985	Mix-9	11:25	22	130	21	17/08/2022	7 days	6 days - STD	100.2	199	2240	**28.5**	
1979/C/196986	Mix-9	11:25	22	130	21	7/09/2022	28 days	27 days - STD	100.1	197	2260	**45.0**	Sulphur Cap
1979/C/196987	Mix-9	11:25	22	130	21	7/09/2022	28 days	27 days - STD	99.6	200	2280	**44.5**	
1979/C/196988	Mix-9	11:25	22	130	21	5/10/2022	56 days	55 days - STD	99.8	199	2280	**47.5**	
1979/C/196989	Mix-9	11:25	22	130	21	5/10/2022	56 days	55 days - STD	100.0	197	2280	**45.0**	

Note 1: Temperature Zone - Standard Tropical Zone
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 3: Sampling from N/A
Note 4: Ground End used on specimens unless otherwise stated.
Note 5: All specimens are measured and weighed uncapped.
Note 6: This report is for concrete sampled and tested by this laboratory.

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

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Approved Signatory: Joseph Comiskey
Form ID: W84Rep Rev 1

Remarks

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MODULUS OF RUPTURE REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	Control 1	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/71953-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38994
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-1	Weather:	Controlled Environment	Structure/s:	Mix-1		
Test Procedures:	AS1012.2, AS1012.8.2 (7.4), AS1012.3.1, AS1012.11, AS1012.12.1			Plant Code / Mix Code:	N/A / Control 1		

Sample No	Batch No	Time Cast	Slump (mm)	Initial Curing (hours)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Width	Depth	Span	Mass per Unit Volume (kg/m³)	Modulus of Rupture (MPa)	Test Remarks
1979/C/196468	Mix-1	08:46	100	23	16/08/2022	7 days	6 days - STD	100.[illegible]	100.1	300	2320	**4.1**	Ref: Flex
1979/C/196469	Mix-1	08:46	100	23	6/09/2022	28 days	27 days - STD	100.[illegible]	100.7	300	2320	**5.3**	Ref: Flex
1979/C/196470	Mix-1	08:46	100	23	6/09/2022	28 days	27 days - STD	100.[illegible]	100.3	300	2340	**6.0**	Ref: Flex

Note 1: Temperature Zone - Standard Tropical Zone
Note 2: Curing Conditions: STD = Standard Moist-Curing, MST = Moist, DRY = Dry
Note 3: Sampling from N/A
Note 4: All beams are measured and weighed uncapped.
Note 5: This report is for concrete sampled and tested by this laboratory.

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 1979

[redacted]

Approved Signatory: Joseph Comiskey
Form ID: W86Rep Rev 1

Remarks

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MODULUS OF RUPTURE REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FW1	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/71954-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38995
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-2	Weather:	Controlled Environment	Structure/s:	Mix-2		
Test Procedures:	AS1012.2, AS1012.8.2 (7.4), AS1012.3.1, AS1012.11, AS1012.12.1			Plant Code / Mix Code:	N/A / FWI		

Sample No	Batch No	Time Cast	Slump (mm)	Initial Curing (hours)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Width	Depth	Span	Mass per Unit Volume (kg/m³)	Modulus of Rupture (MPa)	Test Remarks
1979/C/196481	Mix-2	09:22	150	23	16/08/2022	7 days	6 days - STD	100.2	100.1	300	2320	**4.7**	Ref: Flex
1979/C/196482	Mix-2	09:22	150	23	6/09/2022	28 days	27 days - STD	100.7	100.4	300	2360	**5.9**	Ref: Flex
1979/C/196483	Mix-2	09:22	150	23	6/09/2022	28 days	27 days - STD	100.4	100.8	300	2340	**6.6**	Ref: Flex

Note 1: Temperature Zone - Standard Tropical Zone
Note 2: Curing Conditions: STD = Standard Moist-Curing, MST = Moist, DRY = Dry
Note 3: Sampling from N/A
Note 4: All beams are measured and weighed uncapped.
Note 5: This report is for concrete sampled and tested by this laboratory.

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MODULUS OF RUPTURE REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FW2	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/71955-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38996
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-3	Weather:	Controlled Environment	Structure/s:	Mix-3		
Test Procedures:	AS1012.2, AS1012.8.2 (7.4), AS1012.3.1, AS1012.11, AS1012.12.1			Plant Code / Mix Code:	N/A / FW2		

Sample No	Batch No	Time Cast	Slump (mm)	Inital Curing (hours)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Width	Depth	Span	Mass per Unit Volume (kg/m³)	Modulus of Rupture (MPa)	Test Remarks
1979/C/196494	Mix-3	09:55	130	22	16/08/2022	7 days	6 days - STD	99.8	100.1	300	2320	**4.0**	Ref: Flex
1979/C/196495	Mix-3	09:55	130	22	6/09/2022	28 days	27 days - STD	101.1	100.4	300	2320	**5.3**	Ref: Flex
1979/C/196496	Mix-3	09:55	130	22	6/09/2022	28 days	27 days - STD	101.2	99.8	300	2360	**5.2**	Ref: Flex

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: All beams are measured and weighed uncapped.
Note 2: Curing Conditions: STD = Standard Moist-Curing, MST = Moist, DRY = Dry
Note 5: This report is for concrete sampled and testedby this laboratory.
Note 3: Sampling from N/A

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 1979

[redacted]

Approved Signatory: Joseph Comiskey
Form ID: W86RepRev 1

Remarks

Construction Sciences

Construction Sciences Pty Ltd
ABN: 74 128 806 735

Address:
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Laboratory: Brisbane South Laboratory
Phone: 07 3865 3212 Fax: 07 3320 8599

Email: Brisbane@constructionsciences.net
Website: www.constructionsciences.net

MODULUS OF RUPTURE REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FW3	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/71956-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38997
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-4	Weather:	Controlled Environment	Structure/s:	Mix-4		
Test Procedures:	AS1012.2, AS1012.8.2 (7.4), AS1012.3.1, AS1012.11, AS1012.12.1			Plant Code / Mix Code:	N/A / FW3		

Sample No	Batch No	Time Cast	Slump (mm)	Inital Curing (hours)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Width	Depth	Span	Mass per Unit Volume (kg/m³)	Modulus of Rupture (MPa)	Test Remarks
1979/C/196507	Mix-4	10:46	130	21	16/08/2022	7 days	6 days - STD	100.2	100.0	300	2340	**4.2**	Ref: Flex
1979/C/196508	Mix-4	10:46	130	21	6/09/2022	28 days	27 days - STD	100.2	102.1	300	2340	**5.7**	Ref: Flex
1979/C/196509	Mix-4	10:46	130	21	6/09/2022	28 days	27 days - STD	103.5	98.9	300	2300	**6.0**	Ref: Flex

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: All beams are measured and weighed uncapped.
Note 2: Curing Conditions: STD = Standard Moist-Curing, MST = Moist, DRY = Dry
Note 5: This report is for concrete sampled and testedby this laboratory.
Note 3: Sampling from N/A

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MODULUS OF RUPTURE REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FW4	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/71957-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38998
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-5	Weather:	Controlled Environment	Structure/s:	Mix-5		
Test Procedures:	AS1012.2, AS1012.8.2 (7.4), AS1012.3.1, AS1012.11, AS1012.12.1			Plant Code / Mix Code:	N/A / FW4		

Sample No	Batch No	Time	Slump	Initial Curing	Date of Test	Test Age	Curing	Specimen Dimensions (mm)			Mass per Unit Volume	Modulus of Rupture	Test Remarks
		Cast	(mm)	(hours)			Conditions	Width	Depth	Span	(kg/m³)	(MPa)	
1979/C/196520	Mix-5	11:24	130	22	16/08/2022	7 days	6 days - STD	100.1	100.2	300	2300	**4.1**	Ref: Flex
1979/C/196521	Mix-5	11:24	130	22	6/09/2022	28 days	27 days - STD	102.8	99.5	300	2280	**5.0**	Ref: Flex

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: All beams are measured and weighed uncapped.
Note 2: Curing Conditions: STD = Standard Moist-Curing, MST = Moist, DRY = Dry
Note 5: This report is for concrete sampled and testedby this laboratory.
Note 3: Sampling from N/A

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MODULUS OF RUPTURE REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA1	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/72115-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	7/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39102
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-6	Weather:	Controlled Environment	Structure/s:	Mix-6		
Test Procedures:	AS1012.2, AS1012.8.2 (7.4), AS1012.3.1, AS1012.11, AS1012.12.1			Plant Code / Mix Code:	N/A / FA1		

Sample No	Batch No	Time	Slump	Initial Curing	Date of Test	Test Age	Curing	Specimen Dimensions (mm)			Mass per Unit Volume	Modulus of Rupture	Test Remarks
		Cast	(mm)	(hours)			Conditions	Width	Depth	Span	(kg/m³)	(MPa)	
1979/C/196948	Mix-6	09:31	130	22	17/08/2022	7 days	6 days - STD	100.1	100.0	300	2320	**4.0**	Ref: Flex
1979/C/196949	Mix-6	09:31	130	22	7/09/2022	28 days	27 days - STD	100.4	101.2	300	2320	**5.4**	Ref: Flex
1979/C/196950	Mix-6	09:31	130	22	7/09/2022	28 days	27 days - STD	100.6	100.9	300	2300	**5.8**	Ref: Flex

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: All beams are measured and weighed uncapped.
Note 2: Curing Conditions: STD = Standard Moist-Curing, MST = Moist, DRY = Dry
Note 5: This report is for concrete sampled and tested by this laboratory.
Note 3: Sampling from N/A

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MODULUS OF RUPTURE REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA2	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/72116-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	7/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39104
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-7	Weather:	Controlled Environment	Structure/s:	Mix-7		
Test Procedures:	AS1012.2, AS1012.8.2 (7.4), AS1012.3.1, AS1012.11, AS1012.12.1			Plant Code / Mix Code:	N/A / FA2		

Sample No	Batch No	Time Cast	Slump (mm)	Inital Curing (hours)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Width	Depth	Span	Mass per Unit Volume (kg/m³)	Modulus of Rupture (MPa)	Test Remarks
1979/C/196965	Mix-7	10:08	130	22	17/08/2022	7 days	6 days - STD	100.1	99.8	300	2280	**4.3**	Ref: Flex
1979/C/196966	Mix-7	10:08	130	22	7/09/2022	28 days	27 days - STD	100.2	100.6	300	2300	**6.4**	Ref: Flex
1979/C/196967	Mix-7	10:08	130	22	7/09/2022	28 days	27 days - STD	100.6	101.3	300	2300	**6.5**	Ref: Flex

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: All beams are measured and weighed uncapped.
Note 2: Curing Conditions: STD = Standard Moist-Curing, MST = Moist, DRY = Dry
Note 5: This report is for concrete sampled and testedby this laboratory.
Note 3: Sampling from N/A

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
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[redacted]

Approved Signatory: Joseph Comiskey
Form ID: W66RepRev 1

Remarks

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MODULUS OF RUPTURE REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA3	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/72117-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	7/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39105
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-8	Weather:	Controlled Environment	Structure/s:	Mix-8		
Test Procedures:	AS1012.2, AS1012.8.2 (7.4), AS1012.3.1, AS1012.11, AS1012.12.1			Plant Code / Mix Code:	N/A / FA3		

Sample No	Batch No	Time Cast	Slump (mm)	Inital Curing (hours)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Width	Depth	Span	Mass per Unit Volume (kg/m³)	Modulus of Rupture (MPa)	Test Remarks
1979/C/196978	Mix-8	10:36	130	21	17/08/2022	7 days	6 days - STD	100.1	100.0	300	2300	**3.7**	Ref: Flex
1979/C/196979	Mix-8	10:36	130	21	7/09/2022	28 days	27 days - STD	100.4	100.0	300	2340	**6.4**	Ref: Flex
1979/C/196980	Mix-8	10:36	130	21	7/09/2022	28 days	27 days - STD	100.5	100.4	300	2320	**6.1**	Ref: Flex

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: All beams are measured and weighed uncapped.
Note 2: Curing Conditions: STD = Standard Moist-Curing, MST = Moist, DRY = Dry
Note 5: This report is for concrete sampled and testedby this laboratory.
Note 3: Sampling from N/A

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MODULUS OF RUPTURE REPORT

Client: 1552 - Construction Sciences Beenleigh	Concrete Class: FA4	Date Sampled / Cast: 10/08/2022	Report Number: 1979/R/72118-1
Client Address: [redacted]	Specified Strength (MPa): 0.0	Nom. Slump / Tol (mm): 120 / +/-30	Project Number: 1979/P/2295
Supplied To: n/a	Lot Number:	Agg. Corr. Factor (%):	Report Date: 7/09/2022
Project: James Moller	Sampled By: Jardine Medland	Air Cont. Comp Method:	Test Request No: 1979/T/39106
Supplier: Laboratory Trial	Sampling Location: N/A	Sampling Method:	Constr. Element: -
Client Reference/s: Mix-9	Weather: Controlled Environment	Structure/s: Mix-9	
Test Procedures: AS1012.2, AS1012.8.2 (7.4), AS1012.3.1, AS1012.11, AS1012.12.1		Plant Code / Mix Code: N/A / FA4	

Sample No	Batch No	Time Cast	Slump (mm)	Inital Curing (hours)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Width	Depth	Span	Mass per Unit Volume (kg/m³)	Modulus of Rupture (MPa)	Test Remarks
1979/C/196991	Mix-9	11:25	130	21	17/08/2022	7 days	6 days - STD	100.0	99.9	300	2220	**3.8**	Ref: Flex
1979/C/196992	Mix-9	11:25	130	21	7/09/2022	28 days	27 days - STD	100.1	100.2	300	2220	**6.0**	Ref: Flex
1979/C/196993	Mix-9	11:25	130	21	7/09/2022	28 days	27 days - STD	100.3	100.6	300	2200	**5.7**	Ref: Flex

Note 1: Temperature Zone - Standard Tropical Zone
Note 2: Curing Conditions: STD = Standard Moist-Curing, MST = Moist, DRY = Dry
Note 3: Sampling from N/A
Note 4: All beams are measured and weighed uncapped.
Note 5: This report is for concrete sampled and tested by this laboratory.

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NATA

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[redacted]

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Remarks

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INDIRECT TENSILE STRENGTH REPORT

Client: 1552 - Construction Sciences Beenleigh	Concrete Class: Control 1	Date Sampled / Cast: 9/08/2022	Report Number: 1979/R/71946-1
Client Address: [redacted]	Specified Strength (MPa): 0.0	Nom. Slump / Tol (mm): 120 / +/-30	Project Number: 1979/P/2295
Supplied To: n/a	Lot Number:	Agg. Corr. Factor (%):	Report Date: 6/09/2022
Project: James Moller	Sampled By: Jardine Medland	Air Cont. Comp Method:	Test Request No: 1979/T/38994
Supplier: Laboratory Trial	Sampling Location: N/A	Sampling Method:	Constr. Element: -
Client Reference/s: Mix-1	Weather: Controlled Environment	Structure/s: Mix-1	
Test Procedures: AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.10, AS1012.12.1		Plant Code / Mix Code: N/A / Control 1	

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Length	Mass per Unit Volume (kg/m³)	Indirect Tensile Strength (MPa)	Test Remarks
1979/C/196467	Mix-1	08:46	22	100	23	6/09/2022	28 days	27 days - STD	100.0	202	2320	**5.0**	Ref: Indirect Tensile

Note 1: Temperature Zone - Standard Tropical Zone
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 3: Sampling from N/A
Note 4: No Cap used on specimens unless otherwise stated.
Note 5: All specimens are measured and weighed uncapped.
Note 6: This report is for concrete sampled and tested by this laboratory.

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 1979

[redacted]

Approved Signatory: Joseph Comiskey
Form ID: W84Rep Rev 1

Remarks

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INDIRECT TENSILE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FW1	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/71947-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38995
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-2	Weather:	Controlled Environment	Structure/s:	Mix-2		

Test Procedures: AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.10, AS1012.12.1 — Plant Code / Mix Code: N/A / FW1

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Length	Mass per Unit Volume (kg/m³)	Indirect Tensile Strength (MPa)	Test Remarks
1979/C/196480	Mix-2	09:22	22	150	23	6/09/2022	28 days	27 days - STD	100.4	202	2340	**5.0**	Ref: Indirect Tensile

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: No Cap used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
Note 6: This report is for concrete sampled and tested by this laboratory.

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NATA

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INDIRECT TENSILE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FW2	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/71948-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38996
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-3	Weather:	Controlled Environment	Structure/s:	Mix-3		

Test Procedures: AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.10, AS1012.12.1 — Plant Code / Mix Code: N/A / FW2

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Length	Mass per Unit Volume (kg/m³)	Indirect Tensile Strength (MPa)	Test Remarks
1979/C/196493	Mix-3	09:55	22	130	22	6/09/2022	28 days	27 days - STD	100.0	200	2340	**4.7**	Ref: Indirect Tensile

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: No Cap used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
Note 6: This report is for concrete sampled and tested by this laboratory.

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INDIRECT TENSILE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FW3	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/71949-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38997
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-4	Weather:	Controlled Environment	Structure/s:	Mix-4		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.10, AS1012.12.1			Plant Code / Mix Code:	N/A / FW3		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Length	Mass per Unit Volume (kg/m³)	Indirect Tensile Strength (MPa)	Test Remarks
1979/C/196506	Mix-4	10:46	22	130	21	6/09/2022	28 days	27 days - STD	100.0	201	2280	**4.9**	Ref: Indirect Tensile

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: No Cap used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
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INDIRECT TENSILE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FW4	Date Sampled / Cast:	9/08/2022	Report Number:	1979/R/71950-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	6/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/38998
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-5	Weather:	Controlled Environment	Structure/s:	Mix-5		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.10, AS1012.12.1			Plant Code / Mix Code:	N/A / FW4		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Length	Mass per Unit Volume (kg/m³)	Indirect Tensile Strength (MPa)	Test Remarks
1979/C/196519	Mix-5	11:24	22	130	22	6/09/2022	28 days	27 days - STD	100.0	200	2260	**3.9**	Ref: Indirect Tensile

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: No Cap used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
Note 6: This report is for concrete sampled and tested by this laboratory.

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 1979

[redacted]

Approved Signatory: Joseph Comiskey
Form ID: W84RepRev 1

Remarks

Construction Sciences

Construction Sciences Pty Ltd
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Laboratory: Brisbane South Laboratory
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INDIRECT TENSILE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA1	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/72119-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	7/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39102
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-6	Weather:	Controlled Environment	Structure/s:	Mix-6		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.10, AS1012.12.1			Plant Code / Mix Code:	N/A / FA1		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Specimen Dimensions (mm) Length	Mass per Unit Volume (kg/m³)	Indirect Tensile Strength (MPa)	Test Remarks
1979/C/196947	Mix-6	09:31	22	130	22	7/09/2022	28 days	27 days - STD	100.2	201	2340	**4.5**	Ref: Indirect Tensile

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: No Cap used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
Note 6: This report is for concrete sampled and tested by this laboratory.

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INDIRECT TENSILE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA2	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/72120-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	7/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39104
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-7	Weather:	Controlled Environment	Structure/s:	Mix-7		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.10, AS1012.12.1			Plant Code / Mix Code:	N/A / FA2		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Specimen Dimensions (mm) Length	Mass per Unit Volume (kg/m³)	Indirect Tensile Strength (MPa)	Test Remarks
1979/C/196964	Mix-7	10:08	22	130	22	7/09/2022	28 days	27 days - STD	100.0	199	2320	**4.2**	Ref: Indirect Tensile

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: No Cap used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
Note 6: This report is for concrete sampled and tested by this laboratory.

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INDIRECT TENSILE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA3	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/72121-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	7/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39105
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-8	Weather:	Controlled Environment	Structure/s:	Mix-8		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.10, AS1012.12.1			Plant Code / Mix Code:	N/A / FA3		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Length	Mass per Unit Volume (kg/m³)	Indirect Tensile Strength (MPa)	Test Remarks
1979/C/196977	Mix-8	10:36	22	130	21	7/09/2022	28 days	27 days - STD	99.6	199	2320	**4.6**	Ref: Indirect Tensile

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: No Cap used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
Note 6: This report is for concrete sampled and tested by this laboratory.

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INDIRECT TENSILE STRENGTH REPORT

Client:	1552 - Construction Sciences Beenleigh	Concrete Class:	FA4	Date Sampled / Cast:	10/08/2022	Report Number:	1979/R/72122-1
Client Address:	[redacted]	Specified Strength (MPa):	0.0	Nom. Slump / Tol (mm):	120 / +/-30	Project Number:	1979/P/2295
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	7/09/2022
Project:	James Moller	Sampled By:	Jardine Medland	Air Cont. Comp Method:		Test Request No:	1979/T/39106
Supplier:	Laboratory Trial	Sampling Location:	N/A	Sampling Method:		Constr. Element:	-
Client Reference/s:	Mix-9	Weather:	Controlled Environment	Structure/s:	Mix-9		
Test Procedures:	AS1012.2, AS1012.8.1 (7.4), AS1012.3.1, AS1012.10, AS1012.12.1			Plant Code / Mix Code:	N/A / FA4		

Sample No	Batch No	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Length	Mass per Unit Volume (kg/m³)	Indirect Tensile Strength (MPa)	Test Remarks
1979/C/196990	Mix-9	11:25	22	130	21	7/09/2022	28 days	27 days - STD	99.8	202	2240	**4.1**	Ref: Indirect Tensile

Note 1: Temperature Zone - Standard Tropical Zone
Note 4: No Cap used on specimens unless otherwise stated.
Note 2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
Note 5: All specimens are measured and weighed uncapped.
Note 3: Sampling from N/A
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Remarks

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CONCRETE SHRINKAGE REPORT

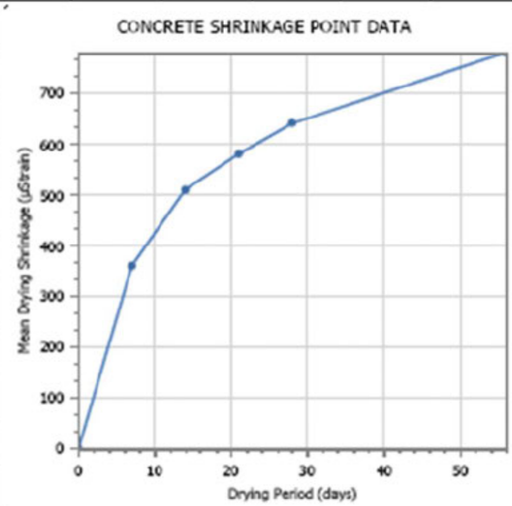
Client:	1979 - Construction Sciences Kingston (Concrete)	Report Number:	1552/R/168369-1
Client Address:	[redacted]	Project Number:	1552/P/405
Project:	Tested As Received	Lot Number:	
Location:	Kingston	Internal Test Request:	1552/T/105446
Component:	1979/T/38994	Client Reference/s:	1979/CC/376
Area Description:	James Moller - Control 1 - Mix-1	Report Date / Page:	17/10/2022 Page 1 of 1

Sample Code:	1552/C/673061
Test Procedures:	AS1012.3.1, AS1012.8.4, AS1012.8.4 (6.2.3), AS1012.13

Condition Received:	Saturated	Date of Demoulding:	10/08/2022
Concrete Supplier:	Laboratory Trial	Date of Initial Reading:	16/08/2022
Class of Concrete:	Control 1	Sample Location:	Laboratory Moulded
Specified Slump (mm):	120 / +/-30	Weather Conditions:	Controlled Environment

Plant Mix Code	Batch Number	Batch Time	Sampling Time	Date/Time Received	Initial Curing Time	Curing Conditions	Slump (mm)	Air Temp (C°)	Conc Temp (C°)
Control 1	Mix-1	9/08/2022 8:36:00 AM	9/08/2022 8:46:00 AM	10/08/2022 8:00:00 AM	23 hours	6 days - STD	100	22	22

Drying Period (days) (date)	Drying Shrinkage (μStrain)			
	Specimen 1	Specimen 2	Specimen 3	Average
7 23/08/2022	370	350	350	**360**
14 30/08/2022	520	500	500	**510**
21 6/09/2022	590	560	580	**580**
28 13/09/2022	650	620	640	**640**
56 11/10/2022	800	760	770	**780**



Remarks

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Form ID: W97Rep Rev3

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CONCRETE SHRINKAGE REPORT

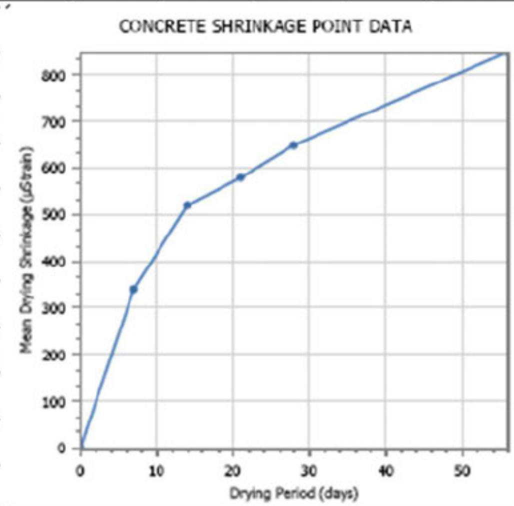
Client:	1979 - Construction Sciences Kingston (Concrete)	Report Number:	1552/R/168370-1
Client Address:	[redacted]	Project Number:	1552/P/405
Project:	Tested As Received	Lot Number:	
Location:	Kingston	Internal Test Request:	1552/T/105447
Component:	1979/T/38995	Client Reference/s:	1979/CC/377
Area Description:	James Moller - FW1 - Mix-2	Report Date / Page:	17/10/2022 Page 1 of 1

Sample Code:	1552/C/673063
Test Procedures:	AS1012.3.1, AS1012.8.4, AS1012.8.4 (6.2.3), AS1012.13

Condition Received:	Saturated	Date of Demoulding:	10/08/2022
Concrete Supplier:	Laboratory Trial	Date of Initial Reading:	16/08/2022
Class of Concrete:	FW1	Sample Location:	Laboratory Moulded
Specified Slump (mm):	120 / +/-30	Weather Conditions:	Controlled Environment

Plant Mix Code	Batch Number	Batch Time	Sampling Time	Date/Time Received	Initial Curing Time	Curing Conditions	Slump (mm)	Air Temp (C°)	Conc Temp (C°)
FW1	Mix-2	9/08/2022 9:16:00 AM	9/08/2022 9:22:00 AM	10/08/2022 8:00:00 AM	23 hours	6 days - STD	150	22	22

Drying Period	Drying Shrinkage (µStrain)			
(days) (date)	Specimen 1	Specimen 2	Specimen 3	Average
7 23/08/2022	350	330	340	**340**
14 30/08/2022	550	500	510	**520**
21 6/09/2022	630	570	580	**580**
28 13/09/2022	720	660	640	**650**
56 11/10/2022	870	780	830	**850**



Remarks

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[redacted]

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Form ID: W97Rep Rev3

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CONCRETE SHRINKAGE REPORT

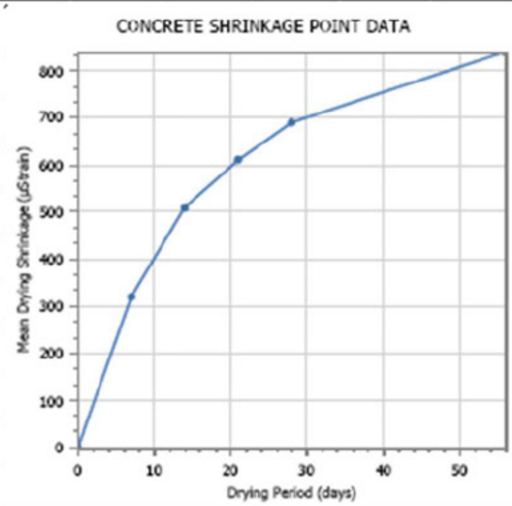
Client:	1979 - Construction Sciences Kingston (Concrete)	Report Number:	1552/R/168371-1
Client Address:	[redacted]	Project Number:	1552/P/405
Project:	Tested As Received	Lot Number:	
Location:	Kingston	Internal Test Request:	1552/T/105448
Component:	1979/T/38996	Client Reference/s:	1979/CC/378
Area Description:	James Moller - FW2 - Mix-3	Report Date / Page:	17/10/2022 Page 1 of 1

Sample Code:	1552/C/673065
Test Procedures:	AS1012.3.1, AS1012.8.4, AS1012.8.4 (6.2.3), AS1012.13

Condition Received:	Saturated	Date of Demoulding:	10/08/2022
Concrete Supplier:	Laboratory Trial	Date of Initial Reading:	16/08/2022
Class of Concrete:	FW2	Sample Location:	Laboratory Moulded
Specified Slump (mm):	120 / +/-30	Weather Conditions:	Controlled Environment

Plant Mix Code	Batch Number	Batch Time	Sampling Time	Date/Time Received	Initial Curing Time	Curing Conditions	Slump (mm)	Air Temp (C°)	Conc Temp (C°)
FW2	Mix-3	9/08/2022 9:50:00 AM	9/08/2022 9:55:00 AM	10/08/2022 8:00:00 AM	22 hours	6 days - STD	130	22	22

Drying Period (days) (date)	Drying Shrinkage (µStrain) Specimen 1	Specimen 2	Specimen 3	Average
7 23/08/2022	350	320	290	**320**
14 30/08/2022	520	510	450	**510**
21 6/09/2022	600	610	540	**610**
28 13/09/2022	680	690	630	**690**
56 11/10/2022	840	880	790	**840**



Remarks	Sampling Conducted By Construction Sciences Brisbane South Laboratory Accreditation No. 1986 Site No.1979

NATA

Accredited for compliance with ISO/IEC 17025 – Testing

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[redacted]

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CONCRETE SHRINKAGE REPORT

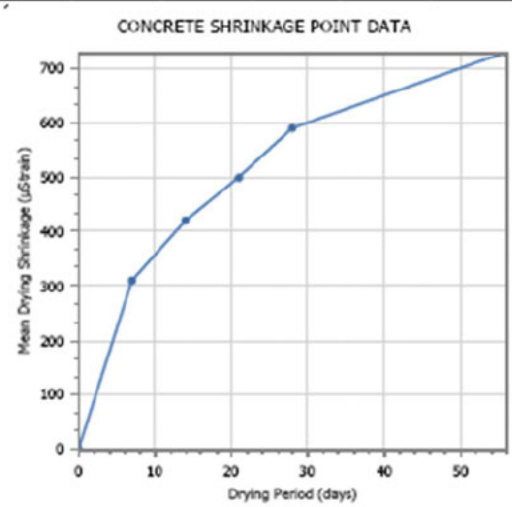
Client:	1979 - Construction Sciences Kingston (Concrete)	Report Number:	1552/R/168372-1
Client Address:	[redacted]	Project Number:	1552/P/405
Project:	Tested As Received	Lot Number:	
Location:	Kingston	Internal Test Request:	1552/T/105449
Component:	1979/T/38997	Client Reference/s:	1979/CC/379
Area Description:	James Moller - FW3 - Mix-4	Report Date / Page:	17/10/2022 Page 1 of 1

Sample Code:	1552/C/673067
Test Procedures:	AS1012.3.1, AS1012.8.4, AS1012.8.4 (6.2.3), AS1012.13

Condition Received:	Saturated	Date of Demoulding:	10/08/2022
Concrete Supplier:	Laboratory Trial	Date of Initial Reading:	16/08/2022
Class of Concrete:	FW3	Sample Location:	Field Moulded
Specified Slump (mm):	120 / +/-30	Weather Conditions:	Controlled Environment

Plant Mix Code	Batch Number	Batch Time	Sampling Time	Date/Time Received	Initial Curing Time	Curing Conditions	Slump (mm)	Air Temp (C°)	Conc Temp (C°)
FW3	120	9/08/2022 10:38:00 AM	9/08/2022 10:46:00 AM	10/08/2022 8:00:00 AM	21 hours	7 days - STD	130	22	22

Drying Period	Drying Shrinkage (μStrain)			
(days) (date)	Specimen 1	Specimen 2	Specimen 3	Average
7 24/08/2022	290	320	310	**310**
14 31/08/2022	400	440	420	**420**
21 7/09/2022	490	520	500	**500**
28 14/09/2022	580	610	590	**590**
56 12/10/2022	710	750	720	**730**



Remarks

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CONCRETE SHRINKAGE REPORT

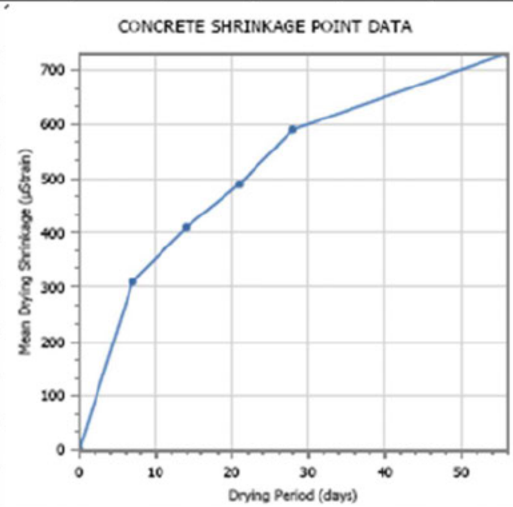
Client:	1979 - Construction Sciences Kingston (Concrete)	Report Number:	1552/R/168373-1
Client Address:	[redacted]	Project Number:	1552/P/405
Project:	Tested As Received	Lot Number:	
Location:	Kingston	Internal Test Request:	1552/T/105450
Component:	1979/T/38998	Client Reference/s:	1979/CC/380
Area Description:	James Moller - FW4 - Mix-5	Report Date / Page:	17/10/2022 Page 1 of 1

Sample Code:	1552/C/673069
Test Procedures:	AS1012.3.1, AS1012.8.4, AS1012.8.4 (6.2.3), AS1012.13

Condition Received:	Saturated	Date of Demoulding:	10/08/2022
Concrete Supplier:	Laboratory Trial	Date of Initial Reading:	16/08/2022
Class of Concrete:	FW4	Sample Location:	Laboratory Moulded
Specified Slump (mm):	120 / +/-30	Weather Conditions:	Controlled Environment

Plant Mix Code	Batch Number	Batch Time	Sampling Time	Date/Time Received	Initial Curing Time	Curing Conditions	Slump (mm)	Air Temp (C°)	Conc Temp (C°)
FW4	Mix-5	9/08/2022 11:15:00 AM	9/08/2022 11:24:00 AM	10/08/2022 9:00:00 AM	22 hours	7 days - STD	130	22	22

Drying Period	Drying Shrinkage (µStrain)			
(days) (date)	Specimen 1	Specimen 2	Specimen 3	Average
7 24/08/2022	300	320	310	**310**
14 31/08/2022	410	400	410	**410**
21 7/09/2022	500	490	500	**490**
28 14/09/2022	600	580	580	**590**
56 12/10/2022	740	700	740	**730**



Remarks

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CONCRETE SHRINKAGE REPORT

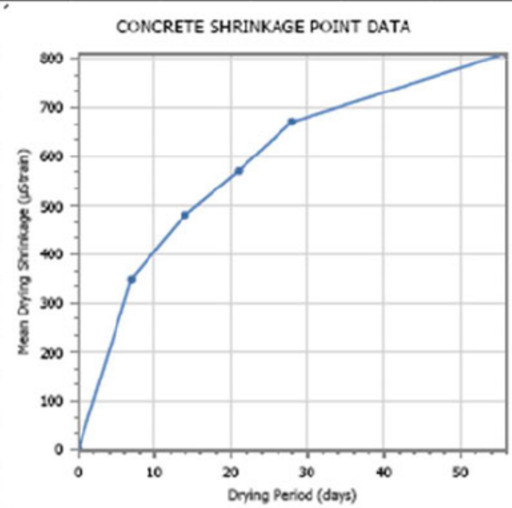
Client:	1979 - Construction Sciences Kingston (Concrete)	Report Number:	1552/R/168374-1
Client Address:	[redacted]	Project Number:	1552/P/405
Project:	Tested As Received	Lot Number:	
Location:	Kingston	Internal Test Request:	1552/T/105451
Component:	1979/T/39102	Client Reference/s:	1979/CC/381
Area Description:	James Moller - FA1 - Mix-6	Report Date / Page:	17/10/2022 Page 1 of 1

Sample Code:	1552/C/673071
Test Procedures:	AS1012.3.1, AS1012.8.4, AS1012.8.4 (6.2.3), AS1012.13

Condition Received:	Saturated	Date of Demoulding:	11/08/2022
Concrete Supplier:	Laboratory Trial	Date of Initial Reading:	17/08/2022
Class of Concrete:	FA1	Sample Location:	Laboratory Moulded
Specified Slump (mm):	120 / +/-30	Weather Conditions:	Controlled Environment

Plant Mix Code	Batch Number	Batch Time	Sampling Time	Date/Time Received	Initial Curing Time	Curing Conditions	Slump (mm)	Air Temp (C°)	Conc Temp (C°)
FA1	Mix-6	10/08/2022 9:19:00 AM	10/08/2022 9:31:00 AM	11/08/2022 8:00:00 AM	22 hours	6 days - STD	130	22	22

Drying Period	Drying Shrinkage (μStrain)			
(days) (date)	Specimen 1	Specimen 2	Specimen 3	Average
7 24/08/2022	350	340	360	**350**
14 31/08/2022	480	460	500	**480**
21 7/09/2022	580	550	590	**570**
28 14/09/2022	670	640	680	**670**
56 12/10/2022	810	790	820	**810**



Remarks	Sampling Conducted By Construction Sciences Brisbane South Laboratory Accreditation No. 1986 Site No.1979

NATA

Accredited for compliance with ISO/IEC 17025 – Testing

Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

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Form ID: W97Rep Rev3

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CONCRETE SHRINKAGE REPORT

Client:	1979 - Construction Sciences Kingston (Concrete)	Report Number:	1552/R/168375-1
Client Address:	[redacted]	Project Number:	1552/P/405
Project:	Tested As Received	Lot Number:	
Location:	Kingston	Internal Test Request:	1552/T/105452
Component:	1979/T/39104	Client Reference/s:	1979/CC/382
Area Description:	James Moller - FA2 - Mix-7	Report Date / Page:	17/10/2022 Page 1 of 1

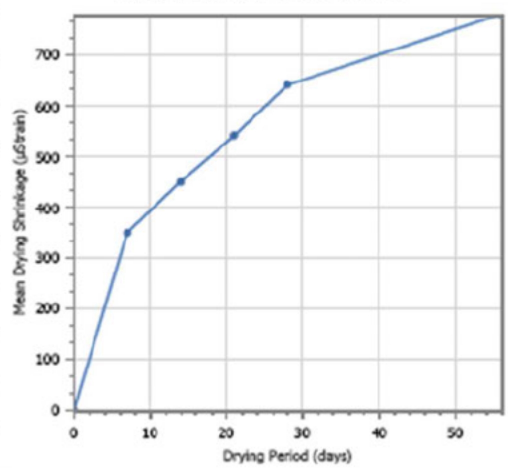
Sample Code:	1552/C/673073
Test Procedures:	AS1012.3.1, AS1012.8.4, AS1012.8.4 (6.2.3), AS1012.13

Condition Received:	Saturated	Date of Demoulding:	11/08/2022
Concrete Supplier:	Laboratory Trial	Date of Initial Reading:	17/08/2022
Class of Concrete:	FA2	Sample Location:	Laboratory Moulded
Specified Slump (mm):	120 / +/-30	Weather Conditions:	Controlled Environment

Plant Mix Code	Batch Number	Batch Time	Sampling Time	Date/Time Received	Initial Curing Time	Curing Conditions	Slump (mm)	Air Temp (C°)	Conc Temp (C°)
FA2	Mix-7	10/08/2022 10:00:00 AM	10/08/2022 10:08:00 AM	11/08/2022 8:00:00 AM	22 hours	6 days - STD	130	22	22

Drying Period	Drying Shrinkage (µStrain)			
(days) (date)	Specimen 1	Specimen 2	Specimen 3	Average
7 **24/08/2022**	330	360	350	**350**
14 **31/08/2022**	430	460	450	**450**
21 **7/09/2022**	530	560	540	**540**
28 **14/09/2022**	640	660	630	**640**
56 **12/10/2022**	790	850	780	**780**

CONCRETE SHRINKAGE POINT DATA



Remarks	Sampling Conducted By Construction Sciences Brisbane South Laboratory Accreditation No. 1986 Site No.1979

NATA

Accredited for compliance with ISO/IEC 17025 - Testing

Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

Approved Signatory: Joseph Comiskey
Form ID: W97Rep Rev3

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Laboratory: Beenleigh Laboratory
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CONCRETE SHRINKAGE REPORT

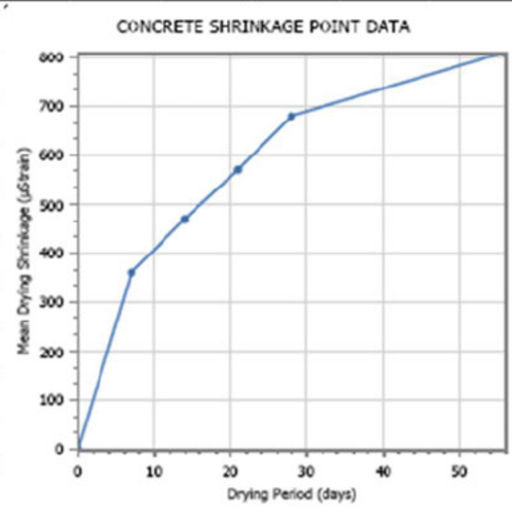
Client:	1979 - Construction Sciences Kingston (Concrete)	Report Number:	1552/R/168376-1
Client Address:	[redacted]	Project Number:	1552/P/405
Project:	Tested As Received	Lot Number:	
Location:	Kingston	Internal Test Request:	1552/T/105453
Component:	1979/T/69216-1	Client Reference/s:	1979/CC/383
Area Description:	James Moller - FA3 - Mix-8	Report Date / Page:	17/10/2022 Page 1 of 1

Sample Code:	1552/C/673075
Test Procedures:	AS1012.3.1, AS1012.8.4, AS1012.8.4 (6.2.3), AS1012.13

Condition Received:	Saturated	Date of Demoulding:	11/08/2022
Concrete Supplier:	Laboratory Trial	Date of Initial Reading:	17/08/2022
Class of Concrete:	FA3	Sample Location:	Laboratory Moulded
Specified Slump (mm):	120 / +/-30	Weather Conditions:	Controlled Environment

Plant Mix Code	Batch Number	Batch Time	Sampling Time	Date/Time Received	Initial Curing Time	Curing Conditions	Slump (mm)	Air Temp (C°)	Conc Temp (C°)
FA3	Mix-8	10/08/2022 10:29:00 AM	10/08/2022 10:36:00 AM	11/08/2022 8:00:00 AM	21 hours	6 days - STD	130	22	22

Drying Period	Drying Shrinkage (µStrain)			
(days) (date)	Specimen 1	Specimen 2	Specimen 3	Average
7 **24/08/2022**	350	360	370	**360**
14 **31/08/2022**	480	460	480	**470**
21 **7/09/2022**	570	550	580	**570**
28 **14/09/2022**	680	660	700	**680**
56 **12/10/2022**	820	780	850	**810**



Remarks	Sampling Conducted By Construction Sciences Brisbane South Laboratory Accreditation No. 1986 Site No.1979

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Accredited for compliance with ISO/IEC 17025 – Testing

Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

Approved Signatory: Joseph Comiskey
Form ID: W97Rep Rev3

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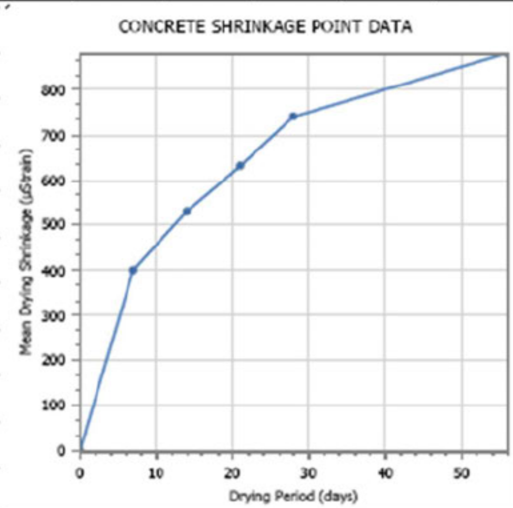
CONCRETE SHRINKAGE REPORT

Client:	1979 - Construction Sciences Kingston (Concrete)	Report Number:	1552/R/168377-2
Client Address:	[redacted]	Project Number:	1552/P/405
Project:	Tested As Received	Lot Number:	
Location:	Kingston	Internal Test Request:	1552/T/105454
Component:	1979/T/69217-1	Client Reference/s:	1979/CC/384
Area Description:	James Moller - FA4 - Mix-9	Report Date / Page:	17/10/2022 Page 1 of 1

Sample Code:	1552/C/673077		
Test Procedures:	AS1012.3.1, AS1012.8.4, AS1012.8.4 (6.2.3), AS1012.13		
Condition Received:	Saturated	Date of Demoulding:	11/08/2022
Concrete Supplier:	Laboratory Trial	Date of Initial Reading:	17/08/2022
Class of Concrete:	FA4	Sample Location:	Laboratory Moulded
Specified Slump (mm):	120 / +/-30	Weather Conditions:	Controlled Environment

Plant Mix Code	Batch Number	Batch Time	Sampling Time	Date/Time Received	Initial Curing Time	Curing Conditions	Slump (mm)	Air Temp (C°)	Conc Temp (C°)
FA4	Mix-9	10/08/2022 11:20:00 AM	10/08/2022 11:25:00 AM	11/08/2022 8:00:00 AM	21 hours	6 days - STD	130	22	22

Drying Period	Drying Shrinkage (µStrain)			
(days) (date)	Specimen 1	Specimen 2	Specimen 3	Average
7 24/08/2022	400	400	350	**400**
14 31/08/2022	520	530	470	**530**
21 7/09/2022	620	630	570	**630**
28 14/09/2022	730	750	680	**740**
56 12/10/2022	860	870	820	**880**



Remarks	Re-issued Report Replaces Report No 1552/R/168377-1 (reason: Slump added.)., Sampling Conducted By Construction Sciences Brisbane South Laboratory Accreditation No. 1986 Site No.1979

NATA

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Accreditation Number: 1986
Corporate Site Number: 1552

[redacted]

Approved Signatory: Joseph Comiskey
Form ID: W97Rep Rev3